

School Of Civil Engineering

Experimental Approach to Investigate Reinforced Clay

Amin Chegenizadeh

**This thesis is presented for the Degree of
Doctor of Philosophy
of
Curtin University**

February 2012

Declaration

To the best of my knowledge and belief this thesis contains no material previously published by any other person except where due acknowledgement has been made. This thesis contains no material which has been accepted for the award of any other degree or diploma in any university.

Refereed Published Journal Papers

1- **Amin Chegenizadeh** and Prof.Hamid Nikraz , “Modulus of Elasticity of Reinforced Clay” , Journal of Advanced Materials Research, 261-263, 969-973, DOI 10.4028/www.scientific.net/AMR.261-263.969

2- **Amin Chegenizadeh** and Prof.Hamid Nikraz ,”Permeability Test on Reinforced Clayey Sand”, Journal of World Academy of Science, Engineering and Technology 78 2011, 130-133

3- **Amin Chegenizadeh** and Prof.Hamid Nikraz, “Automated Shear Test on Reinforced Clayey Sand”, Journal of Advanced Materials Research, 261-263, 1019-1023, DOI: 10.4028/www.scientific.net/AMR.261-263.1019

4- **Amin Chegenizadeh** and Prof.Hamid Nikraz ,”Investigation on Compaction Characteristics of Reinforced Soil”, Journal of Advanced Materials Research, 261-263, 964, 10.4028/www.scientific.net/AMR.261-263.964

5- **Amin Chegenizadeh** and Prof.Hamid Nikraz ,”Shear Test on Reinforced Clay”, Journal of Advanced Materials Research, 250-253, 3223, DOI: 10.4028/www.scientific.net/AMR.250-253.3223

6- **Amin Chegenizadeh** and Prof.Hamid Nikraz ,”Study on Modulus of Elasticity of Reinforced Clay”, Journal of Advanced Materials Research, 243-249, 5885, DOI: 10.4028/www.scientific.net/AMR.243-249.5885

7- **Amin Chegenizadeh** and Prof.Hamid Nikraz ,”Investigation on Strength of Fiber Reinforced Clay”, Journal of Advanced Materials Research, 261-263, 957, 957-963, DOI: 10.4028/www.scientific.net/AMR.261-263.957

8- **Amin Chegenizadeh** and Prof.Hamid Nikraz ,”Geotechnical Parameters of Composite Soil “, Journal of Advanced Materials Research, Advanced design technology ,1651,2011

9- **Amin Chegenizadeh** and Prof.Hamid Nikraz ,”Composite Soil: Fiber Inclusion and Strength”, Journal of Advanced Materials Research,1646, 2011

Journal in press

10- **Amin Chegenizadeh**, Hamid Nikraz ,Interaction of soil and short fiber, , ASTM digital library,2011,In press

11- **Amin Chegenizadeh**, Hamid Nikraz, Composite Clayey Sand and Short Fiber, Advanced Materials Research Journal, In press

Selected Peer-Review Conference by Amin Chegenizadeh and Prof.Hamid Nikraz

1- Investigation on Strength of Reinforced Clayey Sand, International Conference on Technological Advancements in Civil Engineering (ICTACE 2011),India 2011

2- Compaction Parameters of Reinforced Clayey Sand, International Conference on Technological Advancements in Civil Engineering (ICTACE 2011), India 2011

3- Compaction Characteristics of Reinforced Clayey Sand, ICSE11, India 2011

4- Study on Strength of Fibre Reinforced Clayey sand, ICSE11, India 2011

5- Shear Test on Reinforced Clayey Sand, "International Conference on Environmental and CivilEngineering , Bangkok, Thailand, March 2011

6- CBR Test on Reinforced Clayey Sand, "International Conference on Environmental and Civil Engineering , Bangkok, Thailand, March 2011

7- Compaction Parameters of Reinforced Clayey Sand, Bangkok March 2011, "International Conference on Environmental and Civil Engineering

8- Laboratory Study on Strength of Reinforced Clayey Sand, International Conference on Building Science and Engineering", Venice, Italy, 2011

9- Direct Shear Test on Reinforced Clay, International Conference on Building Science and Engineering, Venice, Italy, 2011

10- Randomly Distributed Fiber Effect on Compaction of Composite Sand, The 14th Asian

Regional Conference on Soil Mechanics and Geotechnical Engineering , Hong kong,(May 2011)

11- Laboratory investigation on strength of reinforced soil, The 14th Asian Regional Conference on Soil Mechanics and Geotechnical Engineering , Hong kong,(May 2011)

12- Compaction Characteristics of Reinforced Soil, 5th sastech, 2011, Iran

13- Modulus of Elasticity of Reinforced Soil,5th sastech, 2011, Iran

14- Effect of clay layer thickness on desiccation cracking, 5th Asia pacific, Unsat 2011, Pataya, Thailand, 2011

15- Investigation on Shrinkage behaviour of kaolin clay, 5th Asia pacific, Unsat 2011, Pataya, Thailand, 2011

16- CBR TEST ON REINFORCED CLAY, 2011 Pan-Am CGS, Toronto, Canada

17- Influence of fibre inclusion on crack propagation, XV European Conference on Soil Mechanics and Geotechnical Engineering, Greece, 2011

18-A Review on Effect of Environment on Pavement Design in Queensland, Australia, Madrid,Spain,2012

19-Composite Soil and UCS test, Dubai, UAE,2012

20-Effect of fibre content on compressive strength of reinforced soil, Perth, Australia 2011

ABSTRACT

Soil reinforcement with discrete flexible fibres has always been an issue for further research. In Geotechnical engineering field, the research on sandy soil has considerably been more than the clayey one. The main reason for this lack can be expressed as the complexity of clayey material due to their cohesion and interaction between clay and reinforcement.

The present research aims to show possibility of discrete fibre usage in clay. For this purpose, selection of material has been conducted with special care to make the project outcome applicable to industry projects. The fibre which was used for this research prepared by BASF Company in Western Australia and currently is used in fibre reinforced concrete for infrastructure projects. Kaolin has been used as soil part and provided by Prestige Company.

Experimental approach was applied to investigate the effect of different parameters on composite soil strength. These tests cover the variety range of soil mechanics tests from compaction tests to triaxial compression tests. The results from all the tests were presented in the thesis.

A theoretical model was also developed for clayey material for the first time with the use of modified cam clay model to predict the behaviour of samples precisely. This model is based on the rule of mixture and considers the effect of soil and fibre separately. The model was validated with the results from CD triaxial test.

ACKNOWLEDGEMENTS

This thesis would not have been possible without the encouragement and enthusiasm of Professor Hamid Nikraz, Head of Civil Engineering department of Curtin University, Western Australia. It is with a deep sense of gratitude and much appreciation. I acknowledge Hamid for his always positive approach during all stages of this research. In addition to playing the all important role as thesis supervisor, during the course of this research he has become a personal friend, particularly when help is needed to overcome personal difficulties. He is in fact a friend in need.

I extend my sincere gratitude to Professor David Scott for serving as the chairman of thesis supervisory committee. I would also like to thank Curtin staffs John Murry and Mark Withtaker for technical support in Curtin Geomechanic Lab. I also extend my gratitude to Mrs.Liz Field and Dian Garth for their kind assistance on admin matters.

While conducting my research, I had to work all day sometime evening and holidays. This may cause some inconvenience for my wife, Haleh. I would like to thank her for her supports during this research. I should also be thankful of my great parents who helped me a lot during any stages of my life and also my great parents- in- law for their supports during my studies.

Finally, I wholeheartedly thank Curtin University for providing me this opportunity to achieve my goal at this stage of my career.

Table of Contents

Declaration	ii
Abstract	v
Acknowledgement	vi
Table of Content	vii
List of Figures	xiv
List of Tables	xx
List of Notations	xxi

Chapter 1

1-1 Background	1
1-2 Aims and Objectives	3
1-3 Significance	4
1-4 Research Method	6
1-5 Constitutive model	8
1-5-1 Principle of the model	8
1-5-1-1 Rule of Mixture	8
1-5-1-2 The fibre stiffness matrix	9
1-5-1-3 The clay stiffness matrix	9
1-5-1-4 The final constitutive model	9
1-5-1-5 Model calibration	10
1-5-2 Experimental work	10
1-6-Review of thesis content	10
1-7 Thesis Chapters in details	11

Chapter 2

2-1 Main works on strength of reinforced soil	14
2- 1-1 Effect of fibre mixed with other stabilization materials	24
2- 1-2 Effect of fibre in cemented soil	26
2-2 Predictive model for shear strength of fibre reinforced soil	27
2-2-1 Load transfer approach	31
2-2-2 Statistical approach	37
2-2-3 Energy approach	39
2-2-4 Discrete approach	44
2-3 Effect of sample size in reinforced clay	45
2-4 Fibre inclusion in sand	46
2-5 Confined concrete behaviour and fibre inclusion in concrete	47
2-6 Other influence of fibre	48
2-6-1 Influence of fibre on swelling and shrinkage	48
2- 6-2 Influence of fibre on hydraulic conductivity	49
2-6-3 Influence of fibre on soil compaction	51
2-6-4 Influence of fibre on development of cracks	52
2.7 Conclusion	52

Chapter 3

3-1 Soil	55
3-1-1 Chemical Features	56
3-2 Particle Size Distribution of Clay	57
3-3 Selecting Fibre	58

3-3-2 Used Fibre	59
3-3-2-1 Geofibres	59
3-3-2-2 Description	59
3-3-2-3 Fibre properties	60
3-4 Fibre tensile strength	61
3-4-1 Elongation	61
3-4-2 Modulus	63
3-5 Results of fibre tensile test	66
3-6 Relevant definitions and concepts	67
3-7 Application of fibre reinforced soil	69

Chapter 4

4-1 Overview	73
4-2 Preliminary tests	73
4-3 Permeability test:	73
4-3-1 Principle of the permeability test	74
4-3-2 Applications of the tests	77
4-3-3 Constant Head Permeability Application	77
4-3-4 Falling Head Permeability Application	77
4-3-5 Main Equipments	78
4-3-6 Test Methodology and Procedure	78
4-3-7 Analysing the results	79
4-3-8 Results and discussion	79
4-4 Compaction test	82
4-4-2 Test program	83
4-4-3 Compaction Test Principle	83

4-4-4 Effect of Moisture on Compaction Procedure	84
4-4-5 Compaction Methods	85
4-4-6 Main Equipments	85
4-4-7 Test Methodology and Procedure	86
4-4-8 Results and discussions	87
4-4-9 Conclusion	89
4-5 Consolidation test	89
4-5-1 Main Equipments:	90
4-5-2 Test Procedure:	90
4-5-3 Results	90
4-6 Direct shear test	91
4-6-1 Introduction	91
4-6-2 Theoretical Background of the test	93
4-6-3 Test program	94
4-6-4 Main Equipments	94
4-6-5 Sample Preparation	95
4-6-6 Test Methodology and Procedure	96
4-6-7 Results and discussions	96
4-6-8 Conclusion	98
4-7 CBR TEST	98
4-7-1 Test Program	100
4-7-2 CBR Test principle	100
4-7-3 Main Equipments	100
4-7-4 Test Methodology and Procedure	102
4-7-5 Results and Discussion	102
4-7-6 Conclusion	103

Chapter 5

5-1 The purpose of soil testing	105
5-2 Scope of experimental testing program	106
5-3 Principle of Triaxial machine	106
5-4 Different Type of Triaxial Tests	107
5-5 Used Triaxial Machine	115
5-6 Constants and Variable selection	121
5-6-1 Constants	121
5-6-2 Variables	122
5-7 Sample Preparation	122
5-8 Test Procedure	123
5-9 Results and Discussion	132
5-9-1 CU test results for different fibre content and length	133
5-9-2 CU test results for pure clay	140
5-9-3 CD test results	143

Chapter 6

6-1 Raw Results Analysis	151
6-2 CU test results analysis	151
6-2-1 Effect of fibre content	152
6-2-2 Effect of fibre length	153
6-2-2 Input data extraction for model from CU tests	155
6-2-3 Critical State Line Slope	155
6-2-4 Procedure of computing M	156

6-2-5 Procedure of computing λ and κ	158
6-2-6 Procedure of finding λ and κ	159
6-2-7 CD test results	160

Chapter 7

7-1 A Review of Basic Soil Constitutive Models for Geotechnical Application	164
7-1-1 Introduction	164
7-1-2 Mohr Coulomb	168
7-1-3 Modified Cam Clay	170
7-2 Modified Cam Clay in details	174
7-2-1 Introduction	174
7-2-2 Yield Functions	175
7-2-3 Virgin Consolidation Line and Swelling Lines	177
7-2-4 The Critical State Line	179
7-2-5 Hardening and Softening Behaviour	181
7-2-6 Elastic Material Constants for Cam-Clay and Modified Cam-Clay	183
7-2-7 Summary of Input Parameters for Cam-Clay and Modified Cam-Clay	184
7-3 Proposed Constitutive Model	184
7-3-1 Clay matrix	186
7-3-2 The fibre stiffness matrix	188
7-4 Distribution of fibre orientation	191
7-5 Simulation	197
7-5-1 Software overview	197
7-5-2 Overview of the MATLAB Environment	198
7-5-3 The MATLAB System	199
7-6 Model Verification	201

Chapter 8

8-1 Conclusion	206
8-2 Preliminary tests evaluation	206
8-3 Triaxial tests evaluation	207
8-4 Constitutive Modelling evaluation	207
8-5 Further Work	208
References	213

APPENDICES

APPENDIX A

List of Figures

Figure 1-1: General research procedure	7
Figure 2-1: Effect of water content and fibre inclusion on compressive strength of clay (Maher and ho, 1994)	16
Figure 2-2: Effect of water content and fibre inclusion on tensile strength of clay (Maher and ho, 1994)	17
Figure 2-3: Effect of water content on axial strain and unconfined compressive strength (Maher and ho, 1994)	17
Figure 2-4: Effect of fibre content on cohesion (Prabakar et al, 2002)	19
Figure 2-5: Effect of fibre length on friction angle (Prabakar et al, 2002)	19
Figure 2-6: Effect of fibre inclusion on strength obtained in CU test (Zornberg, 2002)	21
Figure 2-7: Effect of fibre inclusion on excess pore pressure generated during CU test (Zornberg, 2002)	22
Figure 2-8: Effect of fibre inclusion on shear stress envelope in CU test (Zornberg, 2002)	23
Figure 2-9: Effects of fibre and lime on UCS (Cai et al., 2006)	25
Figure 2-10: Effects of fibre on cemented soil (Tang et al., 2006)	26
Figure 2-11: Shear strength envelope of fibre-reinforced soil (Gray and Ohashi, 1983)	28
Figure 2-12: Elastic fibre across the shear zone a) vertical fibre b) inclined fibre (Gray and Ohashi, 1983)	32
Figure 2-13: Principal stress envelope (Ranjan, 1996)	39
Figure 2-14: Stress distribution pattern of fibre reinforcement (Michalowski and Zhao, 1996)	41
Figure 2-15: Principal stress envelope (Michalowski and Zhao, 1996)	43
Figure 2-16: Shear strength envelop according to discrete approach (Zornberg, 2002)	45

Figure 2-17: typical stress-strain curve for concrete with and without fibre (Bencardino et al., 2008)	48
Figure 2-18: Effect of fibre inclusion on hydraulic conductivity (Maher and Ho, 1994)	50
Figure 2-19: Effect of fibre inclusion on optimum moisture content and dry unit weight (Miller and Rifai, 2004)	51
Figure. 3-1 Chemical and Analytical Data of Used Clay	57
Figure. 3-2 Clay Particle Distribution	58
Figure. 3-3 Discrete plastic fibre	61
Figure. 3-4 Typical pattern of stress_strain curve	64
Figure. 3-5 Used Fibre tensile test result	60
Figure. 3-6 Explanation of used notation	67
Figure 4-1. Zones of laminar and turbulent flows (After Taylor, 1948	75
Figure 4-2. Permeability (at 15mm length)	81
Figure 4-3. Permeability Test (at 0.1% fibre content)	81
Figure 4-4. Typical Compaction Curves	82
Figure 4-5. Typical Compaction Curves considering prosity	83
Figure. 4-6 Structure of loose and compacted soil (Online compaction handbook, 2010)	84
Figure. 4-7 Standard compaction sketch (Online compaction handbook,2010)	85
Fig. 4-8 Effect of fiber content on compaction curve (fiber length 10mm)	88
Fig.4- 9 Effect of fiber length on compaction curve (at fiber content 0.4%)	88
Figure 4-10 Consolidation test on pure clay	91
Figure. 4-11 Direct Shear Test Machine	95
Figure. 4-12 Results of direct shear test in different fiber content (at 10mm, Normal stress 100 kPa)	97
Figure. 4-13 Results of direct shear test in different fiber length (at 0.2% fiber content, Normal stress 100 kPa)	97
Figure 4-14 Mechanism of CBR Test Machine (Gray,1983)	101

Figure. 4-15 results of CBR test for plastic fiber	103
Figure 5-1 Triaxial test machine	119
Figure 5-2 Triaxial test machine	119
Figure 5-3 Triaxial test Set up-a) Front view b)Back view	120
Figure 5-4 Initial Triaxial test set up	125
Figure 5-5 Flow Trac-II	126
Figure 5-6 Flow Trac-II and Load Trac	126
Figure 5-7 Connected PC	127
Figure 5-8 PC and Triaxial software	127
Figure 5-9 Failure of sample at 100 kPa	128
Figure 5-10 Failure of sample at 200 kPa	129
Figure 5-11 Failure of sample at 300 kPa	130
Figure 5-12 Balance used in lab	130
Figure 5-13 Mixer	131
Figure 5-14 Sample preparation tools	131
Figure 5-15 Deviatoric stress versus axial strain for pure clay	133
Figure 5-16 Excess pore pressure for pure clay	133
Figure 5-17 Deviatoric stress versus axial strain for 1% fibre content	134
Figure 5-18 Excess pore pressure for 1% fibre content	134
Figure 5-19 Deviatoric stress versus axial strain for 2% fibre content	135
Figure 5-20 Excess pore pressure for 2% fibre content	135
Figure 5-21 Deviatoric stress versus axial strain for 3% fibre content	136
Figure 5-22 Excess pore pressure for 3% fibre content	136
Figure 5-23 Deviatoric stress versus axial strain for 15mm fibre length	137
Figure 5-24 Excess pore pressure for 15mm fibre length	137
Figure 5-25 Deviatoric stress versus axial strain for 20mm fibre length	138
Figure 5-26 Excess pore pressure for 20mm fibre length	138

Figure 5-27 Deviatoric stress versus axial strain for 65mm fibre length	139
Figure 5-28 Excess pore pressure for 65mm fibre length	139
Figure 5-29 Deviatoric stress versus axial strain for pure clay at 100 kPa	140
Figure 5-30 Excess pore pressure for pure clay at 100 kPa	140
Figure 5-31 Deviatoric stress versus axial strain for pure clay at 200 kPa	141
Figure 5-32 Excess pore pressure for pure clay at 200 kPa	141
Figure 5-33 Deviatoric stress versus axial strain for pure clay at 300 kPa	142
Figure 5-34 Excess pore pressure for pure clay at 300 kPa	142
Figure 5-35 Deviatoric stress versus axial strain for pure clay at 100 kPa	143
Figure 5-36 Volumetric strain versus axial strain for pure clay at 100 kPa	143
Figure 5-37 Deviatoric stress versus axial strain for 0.1% fibre clay at 100 kPa	144
Figure 5-38 Volumetric strain versus axial strain for 0.1% fibre clay at 100 kPa	144
Figure 5-39 Deviatoric stress versus axial strain for 0.2% fibre clay at 100 kPa	145
Figure 5-40 Volumetric strain versus axial strain for 0.2% fibre clay at 100 kPa	145
Figure 5-41 Deviatoric stress versus axial strain for 0.3% fibre clay at 100 kPa	146
Figure 5-42 Volumetric strain versus axial strain for 0.3% fibre clay at 100 kPa	146
Figure 5-43 Deviatoric stress versus axial strain for pure clay at 200 kPa	147
Figure 5-44 Volumetric strain versus axial strain for pure clay at 200 kPa	147
Figure 5-45 Deviatoric stress versus axial strain for 0.1% fibre clay at 200 kPa	148
Figure 5-46 Volumetric strain versus axial strain for 0.1% fibre clay at 200 kPa	148
Figure 5-47 Deviatoric stress versus axial strain for 0.2% fibre clay at 200 kPa	149
Figure 5-48 Volumetric strain versus axial strain for 0.2% fibre clay at 200 kPa	149
Figure 5-49 Deviatoric stress versus axial strain for 0.3% fibre clay at 200 kPa	150
Figure 5-50 Volumetric strain versus axial strain for 0.3% fibre clay at 200 kPa	150
Figure. 6-1 Effect of fibre percentage on strength of reinforced clay (fibre length 15mm, Confining100kPa)	152
Figure 6-2 Effect of fibre percentage on excess pore pressure of composite clay (fibre length 15mm, Confining100kPa)	152

Figure. 6-3 Effect of fibre length on deviatoric stress of composite clay (fibre content 1%, Confining 100kPa)	153
Figure. 6-4 Effect of fibre length on excess pore pressure of composite clay (fibre content 1%, Confining 100kPa)	154
Figure. 6-5 Computing M	157
Figure. 6-6 Principle of consolidation and swelling (after Randolph et al, 1979)	158
Figure. 6-7 Principle of consolidation and swelling	159
Figure. 6-8 Deviatoric Stress change for different fibre content	161
Figure. 6-9 Volume Strain Change for different fibre content	161
Figure. 6-10 Deviatoric Stress change for different fibre content	163
Figure. 6-11 Volume Strain Change for different fibre content	163
Figure 7-1: Failure models (Chen, 1985)	166
Figure 7-2: Basic components for material models. (a) Spring-reversible linear/nonlinear elasticity. (b) Dashpot-linear/nonlinear creep. (c) Slider-plastic resistance (strain dependant). (d) Possible elastic, viscoplastic assembly. (Zienkiewicz, 1985).	167
Figure 7-3: Elastic-perfectly plastic assumption of Mohr-Coulomb model. (Kok et al, 2009)	168
Figure 7-4: The Mohr-Coulomb yield surface in principal stress space ($c = 0$) (Kok et al, 2009)	170
Figure 7-5: (a) Response of real soil to hydrostatic stress; (b) Response of idealized soil to hydrostatic stress. (Kok et al, 2009)	172
Figure 7-6: Cam-Clay and Modified Cam-Clay yield surfaces in p' - q space. (Davis and Selvadurai, 2002)	177
Figure 7-7: Behaviour of sample under loading and unloading (Davis and Selvadurai, 2002)	178
Figure 7- 8: CLS and virgin compression line (Davis and Selvadurai, 2002)	180
Figure 7- 9: Yield curve on wet side of the modified cam clay (Davis and Selvadurai, 2002)	182
Figure 7- 10: Yield curve on dry side of the modified cam clay (Davis and Selvadurai, 2002)	182

Figure 7- 11: Phase Diagram for (A) Unreinforced Clay (B) Fibre Reinforced Clay	185
Figure 7-12 Definition of orientation distribution function (after (Michałowski and Čermák, 2002))	190
Figure 7- 13 Fibre contribution (after Diambra, 2010)	191
Figure 7- 14 Axisymmetric cosine fiber orientation distribution (after Michałowski & Čermák (2002))	193
Figure 7- 15 fiber orientation distribution (after Michałowski & Čermák (2002))	194
Figure 7- 16 Horizontal and vertical Cutting Plane (after Diambra et al., 2010)	195
Figure 7- 17 Deviatoric Stress from Simulation and Experimental results for 100 kPa confining pressure and 0.2% fibre	202
Figure 7- 18 Volume Strain from Simulation and Experimental results for 100 kPa confining pressure and 0.2% fibre	203
Figure 7- 19 Deviatoric Stress from Simulation and Experimental results for 200 kPa confining pressure and 0.2% fibre	204
Figure 7- 20 Volume Strain from Simulation and Experimental results for 200 kPa confining pressure and 0.2% fibre	205

List of Tables

Table 3-1. Atterberg Limits of used clay	55
Table 3-2. fibre properties	62
Table 4-1. Coefficient of permeability in different soils	76
Table 4-2: hydraulic conductivity of the samples	80

List of Notations

σ_t = tensile stress

τ_f = frictional resistance

ϕ = friction angle of soil

z = thickness of shear zone

e_f = energy dissipated on the interface of a single fibre

d_f = equivalent diameter of single fibre

A_f = area of fibre in shear

A = area of failure plane

i = initial orientation of fibre

σ_n = confining stress on fibre

σ_{1f} = major principal stress at failure

σ_N = nominal confining stress

δ = angle of skin friction

l_f = total length of fibre

σ_{ncrit} = critical confinement corresponding to the break on the shear strength envelope

ζ = coefficient depends on sand parameter

a = adhesion of intercept of surface friction

c = cohesion of soil

ε_{θ} = strain rate in the direction of fibre

η = aspect ratio of fibre

R = radius of the Mohr's circle

p = Mean principle stress

q = deviatoric Stress

ε_a = Axial strain

ε_r = Radial strain

χ = fibre content

σ_{fult} = yield stress of fibre

1. Introduction

1-1 Background

Traditional methods of soil reinforcement involve the use of continuous planar inclusions (e.g. metallic strips, geogrids, geotextiles) within earth structures. The inclusions provide tensile resistance to the soil in a particular direction. Planes of weakness may be introduced along the interface between reinforcement and soil because the interface shear strength is usually below that of the soil.

Additionally, the use of planar reinforcement requires enough embedment length and/or a properly designed anchorage to provide enough pullout resistance. Short discrete fibres, if mixed uniformly within the soil mass, can provide isotropic increase in the strength of the soil composite without introducing continuous planes of weakness. Also, fibre-reinforcement solutions do not require design considerations regarding anchorage as planar reinforcements do.

The technique of fibre-reinforcement has been increasingly adopted in geotechnical projects involving repair of failed slope and stabilization of thin soil veneers. While significant research has been conducted so far on the analysis and design of structures with continuous planar reinforcement, the behavior of soils reinforced with randomly distributed fibres needs additional evaluation.

Past research has shown that the addition of fibres within soil increases the peak shear strength and reduces the post-peak strength loss. The increase in shear strength due to fibre-reinforcement has been usually quantified by an increased 'equivalent' friction angle and cohesion, which have been typically determined by testing fibre reinforced soil specimens. In current geotechnical practice, the design of fibre reinforcement project requires testing of project-specific fibre-reinforced specimens, which may be expensive or time-consuming. To overcome the need of project specific testing even for small projects, a discrete approach that relies on independent characterization of the properties of soil and fibres was recently developed (Zornberg, 2002).

The current research framework quantifies the shear strength of fibre-reinforced soil as a function of the fibre content, fibre geometry (aspect ratio), and shear strength of the unreinforced soil. The overall objective of this study is to validate and refine a framework for clayey soil reinforcement as well as to provide additional insight into the behavior and the mechanical properties of fibre-reinforced clay. While previous research on fibre-reinforcement has focused on the effect of fibre content and fibre geometry on the shear strength of fibre-reinforced, mainly, on sand, the influence of other factors (e.g. soil type, soil density, fibre orientation) deserves further investigation. Special novelties of this research are firstly investigation of clayey soil through a comprehensive set of experimental approach which has properly been reported rarely and secondly applying Modified Cam Clay and rule of mixture to investigate reinforced clay behaviour.

1-2 Aims and Objectives

In this proposal, the emphasize will be on clayey soil reinforced by discrete fbres. The research proposal will be outlined, with objectives, methodology, experimental and theoretical works that need to be performed. This research aims to develop a constitutive model for the behaviour of fibre reinforced clay.

The model will be based on the rule of mixtures of composite materials and it considers that the fibres behave linearly elastic and the soil, when unreinforced, obeys the linear elastic-plastic model of Modified Cam Clay (MCC). The model will be calibrated and tested using results from a series of conventional triaxial compression tests, which are carried out in this research.

Different fibre contents will be used and the versatility of the model will be highlighted by its ability to accommodate any eventual fibre orientation so that it can model the anisotropy of strength observed experimentally in compression triaxial conditions. The model parameters will be those required for unreinforced clay which is the five parameters of the Modified Cam Clay model, and the parameters required to model the interaction of fibres with soil. The fibre parameter that contributes to the stiffness of the reinforced composite will be a function of the elastic Young's modulus of fibre. The contribution of fibre to deformation behaviour of composite is a new area that will be addressed in this study.

The specific aims of this project are:

- Conduct experimental tests on saturated reinforced clay
- Compare response of fibre application in compression
- Develop a constitutive model for reinforced clay material

1-3 Significance

Unstable soils and bedrock are naturally occurring hazards that pose a threat to life and property. As a result, property or lands could be unsafe for development and site alteration. The consequences of slope instability can be costly and even result in the loss of many lives (Fell, 1994). Any slope failure can result in substantial costs for remediation while in regions of dense population or areas prone to high velocity landslide, the loss of life can be considerable. Therefore, governments and private agencies are increasingly asked to manage the “hazard” of slope instability. In 1972, a major landslide occurred on Hong Kong Island. The landslide is referred to as the Po Shan Road landslide. This landslide became a turning point in the attitude of the people of Hong Kong to the management of slope hazards. Seventy-eight people were killed as a result of the Po Shan Road landslide but it was also clear that the death toll could have been much greater if the management was poor. The cry went out through the publishing of many words saying, “If you allow people to build and live along the mountainside, then the engineers must be able to ensure that the slopes will remain stable”. (Fredlund, 2007)

Application of fibre reinforcement in clayey soil is not limited to stability but the stability by itself is enough to consider this project as a high priority project in nations. Technically, tensile and desiccation cracking have been major concerns for the proper functioning of clay soils. Reinforcement of sand with discrete fibres has been well investigated in the literature. In contrast, clayey soil reinforced with discrete fibres has been less studied. Fibre-Reinforcement has been considered in projects involving slope stabilization, embankment construction, subgrade stabilization, and stabilization of thin veneers such as landfill covers. Some recent researches have indicated that benefits may be gained by inclusion of discrete fibres in clay. Discrete polypropylene fibres have been found to increase the tensile strength of clays for a range of plasticities, induce more ductile failures, and improve the resistance to desiccation cracking (Ziegler et al. 1998).

Therefore due to the importance of research on composite material and no strong evidence of research in constitutive model of clayey composite, this study will focus on developing new model of composite clay to predict the strength behaviour of the composite. Main importance of the new model will be: (i) application of rule of mixture and (ii) considering deformation parameters of the soil as key part of the model.

1-4 Research Method

The main aim of the study will be the modelling of the composite clayey soil to simulate the behaviour of the composite to predict various scenarios and hypotheses. To achieve the goals, a precise and deliberate plan focusing carefully to a comprehensive guideline from start point to end point is very essential. A wisely knowledge of whole necessary steps can decrease the potential of failure. The following several steps as explained below will help to aim purposes:

- To understand the major issues in the field of composite material.
- To select a proper material dealing with this issue.
- To find a accurate methodology to model interaction of fibre and soil part
- To learn the application, whole necessary input data, scientific background, and limitations of model.
- To collect required data from laboratory
- To assess the accuracy of data.
- To plan an accurate approach for failed data.
- To prepare model for simulation.
- To calibrate the constitutive modules parameters for practical conditions.
- To verify model for different application.

Figure 1-1 show the general procedure which will be applied in this research. The details of each part will be well presented in other sections.

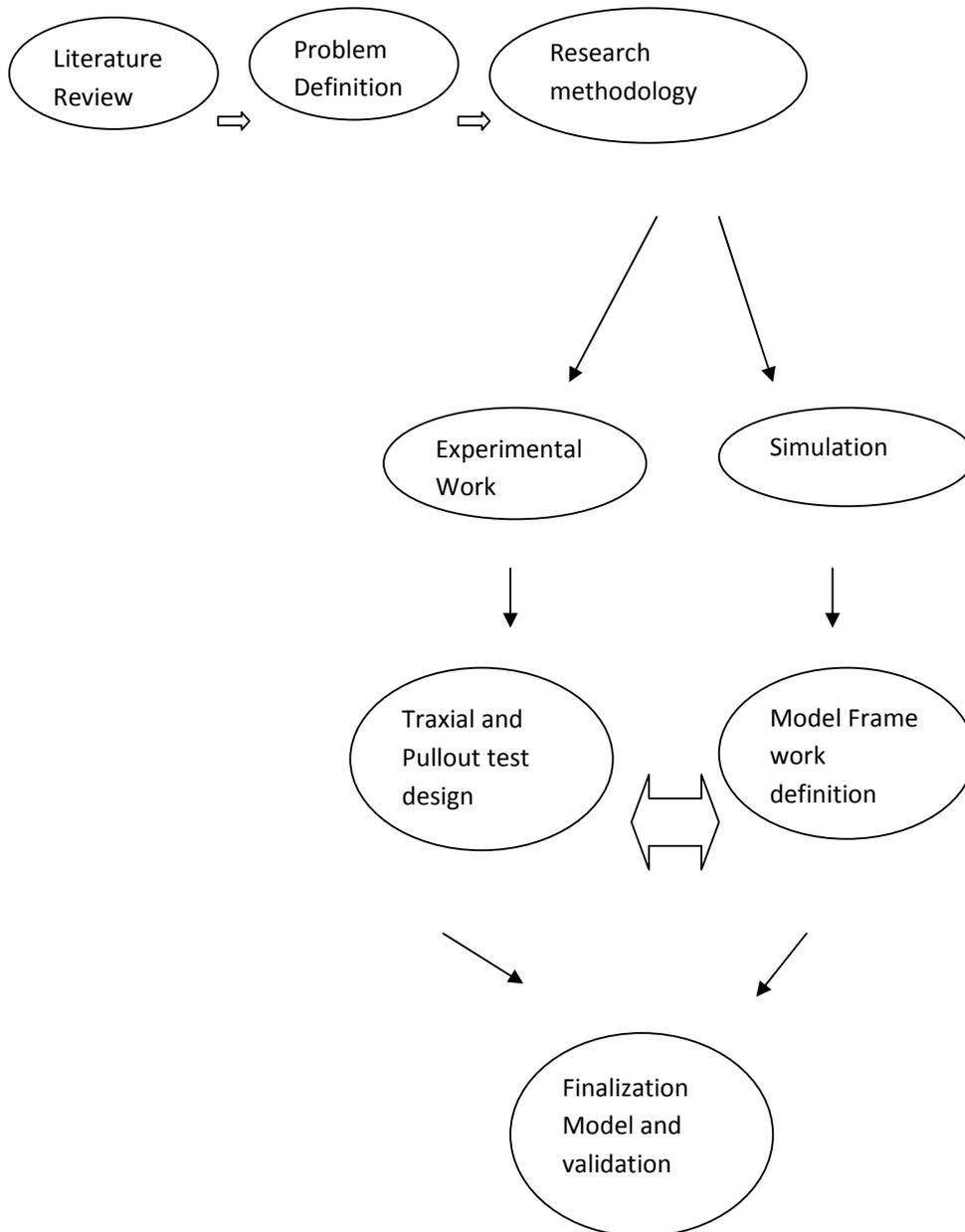


Figure 1-1: General research procedure

1-5 Constitutive model

The below sections describe the components of the constitutive model.

1-5-1 Principle of the model

This section presents the principle of rule of mixture which was used in the model and the other components.

1-5-1-1 Rule of Mixture

The rule of mixture is used for development of a model for fibre-reinforced clay which can be presented as follows:

- Each component of a composite satisfies its own constitutive law
- Each component is homogeneously distributed throughout the composite
- The individual contribution of each component to the overall composite behaviour are scaled according to their volumetric fractions

1-5-1-2 The fibre stiffness matrix

Assuming fibre behaves elastically, the elastic modulus of fibre will be obtained in the lab. A relationship will be derived for the fibre contribution in the constitutive model based on orientation of fibre and modulus of elasticity of the fibre.

1-5-1-3 The clay stiffness matrix

For the purpose of modelling, clay stiffness matrix should be obtained. An appealing feature of the modelling framework presented here is that any constitutive model for describing the stress–strain behaviour of the clay may be used to obtain the stiffness matrix for unreinforced clay. The most suitable elastic plastic constitutive model for clay, i.e., Modified Cam Clay (MCC) model will be used in this study.

1-5-1-4 The final constitutive model

The final format of constitutive model will be defined as combination of fibre stiffness matrix and clay stiffness matrix by using volumetric fraction and rule of mixture. This model will be validating with CD tests results for different fibre content. Validation of the model against fibre length change is not in scope of this project as dealing with clay material and running the test for them takes ages and is recommended for further work.

1-5-1-5 Model calibration

The model will be calibrated using the results of drained and undrained triaxial tests conducted on both unreinforced and reinforced samples. Each clay and fibre matrix will be calibrated separately.

1-5-2 Experimental work

The experimental program will be conducted on saturated clay to prepare input parameters, failure parameter and deformation parameters of the soil, with use of triaxial tests on unreinforced samples. In addition, pull out test will be carried out on single fibre to obtain another input parameters related to fibre matrix.. Finally, a series of triaxial tests will be conducted on reinforced samples to validate the model.

1-6-Review of thesis content

1. *Litrature review of previous works:* considerable time spent on to review previous works to evaluate and use them in current research. Chapter 2 presents the state of art of the previous works.

2. *Preliminary Investigation on behaviour of reinforced clay.* Even though various tests have been proposed in the past, only limited research has been conducted on the discrete fibre reinforced clay and its test results. Variety of tests such as compaction,

direct shear and consolidation were conducted and the results were presented in Chapter 4 of this dissertation.

3. *Evaluation of the shear strength increase of fibre-reinforced clay.* The shear strength of fibre-reinforced clay is more difficult to predict than that of fibre reinforced

sand. This is because of the difficulty in quantifying the pore water pressures and consequently, the interface shear strength. Limited past research conducted on fibre-reinforced clay has shown inconsistent results regarding the shear strength increase due to fibre reinforcement. A triaxial compression testing program was conducted as part of this research using cohesive soil. The factors that influence the equivalent shear strength of fibre-reinforced clay) are evaluated in Chapter 5 of this dissertation.

4. *Evaluation of the stress-strain behavior of fibre-reinforced soil.* While most previous research has focused on the prediction of the equivalent shear strength of fibre-reinforced soil, evaluation of the stress-strain response provides important additional insight for design. While fibres contribute to the shear strength of the mixture by mobilizing tensile forces, the strain levels required for development of the tensile forces may be higher than the strain at peak strength of the soil matrix. This observation from the stress-strain response defines the need of using combination of matrix soil and fibre matrix in the design of a fibre reinforcement project. A discussion on this issue is presented in Chapter 6.

1-7 Thesis Chapters in details

A detailed review of previous work on the experimental and theoretical works on reinforced soil is presented in chapter 2. This begins with a brief history of reinforcement in soil and followed by experimental research and also reinforcement theories in which different classical models are explained. Brief reference also made to

the concrete behaviour as the similarity of usage of fibre in concrete especially in tension.

Appropriate reference is made to the models predicting pure soil behaviour, ie. Mohr coulomb, Cam Clay and Modified Cam Clay. These include investigating the parameters contribute to define the soil behaviour and theoretical background for each model. Relationship between different types of the test which affect the model parameters also fully investigated. Finally, the constitutive model of Modified Cam Clay has been chosen for pure soil modelling.

The details and nature of used material and their relevant parameters are presented in Chapter 3. This chapter mainly focused on how and why these materials have been selected to conduct research.

A series of preliminary tests have been conducted to evaluate effect of fibre on soil. These includes: compaction tests, direct shear test and consolidation test. The results of consolidation test are used to define Cam-Clay model parameters. This will be presented in Chapter 4.

The details of the experimental work are presented in Chapter 5 including information on principle of triaxial test and the automated triaxial test device. Testing procedures applied during the research project are outlined. These include; sample preparation and how the sample provided and why the percentage of fibre selected as such.

The analysis of experimental results is given in Chapter 6 and begins with investigating of effect of fibre length and content in triaxial test and how these results will be used in validating and definition of model parameters.

Chapter 7 is devoted to the constitutive model which proposed and its validation with Matlab software. The results completely supported and showed good agreement with reality. In this chapter the capability of Matlab software also presented as a tool to model the behaviour of reinforced clay. The validation has been conducted with use of CD tests.

Chapter 8 presents conclusions and recommendations for further works.

Finally, the appendices include the raw results from Curtin University Laboratory and selected published papers in peer-review conferences and journals.

2. Literature Review

2-1 Main works on strength of reinforced soil

The idea of fibre-reinforcement in geotechnical projects initially involved the use of plant roots as reinforcement. Gray (1970), Waldron (1977), and Wu et al. (1988) reported that plant roots increase the shear strength of the soil, and accordingly the stability of natural slopes. Synthetic fibres have been used since the late 1980s, when the initial studies using polymeric fibres were conducted. Specifically, triaxial compression tests, unconfined compression tests, and direct shear tests have been conducted to study the effect of fibre presence on shear strength. Fibre-reinforcement can meaningfully increase the peak shear strength and limit the post-peak shear strength loss of a soil mass. (Li and Zornberg, 2003)

Research on the usage of fibre as reinforcement in cohesive soils has been limited. Although fibre inclusion was described to increase the shear strength of cohesive soils, no model has been presented that can be used to assess the effect of fibres on the shear strength of cohesive soils.

Andersland and Khattack (1979) investigated the effect of inclusion of cellulose pulp fibres on the shear strength and stress-strain behaviour of kaolinite clay. They showed that the attraction between clay particles and fibres caused in sufficient bond permitting load transfer through shear when fibres are moved. Results from triaxial tests showed that fibre inclusion increases the peak strength of kaolinite under all testing conditions, i.e., unconfined undrained (UU), consolidated undrained (CU), or consolidated drained (CD) tests. They also presented that the ductility of clay increased by increasing fibre content. Freitag (1986) examined mechanical behaviour of clay randomly reinforced with different types of fibres. Residual limestone soil classified as clay (CL) was used in a series of tests. The results showed that randomly distributed fibres in a compacted fine-grained soil increase the strength and toughness of the soil. The strength increased by about 25% for samples compacted at moisture contents wet of optimum.

Maher and Ho (1994) explored shear strength on Kaolinite clay according to fibre and water content. The clay had a liquid limit of 45% and a plastic limit of 30%. Polypropylene, glass and softwood pulp were used as fibre. The fibre content was varied from 0.5 % to 4%. A series of experimental tests were performed, including unconfined-compression, splitting-tension, three point- bending, and hydraulic-conductivity tests, to survey the mechanical properties of the reinforced-clay. The results from Maher and Ho (1994), which are shown in Figure 2-1, 2-2 and 3-2 showed that the randomly distributed fibres considerably increase the peak compressive strength, ductility,

splitting tensile strength, and flexural toughness of clay. The rise in strength and toughness was a function of fibre length, fibre content, and water content of in the composite samples. Due to increasing in fibre content the compressive and tensile strengths, and the toughness index of the clay were increased, with the effect being clearer at lower water contents. Figure 2-1, 2-2 and 2-3 are evidence of effect of water content in fibre inclusion study.

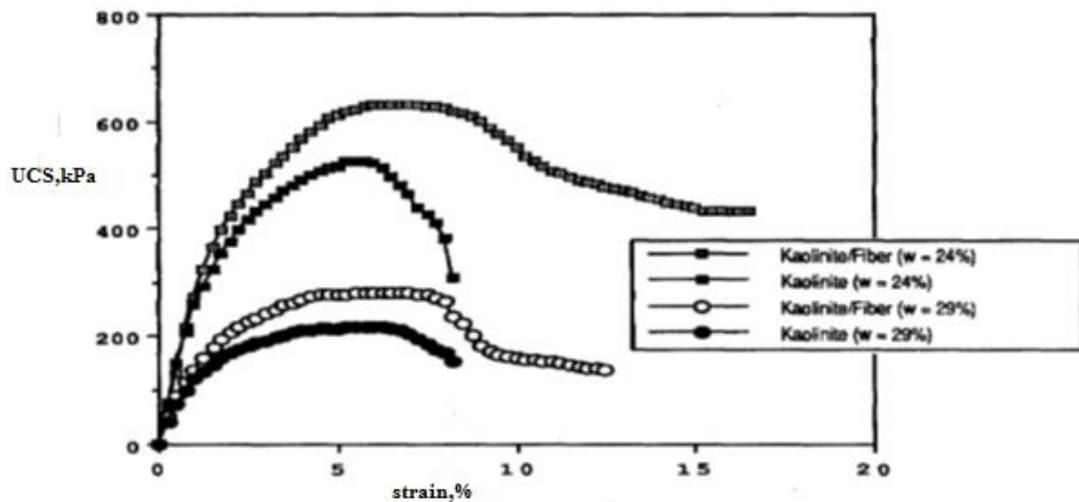


Figure 2-1: Effect of water content and fibre inclusion on compressive strength of clay

(Maher and ho, 1994)

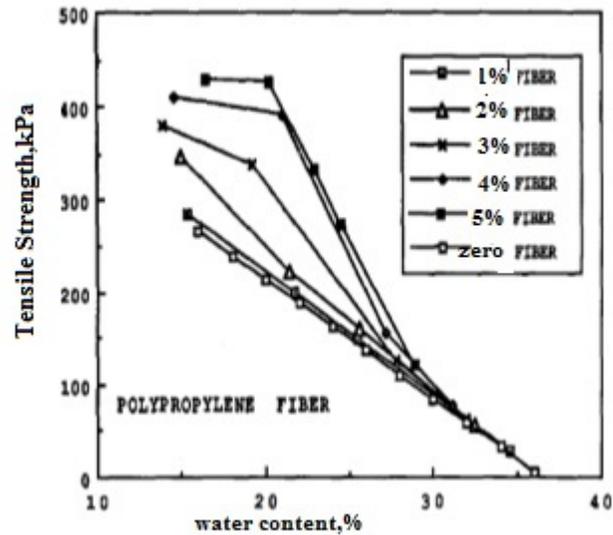


Figure 2-2: Effect of water content and fibre inclusion on tensile strength of clay (Maher and ho, 1994)

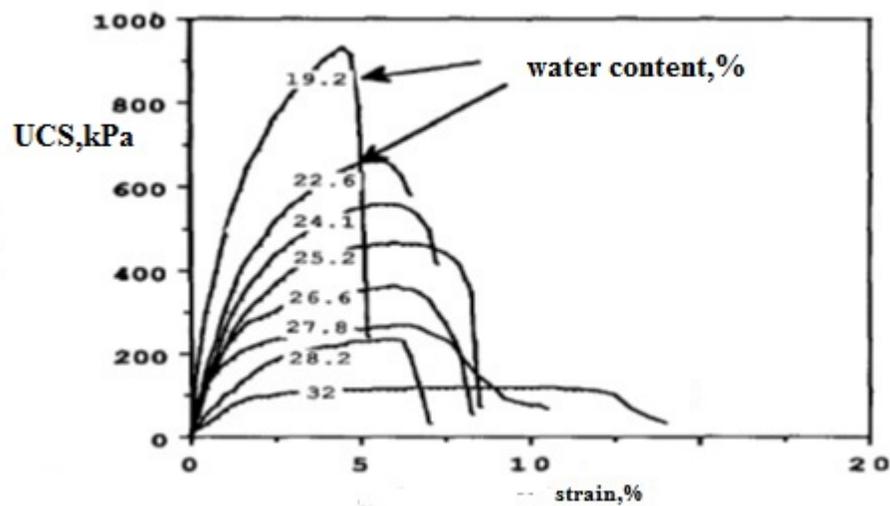


Figure 2-3: Effect of water content on axial strain and unconfined compressive strength (Maher and ho, 1994)

Similar studies were implemented with diverse material and conclusion proved increasing in unconfined compressive strength due to fibre inclusion. (Al Wahab and El-Kedrah, 1995; Akbulut et al., 2007; Sivakumar Babu et al., 2008)

Prabakar and Sridhar (2002) conducted a series of UCS tests to investigate the effect of fibre inclusion on shear strength parameter (C & ϕ) of two expansive soils. Two types of fibres and four fibre percentages were used to prepare the samples. Test results were statistically analysed to investigate the effectiveness of fibre reinforcement on strength. Results proved that the fibre reinforcement increased the UCS. The effects of fibre on cohesion and friction angle have been presented. Figure 2-4 and 2-5 present relationships of cohesion and friction angle with fibre length and fibre content which proved that fibre length together with fibre content is important parameter in fibre inclusion investigation. Figure 2-5 shows a peak point in certain amount of fibre content.

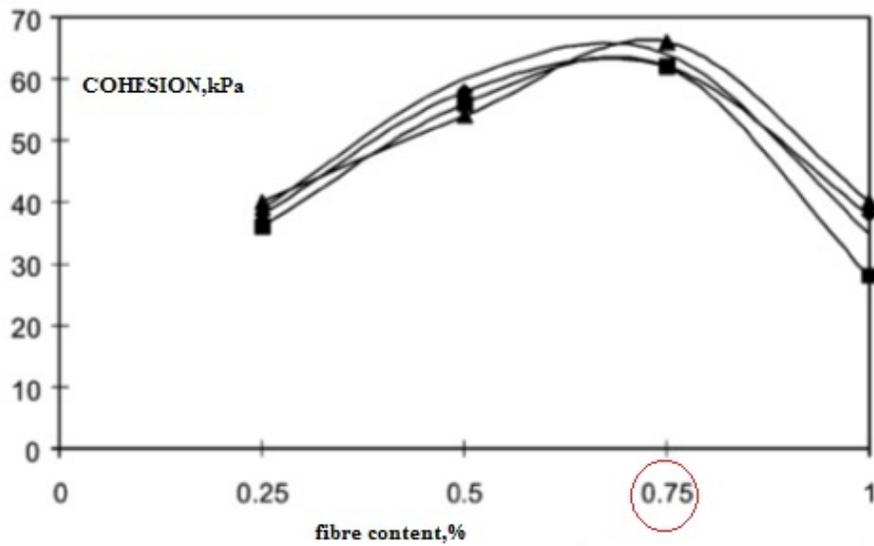


Figure 2-4: Effect of fibre content on cohesion (Prabakar et al, 2002)

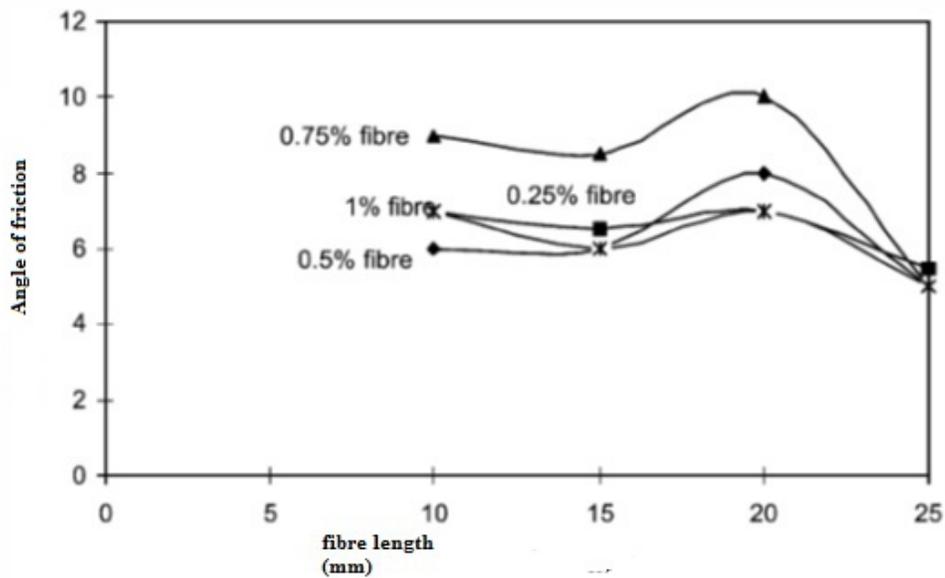


Figure 2-5: Effect of fibre length on friction angle (Prabakar et al, 2002)

Nataraj and McManis (1997) and Ozkul et al. (2007) performed a direct shear tests to explore shear strength of clay reinforced with fibres. Addition of fibres increases both the friction angle and cohesion. The lower confining pressures was used the larger friction angle was attained. The direct shear test can not signify the stress-strain behaviour of clay properly because of the drainage issue.

During the previous works barely conventional triaxial tests such as CD and CU were conducted to examine stress-strain behaviour; however these tests are more suitable for representing the deformation behaviour of composite clay. Zornberg (2002) conducted several CU tests with pore pressure measurement on clay material to study effect of fibre inclusion on stress-strain behaviour. The results are offered in Figure 2-6, 2-7 and 2-8. From these figures the effective parameters in fibre inclusion in clay can be concluded as well as the expectation about fibre inclusion effect.

Figure 2-6 shows the relationship of deviatoric stress and axial strain in different fibre content. Based on this figure, fibre content doesn't have clear influence on deviatoric – axial strain graph.

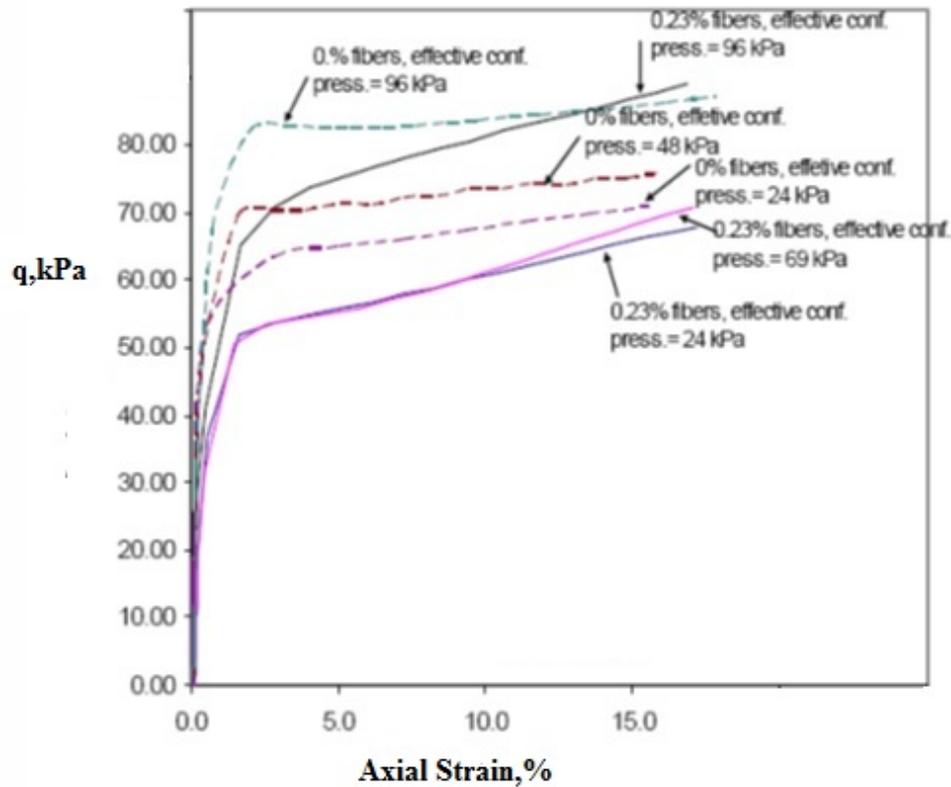


Figure 2-6: Effect of fibre inclusion on strength obtained in CU test (Zornberg, 2002)

Figure 2-7 displays the relationship between excess pore water pressure and axial strain based on different fibre contents. Figure 2-7 explains that pore water pressure excess increases while fibre content rises in constant confining pressure and specific axial strain.

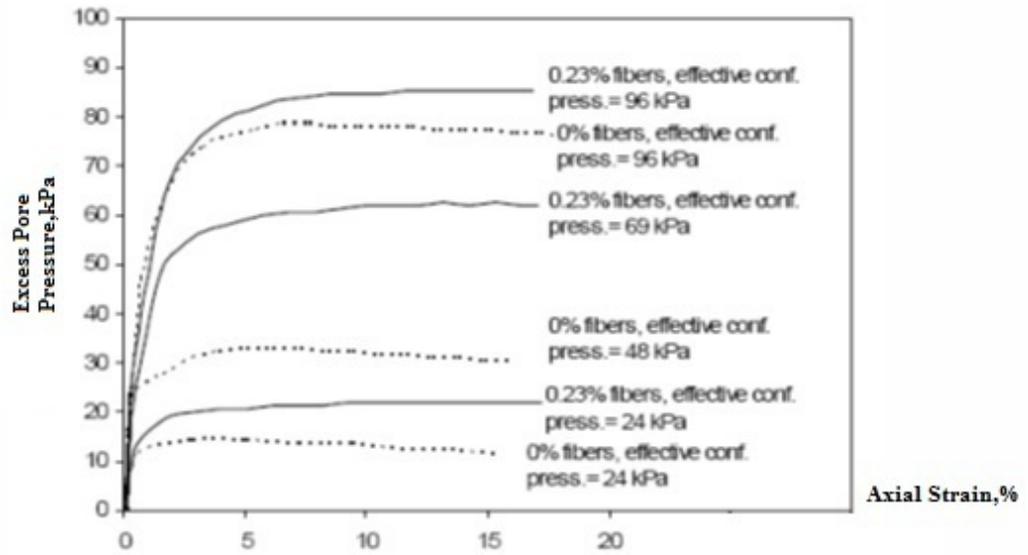


Figure 2-7: Effect of fibre inclusion on excess pore pressure generated during CU test

(Zornberg, 2002)

Figure 2-8 shows the effect of fibre inclusion on the shear stress envelope. The results from Zornberg (2002) verified that fibre inclusion will have effect on shear stress envelope which can be understood in figure 2-8.

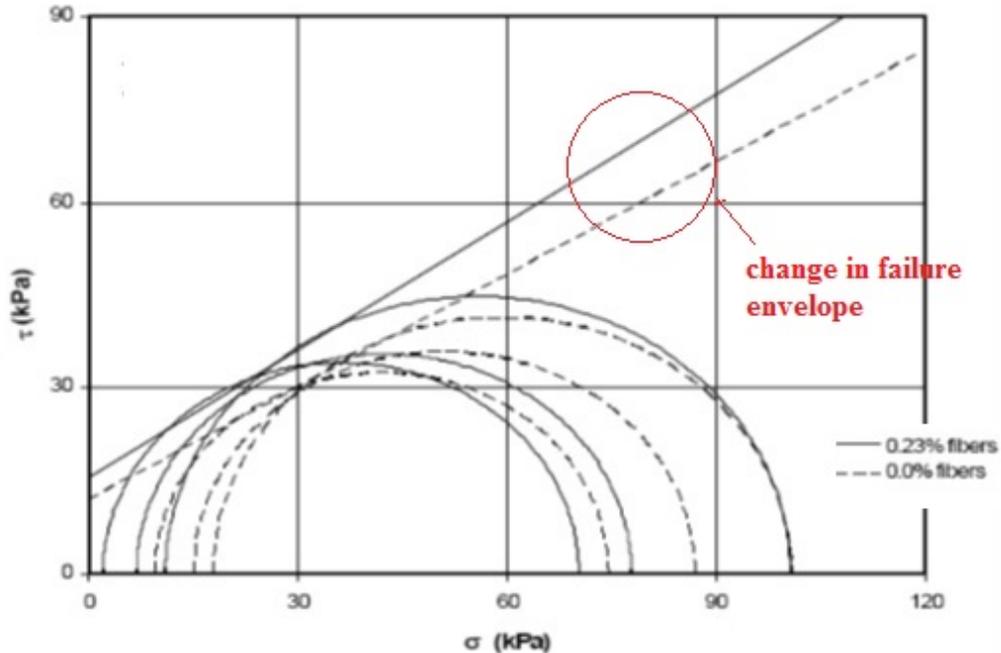


Figure 2-8: Effect of fibre inclusion on shear stress envelope in CU test (Zornberg, 2002)

Ozkul et al. (2007) performed a series of triaxial CD and CU tests on low-plasticity clay with tire buffing, prepared at both standard and modified compaction energy. Experimental observations indicated that the drained shear strength of the clay was unchanged by the inclusion of rubber buffing or by an increment in the level of compaction energy. Its undrained strength was also constant when standard compaction energy was used, but reduced marginally, showing a more ductile failure, when modified energy was applied. Work of Ozkul et al. (2007) was limited to derive stress-strain graph based on experimental data and didn't include any effort to develop a constitutive model for stress-strain behaviour of clay-fibre.

As a summary, research study have not sofar established the fundamental modelling (rely on laboratory data) on the behaviour of clay–fibre mixtures. In this study the effect of fibre inclusions on the stress-strain behaviour of clay under different test conditions will be examined. Conventional triaxial tests CD and CU in compression will be performed. The results from experimental works are used to calibrate and develop a constitutive model. The scope is limited to one fibre type and the main aim is to derive a constitutive model for clay-fibre composite material in saturated condition.

2- 1-1 Effect of fibre mixed with other stabilization materials

Cai et al. (2006) conducted a series of tests on clay fibres mixed with lime to investigate the influence of fibre and lime on the mechanical behaviour of a clayey soil. The results indicated that fibre content, lime content and curing duration had substantial effect on the mechanical reply of the fibre–lime treated soil. An increase in lime content resulted in an initial rise followed by a small reduction in unconfined compressive strength (UCS). Figure 2-9 shows the relationship of UCS and fibre content and lime content.

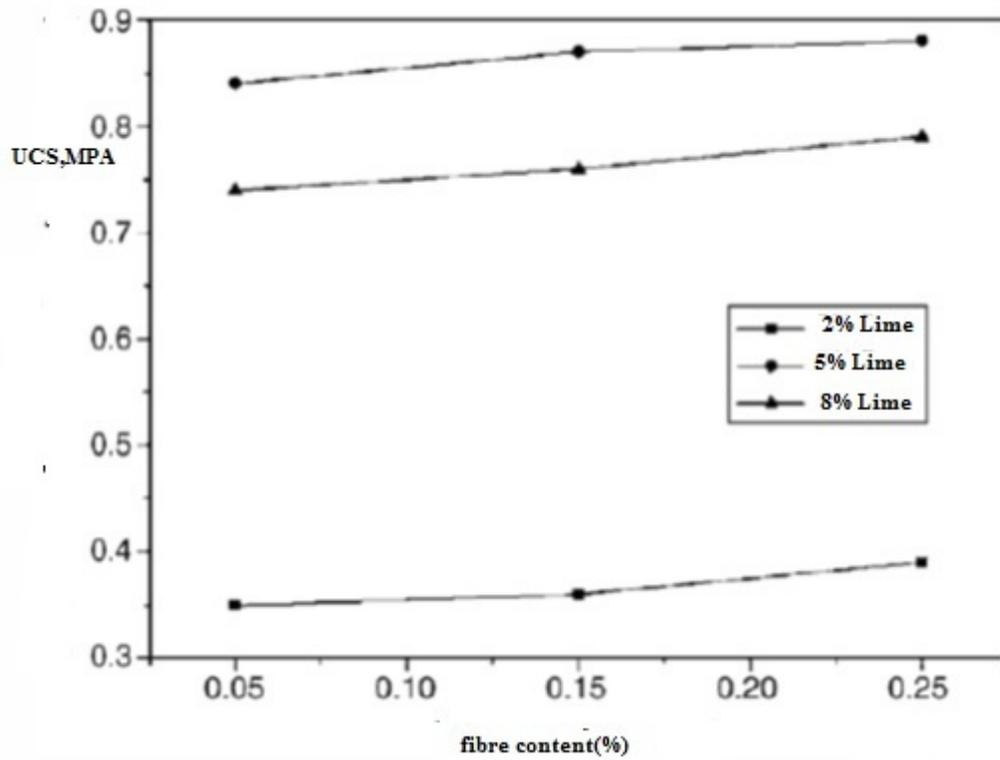


Figure 2-9: Effects of fibre and lime on UCS (Cai et al., 2006)

Figure 2-9 illustrates that increasing in fibre content has more significant influence in UCS than increasing in lime content.

2- 1-2 Effect of fibre in cemented soil

Tang et al. (2007) performed an experimental program to investigate the effect of randomly spread short polypropylene fibre (PP-fibre) on the strength and mechanical behaviour of cemented clayey soil. Various percentages of PP-fibre content were mixed with clay. The test results showed that inclusion of fibre within uncemented and cemented soil causes an increase in the unconfined compressive strength (UCS), shear strength and axial strain at failure, decreases the stiffness and changes the cemented soil's brittle behaviour to a more ductile one. Figure 2-10 shows effect of fibre and cement on UCS.

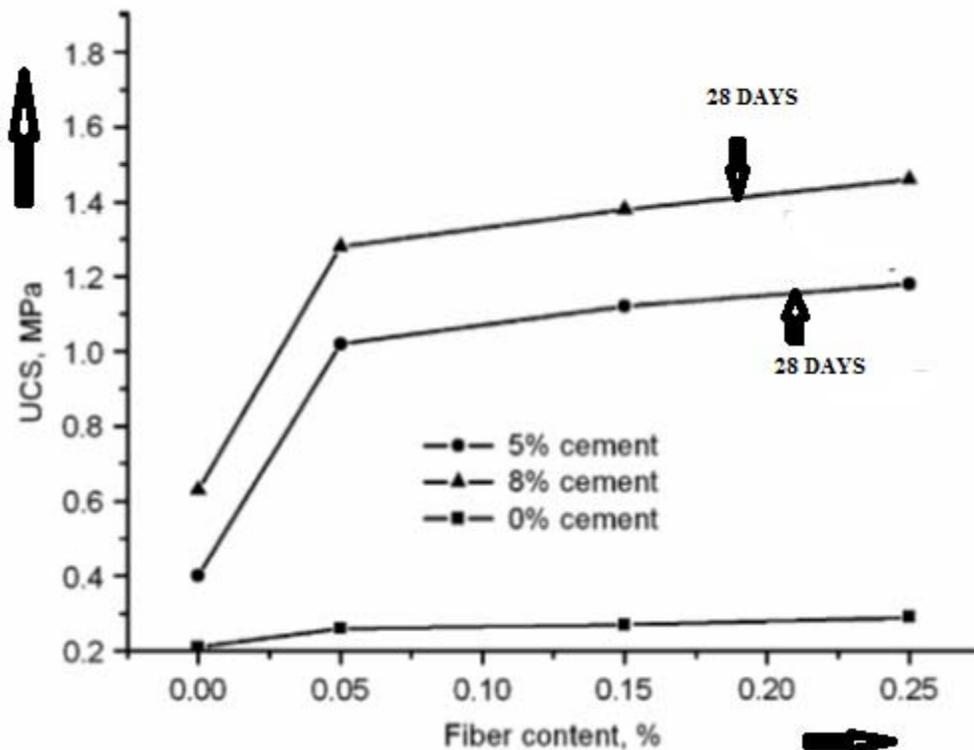


Figure 2-10: Effects of fibre on cemented soil (Tang et al., 2006)

A break point in specific quantity of fibre can be understood in Figure 2-10 and direct effect of fibre and cement on UCS has been offered in this figure which means with increasing both cement and fibre content UCS increases.

2-2 Predictive model for shear strength of fibre reinforced soil

Limited work has addressed the behaviour of clay reinforced material under loading as compared to modelling of reinforced sand. Traditionally, the design of fibre-reinforcement has been performed using a composite' approach, in which the fibre-soil composite is treated as a homogeneous material. An 'equivalent' shear strength envelope has been generally used to quantify the response of the composite under shearing. Gray and Ohashi (1983) reported that the shear strength envelopes of fibre sand mixture show a bilinear trend. The shear strength envelope of fibre-reinforced specimens was found to be parallel to the envelope of unreinforced soil, once the confining pressure exceeds a critical or 'threshold' value. Below the critical confining pressure, the reinforced soil showed a higher friction angle than in the unreinforced soil (Figure 2-11). Gray and Al-Refeai (1986) reported that the critical confining pressure is a function of the surface friction properties of fibre and soils.

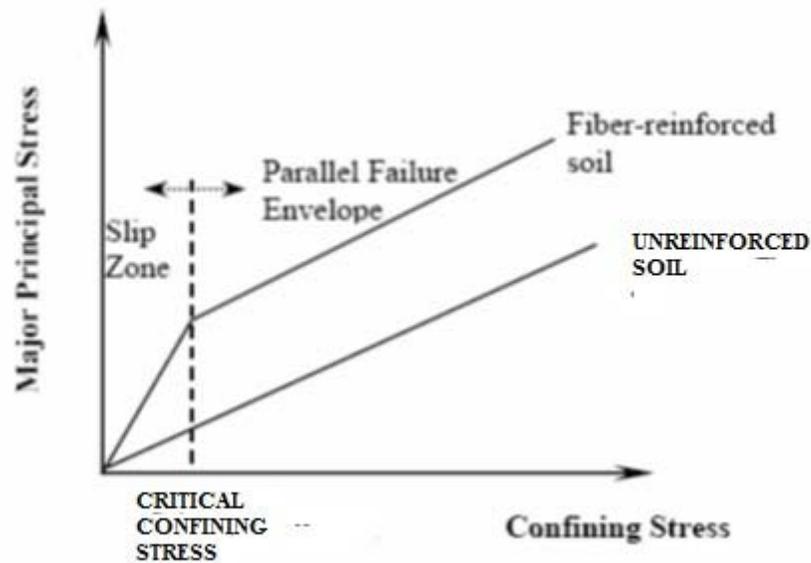


Figure 2-11: Shear strength envelope of fibre-reinforced soil (Gray and Ohashi, 1983)

Previous research on the equivalent shear strength of fibre-reinforced soil has focused on quantifying the effect of fibre content and aspect ratio. Several predictive models have been proposed. These comprise a load transfer model that needs parameters obtained with non-conventional testing of soil-fibre composites (Maher and Gray, 1990), a strain energy approach that uses energy concepts in modelling the behaviour (Michalowski and Zhao, 1996), and a statistical model based on the regression analyses of previous test results (Ranjan et al., 1996). Moreover, discrete design methodology (Zornberg, 2002) uses ideas derived from limit equilibrium, and requires

independent characterization of soils and fibres. Fewer authors have tried to address a common constitutive law for reinforced soils.

Models based on a volumetric homogenisation method but limited to the description of non-linear elastic behaviour have been presented by Ding and Hargrove (2006) for monotonic loading. This study focused on elastic behaviour and did not establish any plastic modelling.

As referred by Diambra et al. (2009), a complete constitutive law for soils reinforced with continuous thread (Texsol) was proposed by Villard et al. (1990) and di Prisco and Nova (1993) employing the superposition of sand and fibre effects. The model proposed by Villard et al. (1990) is the only one that recognises the importance of fibre orientation as a parameter governing the effectiveness of fibre inclusion. Brighenti (2004) and Car et al. (2000) proposed an elastic-plastic model for composite material which finally was calibrated for concrete sample. Recently, a two dimensional distinct element method (DEM) has been developed for the micromechanical analysis of mixtures of granular materials and flexible fibres (Ibraim et al., 2006; Ibraim and Maeda, 2007). Numerical analysis with finite difference code has been performed by Sivakumar Babu et al. (2008). Diambra et al. (2009) presented a new modelling approach for constitutive behaviour of fibre reinforced soils under triaxial conditions. The model was based on the rule of mixtures of composite materials and it considers that the fibres behave linearly

elastic and the soil, when unreinforced, obeys the simple linear elastic perfectly plastic Mohr-Coulomb model. The model is calibrated and tested using results from a series of triaxial compression and extension tests, which are presented in the first part of work of Diambra et al. (2009).

Rifai and miller (2009) planned an easy model based on Mohr-Coulomb concept that applies to the interface area between fibres and clay. The proposed model forecasts that tensile strength will increase by fibre inclusion. The contribution of the unsaturated conditions to the tensile strength of the soil was investigated using the parameters of the Soil Water Characteristic Curve (SWCC). Model sensitivity analyses showed that water content and fibre content have a considerable influence on the model outcome.

As a summary, constitutive modelling of reinforced fine grained material hasn't been studied with consideration of deformation of soil. The following sections focus on traditional modelling of fibre reinforced sand. It is suitable to be aware of these models because of their likely applications in clay behaviour modelling.

2-2-1 Load transfer approach

Gray and Ohashi (1983) presented a force equilibrium model based on the results of a series of direct shear tests performed on sands reinforced with fibres placed at defined orientations. The shearing of soils is assumed to cause fibre distortion along the shear plane, thereby mobilising its tensile resistance (Figure 2-12). The fibre-induced tension was calculated from the extension of fibres assuming that fibres length, interface friction and confining pressure are large enough to prevent pullout failure. In this case, the tension related to fibre inclusion can be stated as a function of fibre modulus, interface friction, fibre diameter and thickness of the shear zone as follows:

$$\sigma_t = \left(\frac{4 e_f \tau_f z}{d_f} \right) (\sec \phi - 1)^{1/2} \quad (2.1)$$

Where:

σ_t = tensile stress

τ_f = frictional resistance

ϕ = friction angle of soil

z = thickness of shear zoon

e_f = energy dissipated on the interface of a single fibre

d_f = equivalent diameter of single fibre

The contribution of the fibre-induced tension to the shear strength of the composite was determined from force equilibrium considerations, and was proposed by the following equation for fibres perpendicular to the shear plane:

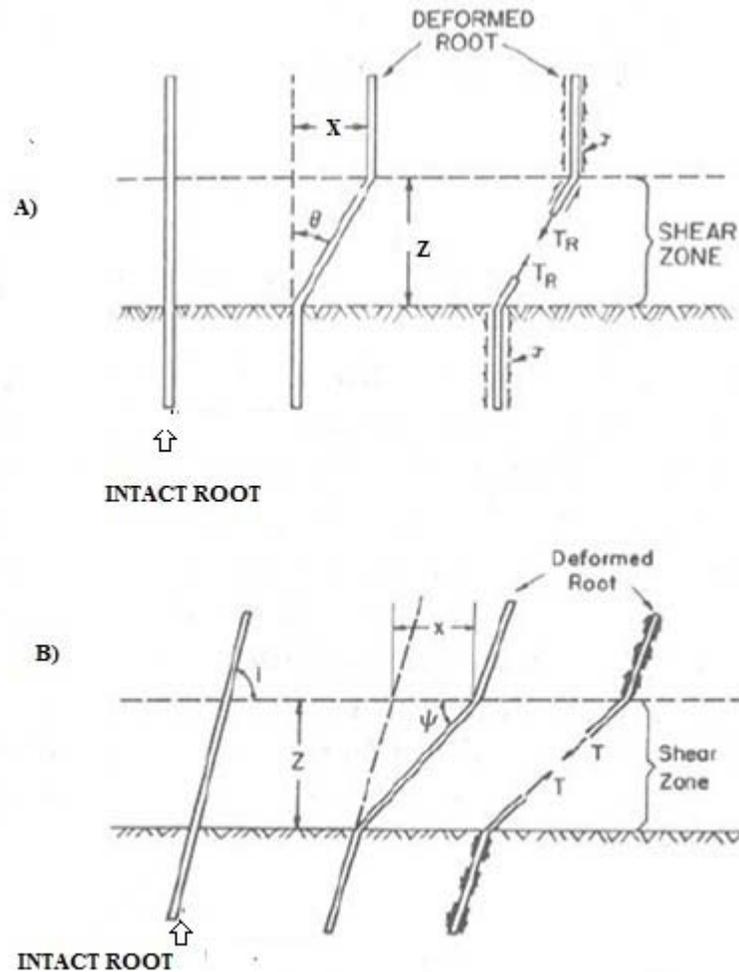


Figure 2-12: Elastic fibre across the shear zone a) vertical fibre b) inclined fibre (Gray and Ohashi, 1983)

$$\Delta S = t(\sin \theta + \cos \theta \tan \phi) \quad (2.2)$$

Where:

θ = angle of distortion of fibre (Figure 2-12)

t = mobilized tensile strength defined as:

$$t = \left(\frac{A_f}{A}\right)\sigma_t \quad (2.3)$$

Where:

A_f = area of fibre in shear

A = area of failure plane

Equation (2.2) can be stated when the fibres are oblique as follows:

$$\Delta S = \sigma'_t [(\sin(90 - \psi) + \cos(90 - \psi) \tan \phi)] \quad (2.4)$$

Where:

ψ = orientation angle of distorted fibre

ψ can be expressed as :

$$\psi = \tan^{-1} \left[\frac{1}{\left(\frac{x}{z}\right) + (\tan i)^{-1}} \right] \quad (2.5)$$

Where:

i = initial orientation of fibre

The fibre-induced tension force in terms of the fibre extension is calculated by Equation (2.1), which is valid only for extensible fibre with a frictional surface. Commonly used polymeric fibres have relatively high tensile strength and deformation modulus but relatively low interface friction. Therefore, this model may be inadequate when failure is governed by the pullout of fibres. In addition, this model requires determination of the thickness of the shear zone as an input parameter, which is difficult to compute (Li and Zornberg, 2003).

Maher and Gray (1990) developed further the model presented by Gray and Ohashi (1983) to apply it to randomly-distributed fibres by incorporating statistical concepts.

The average number of fibres N_s , intersecting the unit area of the shear plane was defined as:

$$N_s = \frac{2\chi}{\pi d_f^2} \quad (2.6)$$

Where:

χ = fibre content

They also defined the tensile stress developed in a fibre as:

$$\sigma_t = 2(\sigma_n \tan \delta) \frac{l_f}{d_f}, \sigma_n < \sigma_{ncrit} \quad (2.7)$$

$$\sigma_t = 2(\sigma_{ncrit} \tan \delta) \frac{l_f}{d_f}, \sigma_n > \sigma_{ncrit} \quad (2.8)$$

Where:

σ_n = confining stress on fibre

δ = angle of skin friction

l_f =total length of fibre

σ_{ncrit} = critical confinement corresponding to the break on the shear strength envelope

The shear strength increase ΔS , induced by fibre presence was obtained by substituting Equations (2.8) into (2.2), as follows:

$$\Delta S = N_s \left(\frac{\pi d_f^2}{4} \right) \left[2(\sigma_n \tan \delta) \frac{l_f}{d_f} \right] (\sin \theta + \cos \theta \tan \phi) (\zeta), \quad \sigma_n < \sigma_{ncrit} \quad (2.9)$$

$$\Delta S = N_s \left(\frac{\pi d_f^2}{4} \right) \left[2(\sigma_{ncrit} \tan \delta) \frac{l_f}{d_f} \right] (\sin \theta + \cos \theta \tan \phi) (\zeta),$$

$$\sigma_n > \sigma_{ncrit} \quad (2.10)$$

ζ = coefficient depends on sand parameter

As in the force equilibrium model planned by Gray and Ohashi (1983), the model proposed by Maher and Gray (1990) still requires the thickness of shear zone as an input, which is hard to quantify. The expression of σ_{ncrit} was derived empirically (Maher, 1988) applying the results from triaxial tests.

2-2-2 Statistical approach

Ranjan et al. (1996) proposed a description for the shear strength of fibre reinforced soil using a statistical analysis of a series of conventional triaxial compression tests. The tests were performed on samples of cohesionless soils and discrete fibres to investigate the effect of fibre characteristics, soil characteristics, and confining stress on shear strength of reinforced sand. The percentage of fibre, fibre aspect ratio, fibre-soil interface friction, and shear strength of raw soil sample were reflected as the major variables affecting the shear strength. These parameters were applied in a statistical survey, which led to the following relationships for shear strength of composite soil:

$$\sigma_{1f} = 12.3 (\chi)^{0.4} \left(\frac{l_f}{d_f}\right)^{0.28} (f^*)^{0.27} (f)^{1.1} (\sigma_3)^{0.68} \quad \sigma_3 < \sigma_{ncrit} \quad (2.11)$$

$$\sigma_{1f} = 8.78 (\chi)^{0.35} \left(\frac{l_f}{d_f}\right)^{0.26} (f^*)^{0.06} (f)^{0.84} (\sigma_3)^{0.73} \quad \sigma_3 > \sigma_{ncrit} \quad (2.12)$$

Where:

σ_{1f} = major principal stress at failure

The definition of coefficient of interface friction f^* and coefficient of internal friction f can be expressed as follows:

$$f^* = \frac{a}{\sigma_N} + \tan \delta \quad (2.13)$$

$$f = \frac{c}{\sigma_N} + \tan \phi \quad (2.14)$$

Where:

a = adhesion or intercept of surface friction

c = cohesion of soil

σ_N = nominal confining stress (100 kPa was suggested)

The shear strength envelope forecasted by equation (2.11) is curvilinear with a transition at specific confining stress (instead of a sharp break) which can be found in Figure 2-13.

The shortcoming of this model is that it does not reflect the mechanisms of fibre-reinforcement and depends deeply on an easy set of experimental results. Consequently, the precision of the prediction depends on the accuracy of the test results used by the author. (Li and Zornberg 2003).

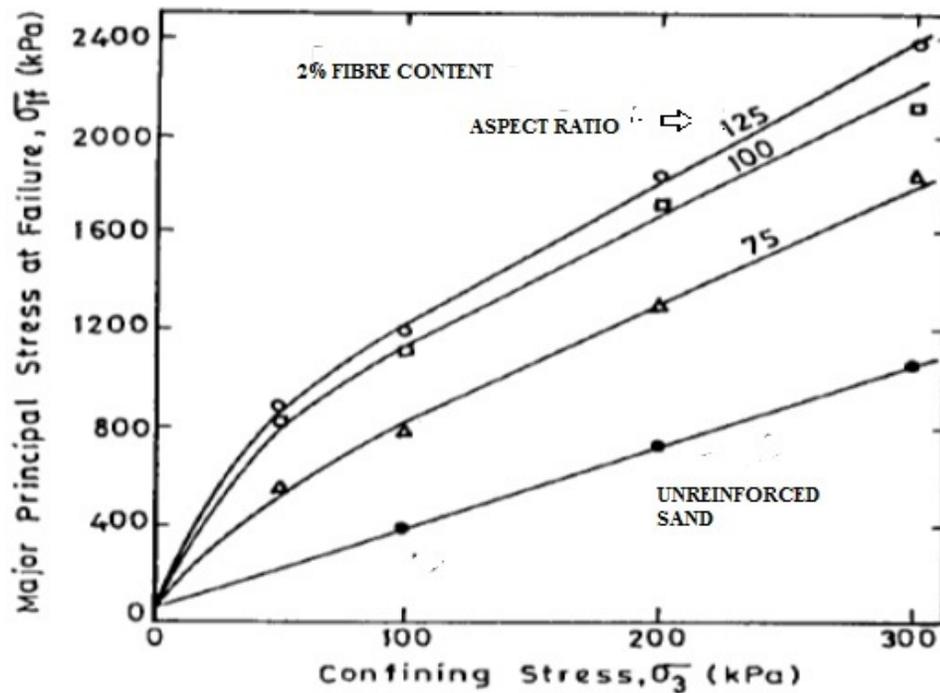


Figure 2-13: Principal stress envelope (Ranjan, 1996)

2-2-3 Energy approach

Michalowski and Zhao (1996) proposed an energy-based homogenisation technique to define a macroscopic failure stress of the fibre-soil composites. The fibres were assumed to be under a stress distribution pattern shown in Figure 2-14, in which fibre slippage takes place on the both ends of the fibres and tensile rupture takes place in the middle of the fibres. The energy dissipation rate during plastic deformation of soil was assumed to

conform to the associate flow rule, which is zero. Therefore, only energy dissipation due to fibre-soil slippage and to fibre tensile rupture needs to be considered as follow:

$$d = \pi d_f s^2 \sigma_n \tan \delta \langle \dot{\varepsilon}_\theta \rangle + \frac{1}{4} \pi d_f^2 (1 - 2s) \sigma_{fult} \langle \dot{\varepsilon}_\theta \rangle \quad (2.15)$$

Where:

d = energy dissipation rate

d_f = fibre diameter

s = length of portion of fibre along which slippage occurs

σ_n = normal stress acting on fibre

δ = interface friction angle

σ_{fult} = yield stress of fibre

$\dot{\varepsilon}_\theta$ = strain rate in the direction of fibre which is 0 for compression and $\dot{\varepsilon}_\theta$ in tension

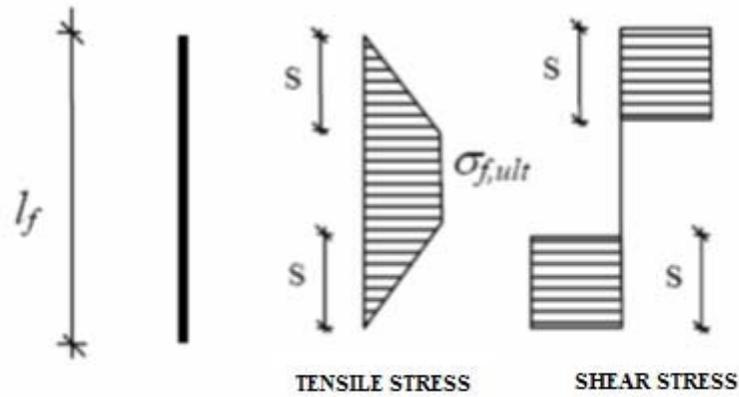


Figure 2-14: Stress distribution pattern of fibre reinforcement (Michalowski and Zhao, 1996)

The total energy dissipation rate per volume of the soil, D , is the integral of equation (2.15) over the volume of fibre soil composite. This is formulated as:

$$D = \frac{\chi \sigma_{fult}}{3} M \left(1 - \frac{1}{4 \eta p \tan \delta} \frac{\sigma_{fult}}{\sigma_{fult}} \right) \varepsilon_1 \quad (2.16)$$

Where:

η = aspect ratio of fibre

p = average normal stress

$$M = \left(\left[\frac{1}{2} + \frac{\phi}{\pi} + \frac{1}{\pi} \cos \phi \right] \tan^2 \left(\frac{\pi}{4} + \frac{\phi}{2} \right) - \frac{1}{2} - \frac{\phi}{\pi} + \frac{1}{\pi} \cos \phi \right) \quad (2.17)$$

A failure criterion was derived as follows:

$$\frac{R}{\chi \sigma_{fult}} = \frac{P}{\chi \sigma_{fult}} \sin \phi + \frac{1}{3} N \left[1 - \frac{1}{4\eta\chi} \frac{\cot \delta}{\frac{p}{\chi \sigma_{fult}}} \right] \quad (2.18)$$

where

R = radius of the Mohr's circle

$$N = \frac{1}{\pi} \cos \phi + \left(\frac{1}{2} + \frac{\phi}{\pi} \right) \sin \phi \quad (2.19)$$

Figure 2-15 indicates the principal stress envelope based on Michalowski and Zhao (1996) model.

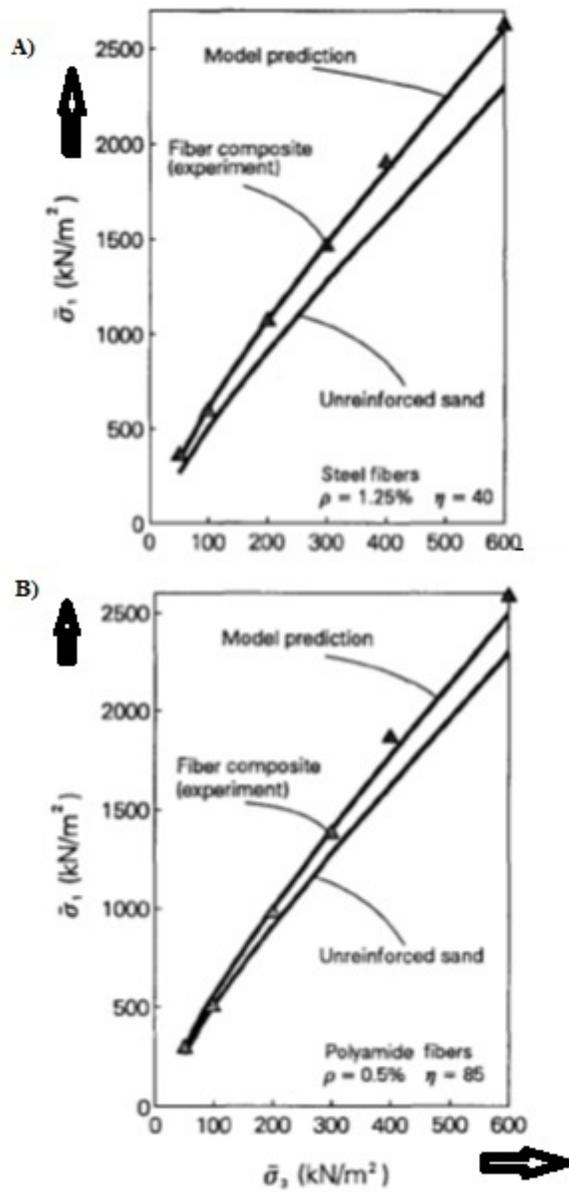


Figure 2-15: Principal stress envelope (Michalowski and Zhao, 1996)

2-2-4 Discrete approach

Zornberg (2002) advanced a ‘discrete’ framework for limit equilibrium analysis of fibre-reinforced soil. In this framework, the equivalent shear strength of the fibre-soil composite could be forecasted applying parameters gained from the independent characterization of soil specimens and of fibre specimens.

The failure criterion was expressed as:

$$S_{eq,t} = (\alpha \cdot \chi \cdot \sigma_{fult}) + (c + \tan \phi \cdot \sigma_n) \quad (2.20)$$

Where:

$S_{eq,t}$ is equivalent shear strength of the fibre reinforced soil when failure is ruled by tensile breakage of the fibres. Figure 2-16 shows bi linear shear strength envelop according to discrete approach.

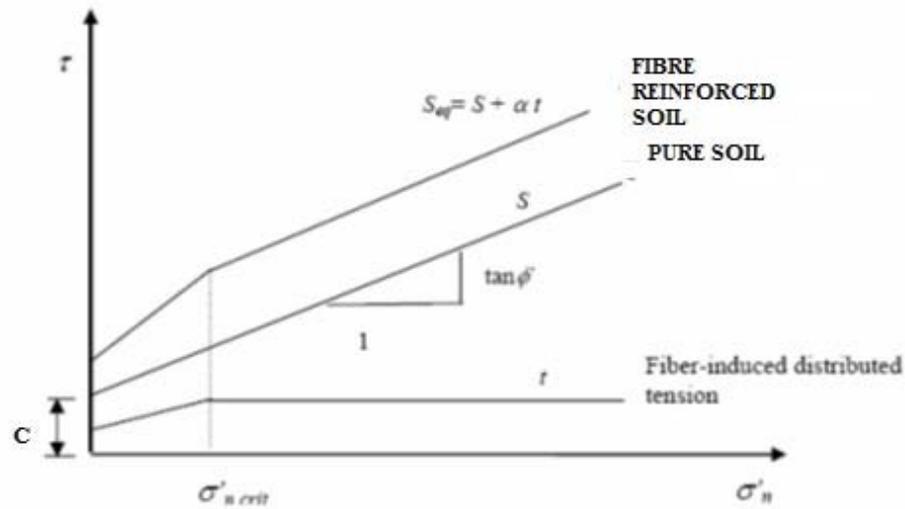


Figure 2-16: Shear strength envelop according to discrete approach (Zornberg, 2002)

The Zornberg (2002) model recommends a break point as a critical point which may need more investigation to be verified.

2-3 Effect of sample size in reinforced clay

Ang and Loehr (2003) performed a series of experimental unconfined compression tests on samples of compacted silty clay to study how the size of samples influences the recorded strength and stress-strain properties. The results gained from these tests

indicated that there was a significant effect of sample size both in terms of the magnitudes of the recorded strengths as well as in terms of the variability of the measured strengths. No clear criteria was derived for effect of sample size.

2-4 Fibre inclusion in sand

Direct shear tests, unconfined compression tests and conventional triaxial compression tests have established that shear strength increases and post-peak strength loss decreases when discrete fibres are included in sandy soils (Al Refeai, 1991; Maher and Ho, 1994; Yetimoglu and Salbas, 2003; Tang et al., 2007 among others).

Fibre characteristic including type, volume fraction, length, aspect ratio, modulus of elasticity, orientation and also soil characteristics including particle size, shape, and particle size distribution, as well as stress level and density have important effects on the strength of composite samples. Moreover, fibre orientation has substantial impact on mechanism of failure and strength (Jewell and Wroth, 1987; Michalowski and Cermak, 2002). Many experimental studies assumed that the fibres are randomly oriented throughout the soil mass. Such a distribution of orientation would preserve the soil strength isotropy and eventually avoid or delay formation of localised deformation planes. However, it has been found that the most common procedure for preparing reinforced specimens, moist tamping, leads to preferred sub-horizontal orientation of fibres (Diambra et al., 2007). Similar results have been found for vibrated fibre

reinforced specimens (Diambra et al., 2008). Since rotations of principal stress and strain rate axes almost always occur within a soil mass, the consequence of an assumed isotropy would be the overestimation of soil design strength for certain loadings. Any account of the fibres must consider fibre orientation (Diambra et al., 2009).

2-5 Confined concrete behaviour and fibre inclusion in concrete

The behaviour of fibre reinforced clay in tension can be similar to that of the fibre reinforced concrete; therefore in this section a brief review of concrete with fibre is presented. Foster and Attard (2001) conducted a series of tests on high-strength fibre-reinforced columns. The columns were tested in either concentric or eccentric compression with varying initial loading eccentricities. The study showed that the introduction of steel fibres into the mix design increased the load capacity as well as the ductility of the columns over that of comparable nonfibre-reinforced specimens.

Bencardino et al. (2008) conducted a series of tests to investigate fibre reinforced concrete in compression. Figure 2-17 shows typical stress-strain curve for concrete with and without fibre. In this figure PC and S represent nonfibre and fibre percentage in volume respectively.

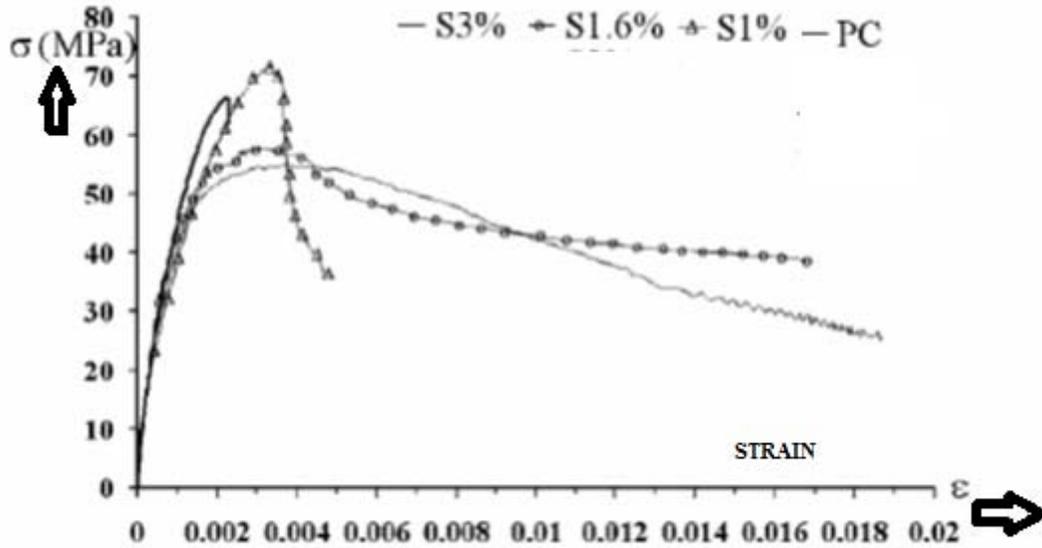


Figure 2-17: typical stress-strain curve for concrete with and without fibre (Bencardino et al., 2008)

2-6 Other influence of fibre

This section presents effect of fibre on the other parameters of soil (i.e. swelling, shrinkage, cracking and hydraulic conductivity of soil).

2-6-1 Influence of fibre on swelling and shrinkage

Generally, swelling potential has been used to describe the ability of a soil to swell, and presented either in terms of volume change or the pressure required to prevent swelling.

Therefore, it has two components: the *swell percent* which is defined as the percentage

of change in height, or the *swell pressure* which is designated as the pressure required to prevent swelling.

Inclusion of fibres in clay changes the shrink-swell behaviour of the clay. A relatively large body of research has been carried out to investigate the effects of fibre on shrink-swell behaviour (Al Wahab and El-Kedrah, 1995; Puppala and Musenda, 2000; Abdi et al., 2004; Al-Rawas et al., 2005; Cai et al., 2006; Viswanadham, 2008; Harianto et al., 2008; Sivakumar Babu et al., 2008). Almost all the researches concluded that inclusion of fibre in clay reduces the swelling potential; however, there is no clear evidence on the effects of fibre on shrinkage potential.

While Al Wahab and El-Kedrah (1995), Puppala and Musenda (2000), Cai et al. (2006), Harianto et al. (2008), Sivakumar Babu et al. (2008) conclude that fibre inclusion reduces the shrinkage potential, experimental investigation of Abdi et al. (2004) shows that it increases shrinkage potential. The difference between the results may be addressed by different sample preparation and different size of the samples, however further investigation is necessary to establish the effect of fibre shrinkage potential.

2- 6-2 Influence of fibre on hydraulic conductivity

Maher and Ho (1994), Abdi et al. (2004) and Miller and Refai (2004) examined the effect of fibre inclusion on the hydraulic conductivity of a kaolinite-fibre composite and

concluded that hydraulic conductivity of the soil increases as the percentage of fibre increases. (Figure 2-18)

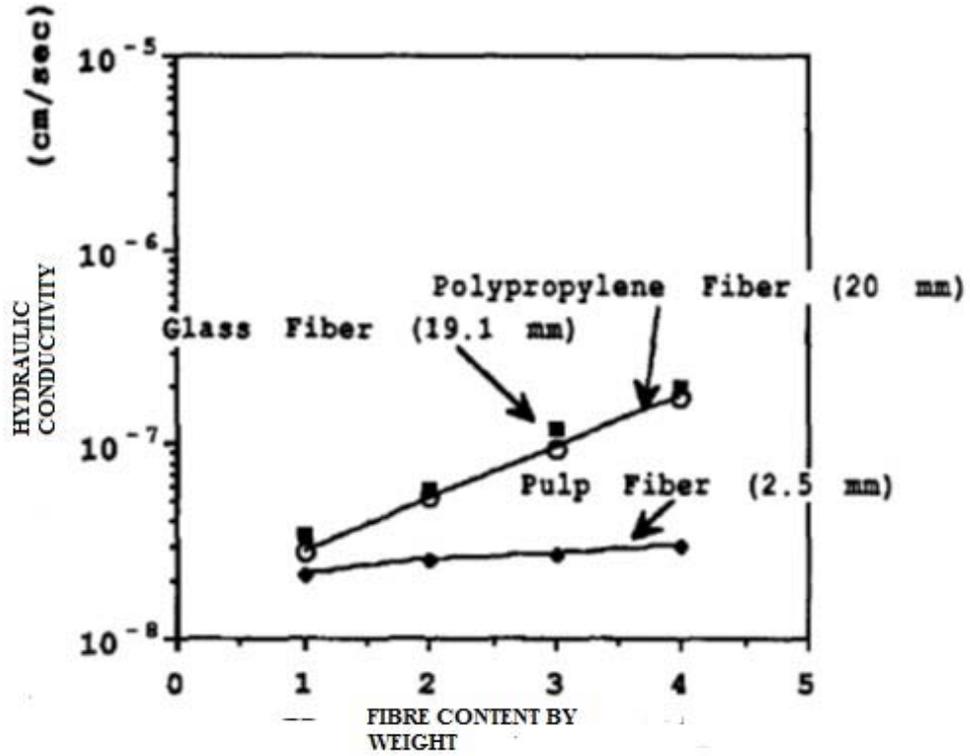


Figure 2-18: Effect of fibre inclusion on hydraulic conductivity (Maher and Ho, 1994)

2-6-3 Influence of fibre on soil compaction

Fletcher and Humphries (1991) examined influence of fibre inclusion on compaction of silty clay soil. Unlike the case of sandy gravel reported by Hoare (1977), the test results indicated that increasing the fibre content causes a modest increase in the maximum dry unit weight. The optimum water content was found to decrease by increasing fibre content. Other researchers (Nataraj and McManis, 1997; Al Wahab and El-Kedrah, 1995; Puppala et al., 2006; Miller and Rifai, 2004; Ozkul et al., 2007; Kumar Tabor, 2003) also reported similar results. Figure 2-19 shows results from Miller and Rifai (2004).

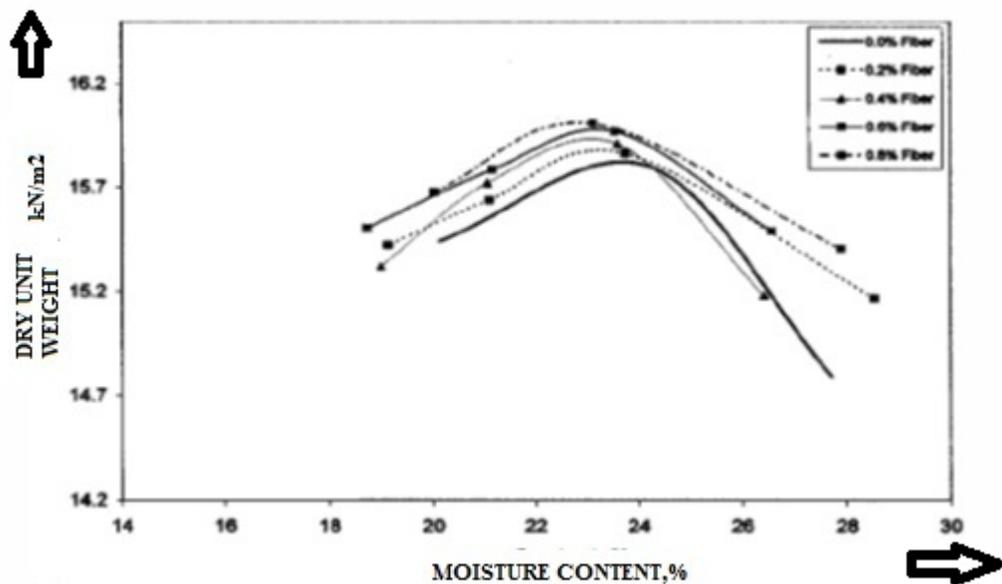


Figure 2-19: Effect of fibre inclusion on optimum moisture content and dry unit weight

(Miller and Rifai, 2004)

2-6-4 Influence of fibre on development of cracks

Limited efforts have also been made to investigate clay cracking by fibre reinforcement (Allan and Kukacka, 1995; Al Wahab and El-Kedrah, 1995; Ziegler et al., 1998). Miller and Rifai (2004) investigated the effects of fibre reinforcement on the development of desiccation cracking in compacted clay samples. Their results indicated that an addition of 0.4-0.5% fibre can reduce the crack density by 50% while the hydraulic conductivity remains in the acceptable range.

2.7 Conclusion

Due to poor and weak shear resistance and tensile capacity of naturally occurring soils, materials that are resistant to tensile strain, such as geofibres (flexible polymeric fibres) can be added to soils in order to enhance their combined mechanical behaviour. A new soil structure with enhanced engineering properties can be created by using short geofibres mixed in soil as reinforcement. The geofibre reinforced soil exhibits significantly improved performance properties (Michalowiski and Zhao 1996).

Most of the research performed so far has mainly focused on fibre reinforcement of sandy soils. Few studies have been carried out on fibre reinforcement of clayey soils particularly its stress-strain behaviour. Most of the researches are narrowed to conduct

small experimental program and hardly have addressed theoretical model for clay material.

Diambara et al. (2010) proposed a new attitude to model the behaviour of reinforced sand. In Diambara et al. (2010) study, Mohr-Coulomb method has been used to derive a constitutive model for sand. They concluded that for granular material in triaxial compression considerable increase of strength was tempted by the presence of fibres, while in extension the benefit of fibres is very limited (Diambara et al., 2010). This approach can be used for reinforced clay material.

As a summary, review of literature shows that using triaxial test as an approach to derive a constitutive model which comprises soil plasticity behaviour for reinforced clay hasn't been addressed and still is a mystery. This research will address the fibre inclusion effects on strength and stiffness of clay and develop a constitutive model for composite clay. This study is a combination of experimental and theoretical work. In order to compensate the lack of comprehensive experimental program on clay, a series of main soil mechanic tests (i.e. direct shear , consolidation, compaction, CBR) together with triaxial test (i.e. CD and CU) are conducted .Finally, the outcome of the test will be used to derive a constitutive model for reinforced clay.

The constitutive model is based on Modified Cam Clay (MCC), consequently the tests are performed and designed so that the modified cam clay parameter such as κ , λ , M can be calculated from these tests and the proposed model can be calibrated. κ and λ can be derived from 1-D consolidation test with emerging deformation behaviour of soil sample in v - $\ln p'$ space and M (slope of critical state line) can be derived from CU test from q - p' space.

3. Material

3-1 Soil

Clayey soil was used throughout this study. The preliminary tests include usage of Western Australian clay and fibre. Finally, a theoretical model developed for pure kaolin clay reinforced with the fibre. (See table 3-1)

Table 3-1. Atterberg Limits of used clay

No.	Type	
2	Liquid Limit	49
3	Plastic Limit	23
4	Plastic Index	26

The PRESTIGE™ line of kaolin clays was used as clay in this study due to availability of this product in Western Australia. The PRESTIGE clay is designed to produce increased strength in plastic forming and extrusion operations. Their plastic properties over a wide moisture range will produce bodies which can withstand the rigors of automated processing and handling without cracking or deformation. PRESTIGE clays are easily dispersed in water, and are ideal for blunging to slurries, filter pressing and extrusion, mulling prior to extrusion and spray drying. In all applications, the rapid pick up and equilibration of

process fluids with these clays help minimize batching and blending time. The PRESTIGE™ line will facilitate quality casting performance over the entire casting curve and the full density range. These materials are excellent in operations where colour and structural properties need to be optimized, including high quality decorative wares, stoneware, white tableware and electrical porcelain. With low carbon content and minimal post firing residues PRESTIGE clays also produce brilliant fired colours and defect free surfaces in a wide variety of glazing systems, including spray, dipping and waterfall glazing.

The PRESTIGE™ series of kaolins are mined and processed under rigid ISO quality programs. The result is consistent mineralogy, and chemical and physical properties, that ensure predictable results with today's demanding ceramic processing techniques.

Sections below present the chemical and other characteristic of Kaolin Clay which used in this work.

3-1-1 Chemical Features

Figure 3-1 shows the chemical properties of the Kaolin clay was used for this study.

CHEMICAL AND ANALYTICAL DATA

Mean Values. These Do Not Represent A Specification.

**Mean Percent By Weight
On Oxide Basis**

		<u>NY</u>
Silicon Dioxide	(SiO ₂)	46.1
Aluminum Oxide	(Al ₂ O ₃)	36.5
Titanium Dioxide	(TiO ₂)	0.8
Iron Oxide	(Fe ₂ O ₃)	0.9
Calcium Oxide	(CaO)	0.9
Magnesium Oxide	(MgO)	0.5
Potassium Oxide	(K ₂ O)	0.2
Sodium Oxide	(Na ₂ O)	0.1
Loss on Ignition	(LOI)	14.3

M.B.I (meq/100g)	In-House	6.3
Surface Area (m ² /g)	UAL 2.8(c)	18.2
pH @20% Slurry	UAL 2.11	9.3
M.O.R. (Dried @ 110°C) (lbf/in ²)	In-House	262.6
% Water Absorption 1120°C	In-House	26.8
1220°C		11.5
% Linear Shrinkage Dry-Fired 1120°C	In-House	8.8
1220°C		14.8

Figure 3-1 Chemical and Analytical Data of Used Clay

3-2 Particle Size Distribution of Clay

Figure 3-2 shows the particle size distribution of kaolin clay.

PARTICLE SIZE ANALYSIS AND PROPERTIES
Mean Values. These Do Not Represent A Specification.

	<u>MICRONS</u>	<u>NY</u>
% Finer	53 μ	99.0
	20 μ	97.5
	10 μ	95.3
	5 μ	90.8
	2 μ	79.4
	1 μ	64.7

Figure 3-2 Clay Particle Distribution

3-3 Selecting Fibre

Due to importance of fibre material which used in this research, two fibre materials were used and the samples were compared. The first flexible fibre used., the usage of flexible fibre results non uniform distribution of fibre which was not suitable for the purpose of project.

3-3-2 Used Fibre

The fibre which was used in this project was obtained from BASF Company in Perth, Western Australia. This fibre is currently used as a mixed fibre with concrete in structural and infrastructure project to increase the strength of concrete composite. Sections below will describe the used fibre features.

3-3-2-1 Geofibres

The polypropylene fibres used in the experimental testing program are commercially available polypropylene fibres. The fibre is called MEYCO® FIB SP 65.

3-3-2-2 Description

Meyco FIB SP 65 is a macro structural synthetic polypropylene fibre which generates a very high energy absorption rate when used in the matrix for shotcreting, enabling the concrete to provide greater flexural toughness.

This fibre is currently used for:

- Shotcrete
- Pre-cast concrete
- Concrete slabs

3-3-2-3 Fibre properties

Non-corrosive – making it an excellent reinforcing in harsh environments Generates a very high energy absorption rates when used in the concrete mix for shotcreting, enabling the matrix to provide greater flexural toughness. Uniquely designed and packaged allowing to be evenly dispersed through the matrix, ensuring that no balling or pumping problems occur. Table 3-2 presents the plastic fibre properties and Figure 3-3 shows a picture of used fibre.

Table 3-2. fibre properties

No.	Type	
1	Material	Polypropylene
2	Specific Gravity	0.92
3	Width	1.6825 mm



Figure. 3-3 Discrete plastic fibre

3-4 Fibre tensile strength

As one of the main parameter of the fibre is its Young's modulus, E_f . These sections investigate this parameter with detail. It should be noted that this parameter finally will be used in the final constitutive model.

3-4-1 Elongation

The important thing to understand about a polymer's mechanical properties than merely knowing is how strong it is. All strength points out to the experts how much stress is required to break something. It doesn't show anything about what happens to

the specimen while trying to break it. That is where it worth to study the elongation response of a polymer samples. Elongation is a type of deformation. Deformation is simply an alteration in shape that anything experiences stress. When the sample deforms due to tensile stress stretches , and becomes longer. This phenomenon is called elongation.(Polymer Learning Centre, 2005)

Usually percentage of elongation is defined as the length the polymer sample is after it is stretched (L), divided by the original length of the sample (L_0), and then multiplied by 100. (See Equation (3.1))

$$\frac{L}{L_0} \times 100 = \% \text{ elongation} \quad (3.1)$$

Dealing with elongation, there are a number of items are essential to be measured and measured. These items depend on the type of material. Ultimate elongation and elastic elongation are measured regards to fibre responses. (Polymer Learning Centre, 2005)

Ultimate elongation is significant for any types of material. There is not anything more important than the quantity that can be strained before it fails. Elastic elongation is the percent elongation that can be grasped without eternally deforming. Dealing with fibre, the amount that fibre can be stretched and still fibre can back to its original length once the stress is released is called elongation. “This is important if the material is an elastomer. Elastomers have to be able to stretch a long distance and still bounce

back. Most of them can stretch from 500 to 1000 % elongation and return to their original lengths without any trouble”. (Polymer Learning Centre, 2005)

3-4-2 Modulus

Elastomers are to show high elastic elongation. But for some other kinds of materials, such as plastics, it is typically preferred that they not stretch or deform so simply. In order to investigate how well a material resists deformation, modulus is recorded. Same procedure (as to measure strength and ultimate elongation) of measurement will be applied to define tensile modulus. The tensile strength will be measured versus the deformation of the material.

Till the sample breaks the amount of stress progressively will be increased, and then the elongation was recorded as the sample undergoes at each stress level. (Polymer Learning Centre, 2005)

This graph is named a stress-strain curve. (Strain is any kind of deformation, including elongation. Elongation is the word is used if talking specifically about tensile strain.) The tensile strength represents the height of the curve when the sample break and the tensile modulus is the slope of this graph. The sample has a high tensile modulus if the slope is steep, that equates resistance to deformation. If the slope is gentle, then the

sample has a low tensile modulus, which means it is simply deformed. (Polymer Learning Centre, 2005)

The stress-strain curve is not always nice and straight. As an instance, particularly flexible plastics, different curves are derived similar to Figure 3-4.

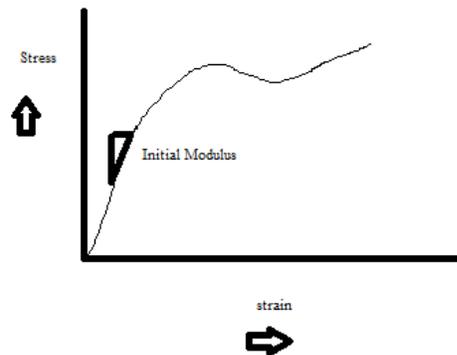


Figure. 3-4 Typical pattern of stress_strain curve(after Wiley,1991)

As it can be seen, the slope is not constant when stress enhances and the modulus is changing with stress. In such a case, typically the initial slope is considered as the modulus, as can be seen in the above graph. (Polymer Learning Centre, 2005)

In overall, fibres have the maximum tensile moduli however elastomers have the lowest, and plastics have tensile moduli somewhere in between fibres and elastomers. (Polymer Learning Centre, 2005)

Modulus is defined by calculating stress and dividing by elongation, and would be measured in units of stress divided by units of elongation. However as the elongation is non-dimensional, it has no units by which can be divided. So modulus will be reported similar units as strength, such as N/cm^2 . (Polymer Learning Centre, 2005)

3-5 Results of fibre tensile test

To obtain one of the main important parameter affect the fibre matrix and fibre contribution. Tensile stress-strain curve for used fibre were derived as Figure 3-5. The E_f was emerged as 577 Mpa, which later on will be used as one of the inputs in the model.

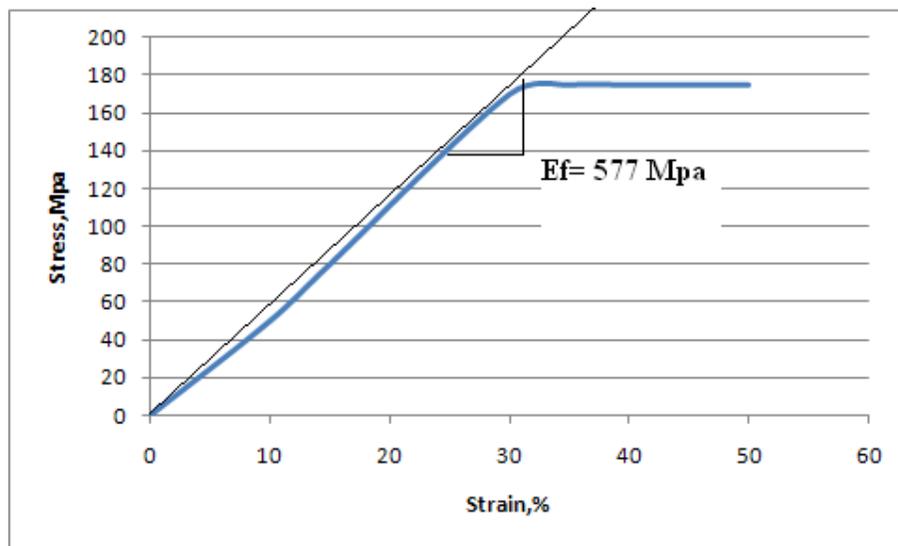


Figure. 3-5 Used Fibre tensile test result

3-6 Relevant definitions and concepts

This section presents general concepts and definitions used in this study on fibre-reinforced soil. Figure (3-6) shows an explanation of notations.

$$p = \sigma_a + 2\sigma_r/3 \quad (3.2)$$

$$q = \sigma_a - \sigma_r \quad (3.3)$$

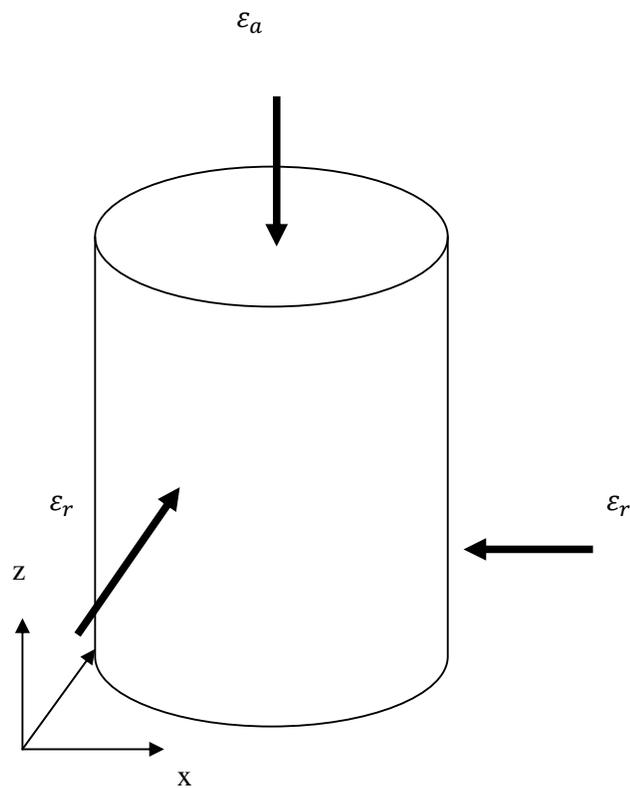


Figure. 3-6 Explanation of used notation

The fibre geometry is addressed by the aspect ratio, which is defined as:

$$\eta = l_f / d_f \quad (3.4)$$

where:

l_f is the length of fibre

d_f is equivalent diameter of fibres.

As the fibre diameter is considerably small compare to the length of fibres, in this study mostly length was considered as main effective parameter.

3-7 Application of fibre reinforced soil

Fibre-reinforcement has been considered in projects involving slope stabilization, embankment construction, subgrade stabilization, and stabilization of thin veneers such as landfill covers. The main advantages of fibre reinforcement are: (Li and Zornberg, 2005)

1. Field placement of fibres can be conducted using conventional construction equipment. In order to mix the fibres within the soil lift, a rotary mixer of the type typically used in lime-soil mixing can be used. The lift can then be compacted using standard soil compaction methods, without the concern of damaging the reinforcement.
2. The weather condition unlike lime, cement and other chemical stabilization methods does not considerably affect the construction procedure.
3. The materials that can be used for fibre-reinforcement are easily available. Plant roots, shredded tires, and recycled waste fibres (Foose et al., 1996; Murray et al., 2000; Consoli et al., 2002) can also be considered as reinforcement in addition to factory-manufactured synthetic fibres.

Li and Zornberg (2005) indicated that a promising application of fibre-reinforcement is in the localized repair of failed slopes. In this case, the irregular shape of the soil

“patches” limits the use of continuous planar reinforcement, making the fibre-reinforcement an appealing alternative. Unlike planar reinforcement, fibre-reinforcement does not require a large anchorage length, thus minimizing the excavation depth.

Another application is the stabilization of soil veneers (e.g. landfill covers) that are too steep for stabilization using parallel-to-slope continuous reinforcements (Zornberg et al., 2001; Zornberg, 2005). Continuous horizontal reinforcement has been used, but this requires anchoring of the reinforcement into competent material underlying the

soil veneer. Also, parallel-to-slope reinforcement requires anchoring the reinforcement at the slope crest. In contrast, the use of discrete fibres does not require anchoring, and is economically and technically feasible.

In pavement construction, fibre-reinforcement can be used to stabilize a wide variety of subgrade soils ranging from sand to high-plasticity clays (Santoni, et al., 2001; Grogan and Johnson, 1993). The number of passes to failure in field road test was reported to increase by fibre-reinforcement. (Li and Zornberg, 2005)

Fibre reinforcement has also been used in combination with planar geosynthetics for reinforced slopes or walls (Gregory, 1998). By increasing the shear strength of the backfill materials, fibre reinforcement reduces the required amount of planar

reinforcement and may eliminate the need for secondary reinforcement. Fibre-reinforcement has been reported to be helpful in eliminating the shallow failure on the slope face and reducing the cost of maintenance.

Fibres have also been reported to provide cracking control (Ziegler et al., 1998; Allan and Kukacka, 1995). Earth structures constructed using clayey soils, develop desiccation cracks when subjected to wet-dry cycles. Fibres were found to effectively in reduce the number and width of desiccation cracks.

Fibre reinforcement can also mitigate potential cracking induced by differential settlements because fibre-reinforcement increases the ductility of the soil. Fibre

reinforcement can also provide erosion control and facilitate vegetation development since the compaction effort needed for fibre-reinforced soil is less than for unreinforced soil of equivalent strength, which makes it appealing in the design of evapo transpirative cover system for landfills. (Li and Zornberg, 2005)

Fibre-reinforcement has also been used for stabilization of expansive soil (Puppala, 2000). Fibres were found to reduce shrinkage and swell pressures of expansive clays.

The use of fibre was also reported to increase the free swell potential of the soils. The inclusion of fibres was also reported to improve the response of a soil mass subjected to dynamic loading (Maher and Woods, 1990; Noorany and Uzdavines, 1989). Reported test results have shown that fibres contribute to increase the dynamic shear modulus and decrease the liquefaction potential. (Li and Zornberg, 2005)

4. Preliminary Experimental Work

4-1 Overview

The experimental tests consisted of two parts: preliminary tests and main tests. All tests have been designed systematically to reach the proposed goals.

4-2 Preliminary tests

These tests include permeability test, compaction test, consolidation test, small scale direct shear test and CBR test.

4-3 Permeability test:

Permeability is a measure of the ease in which water can flow through a soil volume. It is one of the most important geotechnical parameters. However, it is probably the most difficult parameter to determine. In large part, it controls the strength and deformation behavior of soils. It directly affects the following:

- quantity of water that will flow toward an excavation
- design of cutoffs beneath dams on permeable foundations
- design of the clay layer for a landfill liner.

For fine grained soil Falling head permeability test is done, whereas constant head permeability test is done for the coarse grained soil.

4-3-1 Principle of the permeability test

Darcy equation in laminar flow condition is the principle of test which can be express as:

$$V = K \times i \quad (4.1)$$

Where:

V = velocity

K = coefficient of permeability

i = Hydraulic gradient

Figure 4-1 shows change of flow regime based on velocity of flow.

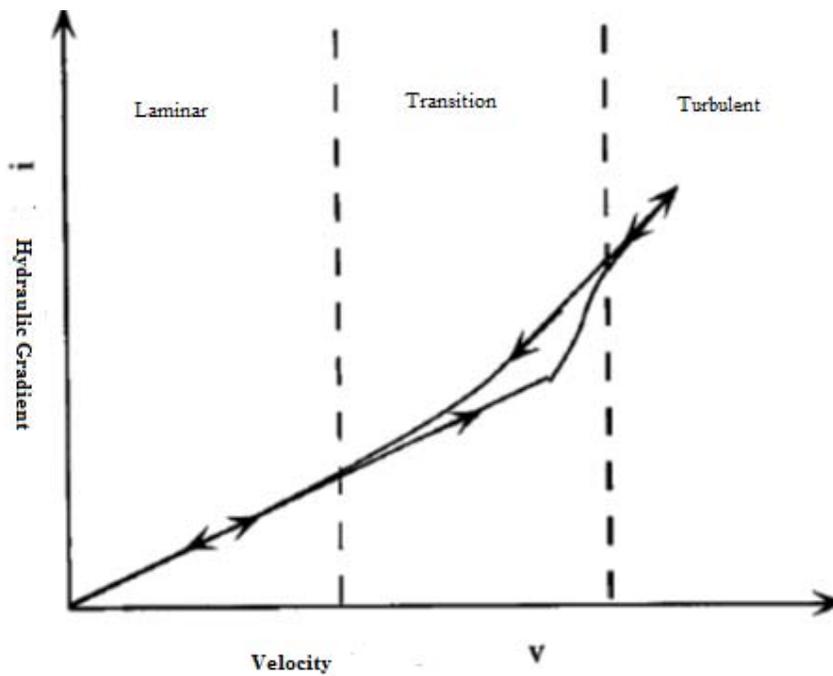


Figure 4-1. Zones of laminar and turbulent flows (After Taylor, 1948)

Table 4-1 shows the typical value of, coefficient of permeability. The table is used to double check the final value which is obtained from the test.

Table 4-1. Coefficient of permeability in different soils

**Classification of soils according to their coefficients of permeability
(after Kulhawy and Mayne, 1990; and Terzaghi and Peck, 1967)**

Soil Type	Coefficient of permeability k (cm/s)	Permeability Degree
Gravel	More than 10^{-1}	High
Sandy gravel, clean sand, fine sand	10^{-1} to 10^{-3}	Medium
Sand, dirty sand, silty sand	10^{-3} to 10^{-5}	Low
Silt, silty clay	10^{-5} to 10^{-7}	Very low
Clay	Less than 10^{-7}	Practically impermeable

Two types of permeability test are used to examine the coefficient of permeability which are listed below:

- Constant head
- Falling head

4-3-2 Applications of the tests

Constant Head Permeability Test is performed on sands as the pore openings are large and hence high permeability. Falling head Permeability Test is performed on clays as the pore openings are small and hence low permeability.

4-3-3 Constant Head Permeability Application

- Calculation of seepage through earth dams, embankments of canals, under sheet pile walls.
- Estimate settlements in foundations and slope stability analysis.

4-3-4 Falling Head Permeability Application

- Settlements in structures
- Methods for lowering the ground water table during construction
- Design grouting pressures and quantities for soil stabilization
- Freeze Thaw movements in soils (Note that coefficient of permeability (k) varies with temperature as the viscosity of the fluids changes with temperature)
- Design of recharge pits

Effect of fibre inclusion on composite clay sample permeability is investigated in this section.

4-3-5 Main Equipments

The main equipments used for the permeability tests are:

- Sample Chamber
- Specimen preparation equipments such as compaction tools
- Balance
- Falling head device

4-3-6 Test Methodology and Procedure

- The sample was compacted in the lower chamber section of the Permeameter, in layers approximately 1.5 cm deep, to within about 2 cm of the lower chamber rim. An appropriate tamping device was used to compact the sample to the desired density.(90% compaction effort made for the tests)
- The length of the specimen was measured and recorded.
- The clamp was used to attach the falling head burette to the support rod. the burette was placed as high as is possible for practicality. the meter stick was put directly behind the burette, so the height of water in the burette above the chamber outflow port can be read.
- The specimen was saturated, following the steps outlined above.
- The heights of the two levels from the outflow level were measured.
- After a stable flow has been established, the drop in head (Δh) in 2 hours was recorded.

4-3-7 Analysing the results

The following equation was used for calculating the results from Falling head:

$$k = \frac{a \times L}{A \times t} \ln \frac{h_0}{h_1} \quad (4.2)$$

Where,

K = Coefficient of permeability

a = Area of the burette

L = Length of soil column

A = Area of the soil column

h₀ = Initial height of water

h₁ = Final height of water = h₀ - Δh

t = Time required to get head drop of Δh

4-3-8 Results and discussion

The permeability tests were performed in order to determine effect of fibre inclusion on hydraulic conductivity of reinforced clayey composite. Table 4-2 shows the effect of fibre on hydraulic conductivity of the samples.

Table 4-2: hydraulic conductivity of the samples

Sample type	Coefficient of permeability (Cm/S)
Unreinforced sample	1 E- 8
Reinforced with 0.1 % of fibre at 15mm	2.2 E -8
Reinforced with 0.2% of fibre at 15mm	2.6 E -8
Reinforced with 0.3 % of fibre at 15mm	3.1 E -8
Reinforced with 10mm of fibre at 0.1% content	2.05 E -8
Reinforced with 25mm of fibre at 0.1% content	2.68 E -8

Figure 4-2 and Figure 4-3 visualize the results of the tests. The results proved with increasing in fibre content and length the hydraulic conductivity increased. The best line which could represent the laboratory data was derived and regression of that was determined. A series of permeability test performed. The methodology which applied to the test was falling head method. The clayey soil was reinforced by short plastic fibre .The results from the tests presented in this paper which showed effect of each fibre parameters on permeability characteristics of composite samples. It was proved that increase in fibre content and length caused increase in hydraulic conductivity. The value of coefficient of permeability jumped from 1 E- 8 (cm/s) to 3.1 E -8 (cm/s) with increasing in fibre content from zero to 0.3% and also with increasing in fibre length from 10mm to 15 mm the value of coefficient of permeability increased from

2.05 E -8 (cm/s) to 2.2 E -8 (cm/s). The behaviour of composite soil in terms of hydraulic conductivity was not linear due to change in fibre content and fibre length. Interaction of fibre and soil could be reason of increasing hydraulic conductivity as may cause creating some paths for water to escape in soil matrix.

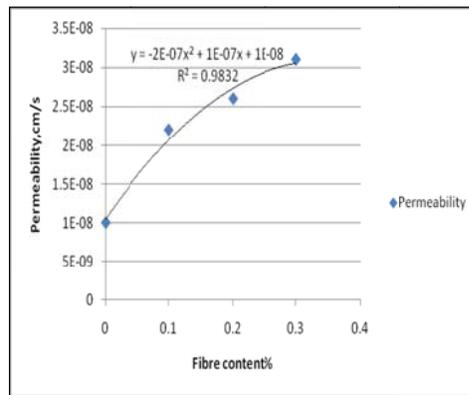


Figure 4-2. Permeability (at 15mm length)

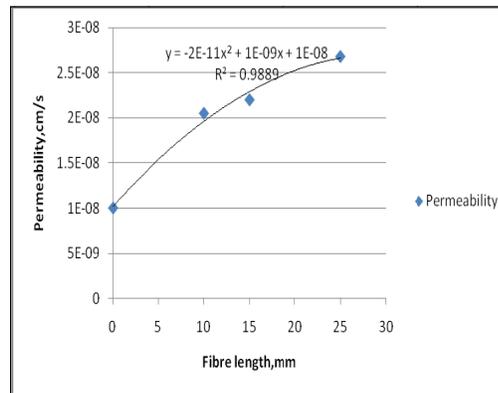


Figure 4-3. Permeability Test (at 0.1% fibre content)

4-4 Compaction test

The purpose of the standard Proctor compaction test is to determine the optimum water content and the maximum dry density that can be achieved with a certain compaction effort. The relationship between the moisture content and the density of the soil will be obtained in the process. Compaction effort designed in this laboratory test is comparable with that obtained in the field. Compaction is the process of increasing the bulk density of the soil or aggregate by driving out the air. For a given soil, for a given amount of compaction effort, the density obtained depends on the moisture content. Figure 4-4 shows the typical compaction curves with different compaction efforts.

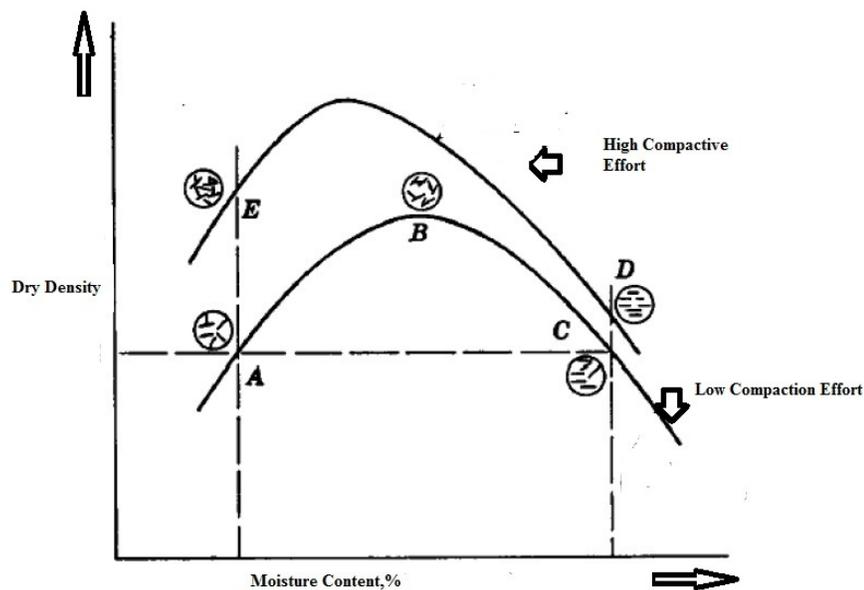


Figure 4-4. Typical Compaction Curves (Lambe, 1962)

The figure 4-5 shows the typical compaction curve considering porosity and void ratio.

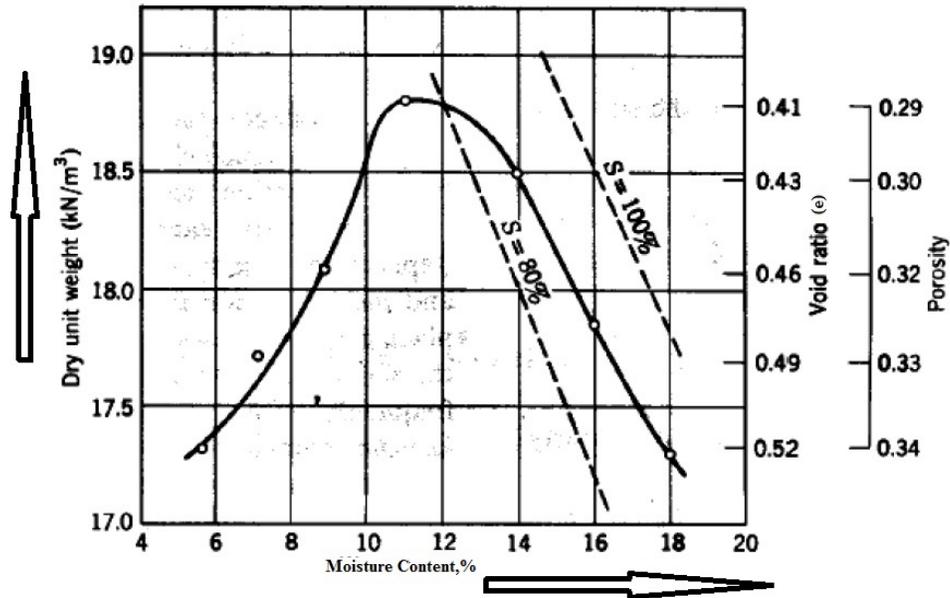


Figure 4-5. Typical Compaction Curves considering porosity (Lambe, 1961)

4-4-2 Test program

A series of compaction tests have been conducted. The results of the tests have been presented and well discussed.

4-4-3 Compaction Test Principle

Soil compaction is a mean to increase the density of soil. In geotechnical projects, soil density is an important parameter. Any difficulty related to compaction may cause settlement of the soil and as a consequence unnecessary maintenance costs or structure

failure will be needed. Therefore, all types of construction sites and construction projects use mechanical compaction method Figure 4-6 shows the difference between compacted and loose soil.

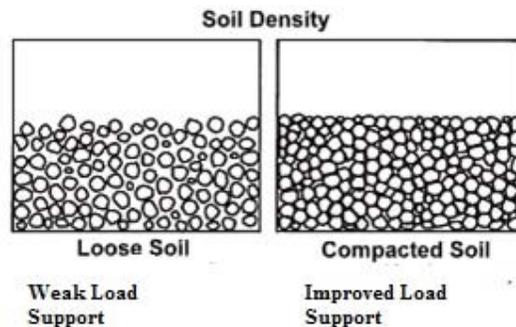


Figure. 4-6 Structure of loose and compacted soil (Online compaction handbook, 2010)

4-4-4 Effect of Moisture on Compaction Procedure

To compact properly moisture content is vital. Moisture plays as a lubricant within soil, sliding the particles together. If moisture content is very low amount that means inadequate compaction - the particles cannot slip well to achieve density. In contrast, if moisture is too high then weakens the load-bearing ability. The maximum density for most soils is at a specific water content for a given compaction effort. Therefore, the drier the soil is more unsuitable for compaction.

4-4-5 Compaction Methods

The standard compaction Test determines the maximum density of a soil needed for a specific project. Standard compaction method is widely used in geotechnical engineering. Figure 4-7 shows the technical specification for standard compaction method.

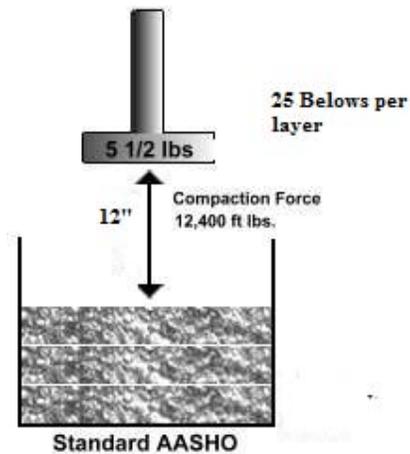


Figure. 4-7 Standard compaction sketch (Online compaction handbook,2010)

4-4-6 Main Equipments

- Proctor mould with a detachable collar assembly and base plate.
- Manual rammer weighing 2.5 kg and equipped with height of drop to a free fall of 30 cm.

- Sample Extruder.
- A sensitive balance.
- Straight edge.
- Moisture cans.
- Drying Oven

4-4-7 Test Methodology and Procedure

- About 4.5 kg of air-dried soil was put in the mixing pan so that it could pass No. 4 sieve.
- The moisture content was increased by about 5%.
- The weight of empty mould without the base plate and the collar was recorded as W_1 (gr).
- The collar and base plate was fixed and the first soil part was compacted with 25 blows in proctor mould
- Some scratches were put with a spatula forming a grid to ensure uniformity in distribution of compaction energy to the subsequent layer. The second and third layer was placed and 25 blows were applied.
- The final layer was placed so that the compacted soil is just above the rim of the compaction mould when the collar is still attached.
- The collar carefully was detached without disturbing the compacted soil inside the mould and edge was used to trim the excess soil leveling to the mould.
- The weight of the mould with the moist soil W_2 , (gr) was determined.

- Sample was extruded the sample and evaluated for water content in some cans
- The rest of the compacted soil was broken with hand to pass US Sieve No.4. and moisture content was increased by 2%.
- Repeat previous steps for different moisture contents.
- The dry density plotted versus moisture contents.

4-4-8 Results and discussions

The results of laboratory investigation are presented in this section. As the tests were designed systematically the effect of each fibre parameter can be observed in this study. The first engineering graph is related to effect of fibre dosage on compaction curve of composite soil. Respectively, second part is focused on effect of fibre length (aspect ratio) on soil composite compaction characteristics.

The results from laboratory compaction test were interpreted and Figure 4-8 shows the effect of fibre content on maximum dry density and optimum moisture content while the fibre length kept constant at 10mm. Respectively, Figure 4-9 indicates effect of fibre length on maximum dry density and optimum moisture content while the fibre content is constant at 0.4%.

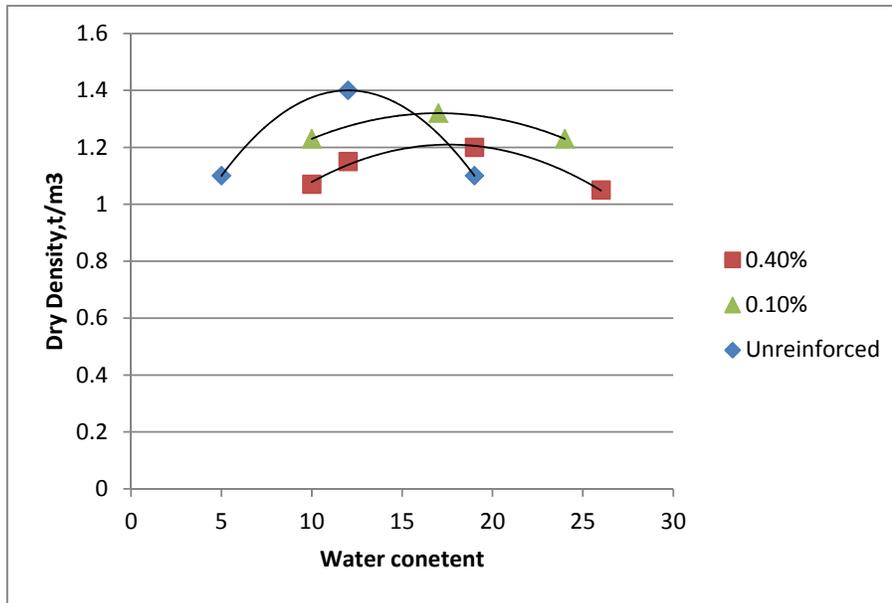


Fig. 4-8 Effect of fibre content on compaction curve (fibre length 10mm)

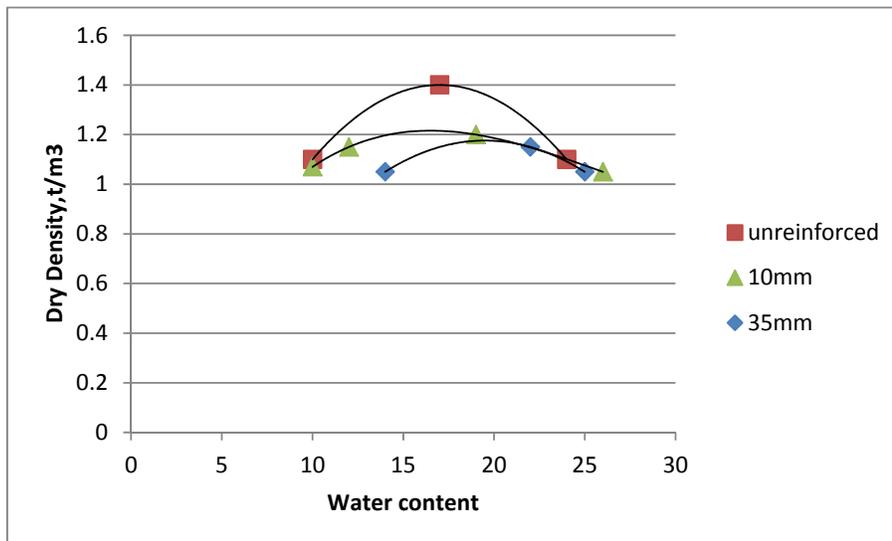


Fig.4- 9 Effect of fibre length on compaction curve (at fibre content 0.4%)

4-4-9 Conclusion

Compaction tests were performed on composite clay. This investigation proved that:

- 1- Induction of fibre caused decrease in maximum dry density
- 2- Optimum Moisture Content (OMC) increased with increasing in fibre content
- 3- Increasing in compaction effort causes increasing maximum dry density; this fact was observed for composite soil as well.
- 4- Plastic fibre showed to be good material to be used in practical projects

4-5 Consolidation test

This test is performed to determine the magnitude and rate of volume decrease that a laterally confined soil specimen undergoes when subjected to different vertical pressures. From the measured data, the consolidation curve (pressure-void ratio relationship) can be plotted. This data is useful in determining the compression index, the recompression index and the pre consolidation pressure (or maximum past pressure) of the soil. In addition, the data obtained can also be used to determine the coefficient of consolidation and the coefficient of secondary compression of the soil. The consolidation properties determined from the consolidation test are used to estimate the magnitude and the rate of both primary and secondary consolidation settlement of a structure or an earthfill. Estimates of this type are of key importance in the design of engineered structures and the evaluation of their performance.

4-5-1 Main Equipments:

Digital Consolidation device (including ring, porous stones, water reservoir, and load plate), Sample trimming device, glass plate, Metal straight edge, Clock, Moisture can, Filter paper.

4-5-2 Test Procedure:

1. the empty consolidation ring together with glass plate was weighted
2. the height (h) of the ring and its inside diameter (d) is being measured
- 3 the soil sample from the sampler, generally thin-walled Shelby tube will be extruded.
- 4 approximately a three-inch long sample was cut. the sample on the consolidation ring has been placed and the sides of the sample to be cut approximately the same as the outside diameter of the ring.
- 5 carefully the vertical load applied on specimen and the volume change recorded
- 6 Final graph of consolidation was derived according to the recorded values.

4-5-3 Results

Figure 4-10 shows the consolidation graph of pure kaolin clay. The graph consists of two phase of loading and unloading. Parameters κ and λ are shown in the graph and represent the slope of loading and unloading phase. These values later will be used as input parameters for Modified Cam Clay model.

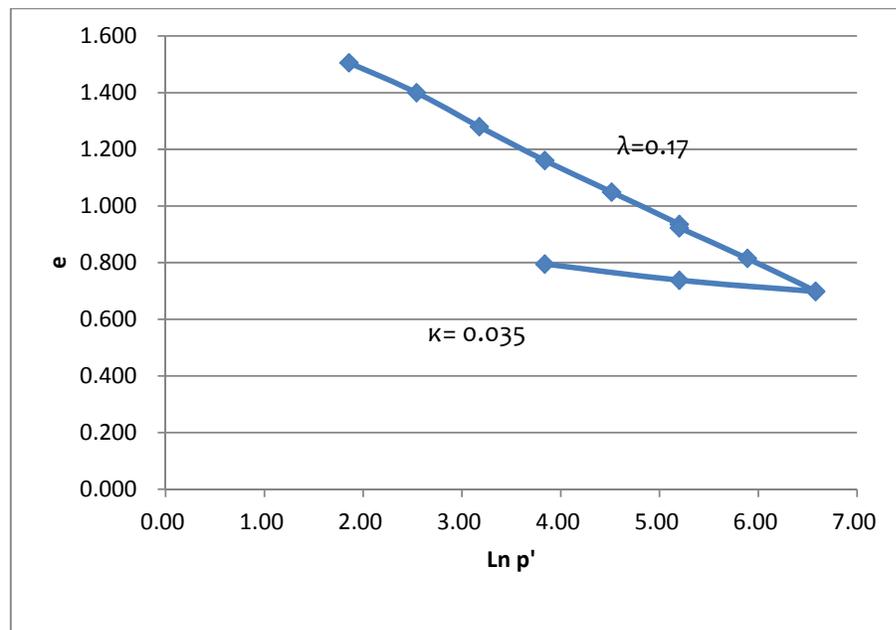


Figure 4-10 Consolidation test on pure clay

4-6 Direct shear test

This section focus on the effect of fibre content and fibre length on soil sample exposing to direct shear test.

4-6-1 Introduction

The direct shear test is one of the oldest strength tests for soils. In this study, a direct shear device will be used to determine the shear strength of a fibre reinforced soil.

Applications of soil strengthening or stabilization range from the mitigation of

complex slope hazards to enhancing the subgrade stability. Together with the many applications for improving soil, there are several widely varied methods. The mixing

of randomly oriented fibres to a soil sample may be considered same as other admixtures used to stabilize soil. Material used to make fibres for reinforcement may be obtained from paper, metal, nylon, polyester and other materials having widely varied physical properties. There have been numerous past papers published on the topic of fibre strengthening of soils. Examples include Lee et al., 1973, Hoare, 1979, Andersland and Khattac, 1979, Freitag, 1986, Gray and Ohashi, 1983, Gray and Rafeai, 1986, Maher and Gray 1990, Maher and Ho, 1994, Michalowski and Zhao 2002, Ranjan et al. 1996, Kaniraj and Havanagi 2001, Consoli et al. 2009.

However, all of the papers listed above have generally shown that; strength of the soil (mostly sand) was improved by fibre reinforcement; the investigation on clay is very limited. The purpose of this survey is to evaluate clayey sand behaviour induced by fibre inclusion.

The test is carried out on either undisturbed samples or remoulded samples. To facilitate the remoulding purpose, a soil sample may be compacted at optimum moisture content in a compaction mould. Then specimen for the direct shear test could be obtained using the correct cutter provided. Alternatively, sand sample can be placed in a dry state at a required density, in the assembled shear box.

A normal load is applied to the specimen and the specimen is sheared across the pre-determined horizontal plane between the two halves of the shear box. Measurements of shear load, shear displacement and normal displacement are recorded. The test is repeated for two or more identical specimens under different normal loads. From the results, the shear strength parameters can be determined.

4-6-2 Theoretical Background of the test

The strength of a soil depends of its resistance to shearing stresses. It is made up of basically the components;

1. Frictional – due to friction between individual particles.
2. Cohesive - due to adhesion between the soil particles

The two components are combined in Colulomb's shear strength equation,

$$\tau_f = c + \sigma_f \tan \phi \quad (4.3)$$

Where:

τ_f = shearing resistance of soil at failure

c = apparent cohesion of soil

σ_f = total normal stress on failure plane

ϕ = angle of shearing resistance of soil (angle of internal friction)

This equation can also be written in terms of effective stresses.

$$\tau_f' = c' + \sigma_f' \tan \phi' \quad (4.4)$$

Where:

c' = apparent cohesion of soil in terms of effective stresses

σ_f' = effective normal stress on failure plane

ϕ' = angle of shearing resistance of soil in terms of effective stresses

$\sigma_f' = \sigma_f - u_f$

u_f = pore water pressure on failure plane

4-6-3 Test program

A series of direct shear tests have been conducted on reinforced sand composite.

4-6-4 Main Equipments

- Direct Shear Test Machine
- Specimen preparation equipment
- Balance

Figure 4-11 shows automated direct shear which was used to run shear test. The

device is fully automated so the results easily transferred without any user interference.

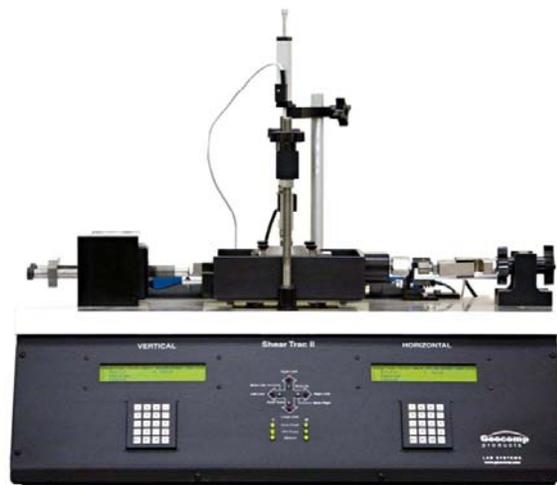


Figure. 4-11 Direct Shear Test Machine

4-6-5 Sample Preparation

The samples were prepared by mixing clay and three percentage of fibre (i.e. 0.2%, 0.3%, and 1%). Two types of fibre were used in this study: plastic fibre. The soil was first dried under laboratory air-dried conditions then ground and passed through a 2 mm sieve. The dry powder was carefully wetted with a spray gun to the standard optimum moisture content. The moist soil was then put in sealed plastic bags in a

humidity room for about two days before use. The moist residual soil was then compacted in a 30 mm x 30 mm shear box mould by machine compaction to the appropriate height and unit weight at the optimum moisture content.

4-6-6 Test Methodology and Procedure

1. The shear box was assembled and the specimen was put into the shear box. Special care was made that the alignment screws working well.
2. The shear box was placed into the shearing device.
3. Normal load was applied to the specimen using the load transfer plate and the loading hanger.
4. Set the shearing device the advance at a rate of 0.50 mm/min.
7. The data acquisition system was run.
8. Once data acquisition has begun, the shearing device was started.
9. The Shear Stress-Displacement curve plot used for strength behavior investigation

4-6-7 Results and discussions

The direct shear tests were performed in order to determine effect of fibre inclusion on shear strength of reinforced clay. Figure 4-12 showed the stress-displacement curve obtained from the tests at 10mm fibre length and constant normal stress of 100 kPa.

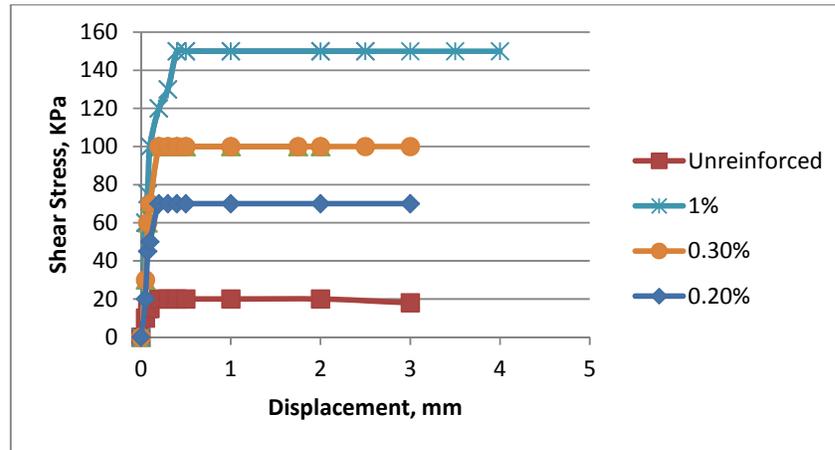


Figure. 4-12 Results of direct shear test in different fibre content (at 10mm, Normal stress 100 kPa)

Figure 4-12 proved increasing in fibre content will increase the strength. Figure 4-13 shows the effect of fibre length on strength of composite clay at constant fibre content of 0.2% and normal stress of 100 kPa.

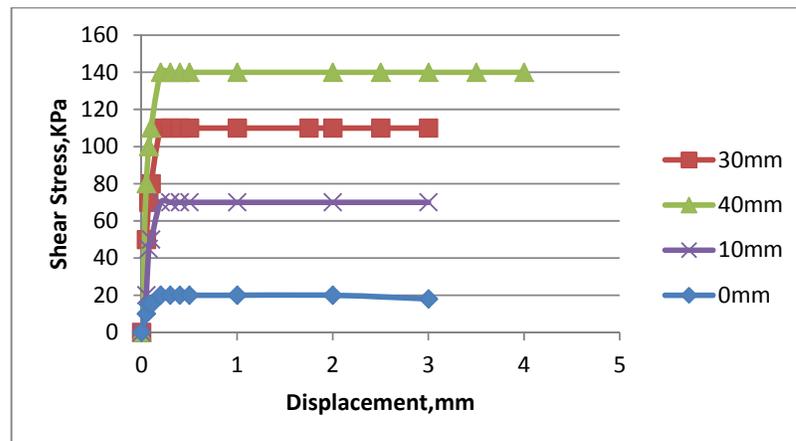


Figure. 4-13 Results of direct shear test in different fibre length (at 0.2% fibre content, Normal stress 100 kPa)

4-6-8 Conclusion

The direct shear tests were conducted. Following conclusions were derived:

- Increasing in fibre percentage increased shear strength in clay samples
- During the test, it was observed that ductility behaviour of reinforced sand increased because of fibre inclusion.
- The results proved that with increasing in fibre length, the shear stress of composite clay was increased.
- Short and randomly Fibre inclusion showed to be reliable in industry projects as it helps to minimize the cost of projects.

4-7 CBR TEST

CBR test is the ratio of force per unit area required to penetrate a soil mass with standard circular piston at the rate of 1.25 mm/min. to that required for the corresponding penetration of a standard material. The California Bearing Ratio Test (CBR Test) is a penetration test developed by California State Highway Department (U.S.A.) for evaluating the bearing capacity of subgrade soil for design of flexible pavement. Tests are carried out on natural or compacted soils in water soaked or unsoaked conditions and the results so obtained are compared with the curves of standard test to have an idea of the soil strength of the subgrade soil. Applications of soil strengthening or stabilization range from the mitigation of complex slope hazards to enhancing the subgrade stability. Together with the many applications for improving soil, there are several widely varied methods. The mixing of randomly

oriented fibres to a soil sample may be considered same as other admixtures used to stabilize soil. Material used to make fibres for reinforcement may be obtained from paper, metal, nylon, polyester and other materials having widely varied physical properties. There have been numerous past papers published on the topic of fibre strengthening of soils. Examples include Lee et al., 1973, Hoare,1979, Andersland and Khattac,1979, Freitag,1986, Gray and Ohashi, 1983, Gray and Rafeai, 1986, Maher and Gray 1990, Maher and Ho, 1994, Michalowski and Zhao 2002, Ranjan et al. 1996, Kaniraj and Havanagi 2001, Consoli et al. 2009.

All of the papers listed above have generally shown that; strength of the soil was improved by fibre reinforcement. The investigation on clayey soil is very limited. The purpose of this survey is to evaluate of CBR values of clayey soil induced by fibre inclusion. The CBR tests were conducted as per ASTM D1883 on the selected soils with and without reinforcement to investigate the influence of length and fibre content on CBR values. Moreover, the obtained CBR values were taken as indication of improvement in the soil strength due to fibre reinforcement. For different length and fibre contents, the dry weight required to fill the CBR mould was calculated based upon maximum dry densities of the soil and the volume of the mould. The water corresponding to Optimum Moisture Content (OMC) was put and mixed thoroughly. The water was added prior to fibre to prevent floating problems.

4-7-1 Test Program

A series of CBR tests have been conducted on reinforced clay composite. Reinforced samples prepared by putting plastic fibre inside clay.

4-7-2 CBR Test principle

The California Bearing Ratio (CBR) test was developed by the California Division of Highways as a method of classifying and evaluating soil- subgrade and base course materials for flexible pavements. CBR is a measure of resistance of a material to penetration of standard plunger under controlled density and moisture conditions. CBR test may be conducted in remoulded or undisturbed sample. Test consists of causing a cylindrical plunger of 50mm diameter to penetrate a pavement component material at 1.25mm/minute. The loads for 2.5mm and 5mm are recorded. This load is expressed as a percentage of standard load value at a respective deformation level to obtain CBR value.

4-7-3 Main Equipments

- Mould
- Steel Cutting collar
- Spacer Disc
- Surcharge weight
- Dial gauges

- IS Sieves
- Penetration Plunger
- Loading Machine
- Miscellaneous Apparatus

Figure 4-14 shows the mechanism of CBR test machine.

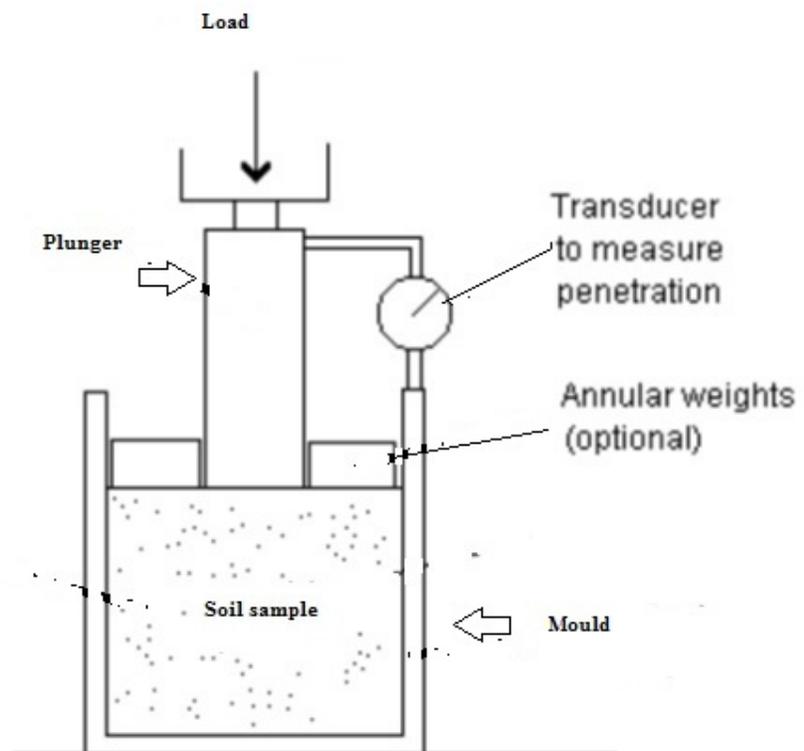


Figure 4-14 Mechanism of CBR Test Machine (Gray,1983)

4-7-4 Test Methodology and Procedure

The sample was sieved through 20mm sieve. 5kg of the sample of soil specimen was taken. Water was added to the soil in the quantity such that optimum moisture content or field moisture content was reached. Then soil and water were mixed thoroughly. Spacer disc was placed over the base plate at the bottom of mould and a coarse filter paper was placed over the spacer disc. The prepared soil water mix was divided into five. The mould was cleaned and oil was applied. Then was filled one fifth of the mould with the prepared soil. That layer was compacted by giving 56 evenly distributed blows using a hammer of weight 4.89kg. The top layer of the compacted soil was scratched. Again second layer was filled and process was repeated. After 3rd layer, collar was also attached to the mould and process was continued. After fifth layer collar was removed and excess soil was struck off. The base plate was removed and the mould was inverted. Then it was clamped to base plate. Then the normal load was applied and CBR values recorded. The fibre content and length were varied during the tests. Fibre contents were selected as 0.1%, 0.2% and 0.3%. On other hand, fibre lengths were varied from 10mm up to 50mm.

4-7-5 Results and Discussion

The CBR tests were performed in order to determine effect of fibre inclusion on CBR values of reinforced clayey soil. Figure 4-15 showed the CBR values obtained from the tests at different plastic fibre length and content. The maximum CBR value obtained for a length of 50mm and .0.3 percent fibre content.

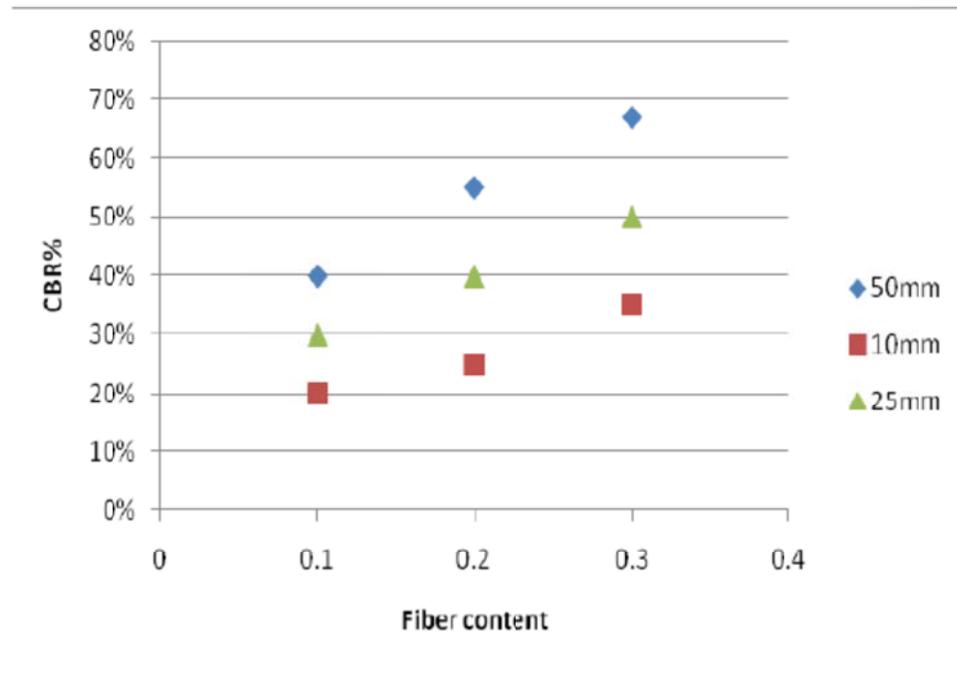


Figure. 4-15 results of CBR test for plastic fibre

The maximum CBR value for plastic fibre obtained in fibre content of 0.3% and length of 50mm. The results for plastic fibre proved that fibre inclusion will be recommended for practical projects.

4-7-6 Conclusion

Two important parameters have been well investigated in this paper. The first parameter is fibre content and the second one is aspect ratio. The effect of these two parameters studied on CBR values. Plastic fibre used in this study and following results were derived:

- Increasing in fibre percentage increased CBR values in clayey samples for plastic fibre
- The results proved that with increasing in fibre length, the CBR values of composite clayey were increased for plastic fibre

5. Triaxial Test

5-1 The purpose of soil testing

In general, soil is tested in order to assess its variability and in order to obtain parameters for particular geotechnical calculations. These two different reasons for testing cause to run different testing programmes. Routine tests carried out to let the soil on a site to be separated into groups should ideally be planned for an initial phase of testing. Following more costly and complex tests are usually carried out on soil which is thought to be illustrative of each group; the samples to be verified cannot be so well designated before the results of classification tests are recognized. Due to time and economy, this ideal arrangement cannot typically be used. More difficult tests require a longer test. According to Clayton 1995, "when testing is started at about the same time as samples start to arrive from site, the engineer initially may have to rely completely on soil descriptions for a division of the *in situ* soil". (Clayton et al, 1995)

In order to define a minor number of different groups of soil on any site, soil classification is carried out. Each soil group can contain of a stratigraphically defined geological unit. "More often it may disregard geological boundaries due to the spirit of the soil group should be that materials within it involve (or are estimated to involve) similar geotechnical properties. Particle size, plasticity and organic content may be

more important to the geotechnical engineer than time of deposition. The three main tools used to classify soil are soil description, particle size distribution analysis and plasticity testing”. (Clayton et al, 1995)

5-2 Scope of experimental testing program

The scope of the experimental work is focused on triaxial tests. A series of triaxial compression test tests were conducted. This chapter is mainly presents the equipment used in testing program. Finally, the raw results of triaxial tests are presented.

5-3 Principle of Triaxial machine

Bishop and Henkel (1962) explained the triaxial apparatus in details. Cylinder will typically be test specimen shape and normally with an aspect ratio of two, which is sealed on its sides and a rubber membrane attached by rubber ‘O’ rings to a base pedestal and top lid. The horizontal principal total stresses will be applied by water pressure inside the triaxial cell, while the vertical pressure at the top cap is produced by the cell fluid pressure and the ram force. The reason of choosing of an aspect ratio of two guarantees that the effects of the radial shear stresses between soil, and top lid and base-pedestal are irrelevant at the centre of the specimen. (Clayton et al, 1995)

The triaxial apparatus requires one or two self-compensating constant pressure systems, a volume change measuring device and several water pressure sensing

devices. The ram force may be measured outside the cell using a proving ring, but most modern systems now use an internal electrical load cell mounted on the bottom of the ram. The ram is driven into the triaxial cell by an electrical loading frame which will typically have a capacity of 5000 or 10000 kgf and is capable of running at a wide range of constant speeds; triaxial tests are normally carried out at a controlled rate of strain increase. (Clayton et al, 1995)

By using this apparatus to amount strength the specimen is typically failed in triaxial compression, this failure accompanies with the middle principal stress kept constant and equal to the minor principal stress and with the major principal stress improved to bring about failure. Under these circumstances the height of the specimen drops in shearing. (Clayton et al, 1995)

5-4 Different Type of Triaxial Tests

The three most common forms of test are: (Clayton et al, 1995)

1. the unconsolidated undrained triaxial compression test, without pore water pressure measurement
2. the consolidated undrained triaxial compression test, with pore water pressure measurement

3. the consolidated drained triaxial compression test, with volume change measurement

The unconsolidated undrained triaxial compression test is performed on ‘undisturbed’ specimens of clay in order to define the undrained shear strength of the deposit *in situ*. Water pressures are not recorded while running this test and therefore the results can only be interpreted in terms of total stress. Three test specimens, which may be either 38mm or 102mm dia. and will typically have an aspect ratio of 2, are extruded from a core and sealed using a rubber membrane, ‘O’ rings and top and bottom lids. Once a specimen is inside the triaxial cell, the cell pressure is increased to a prearranged value and the specimen is failed by enhancing the vertical stress; during this period systematic readings of the ram load and height of samples reduction are made. The cell pressures used will normally increase by a factor of two between each of the three specimens, with the middle pressure approximately corresponding to the vertical total stress at the level of sampling in the ground. Thus for a sample taken from 5 m depth cell pressures of 50, 100 and 200 kN/m² would be used. (Clayton et al, 1995)

The rate of strain applied during the test will typically considered to be 2%/mm. This rate is based on the specifications given in the 1975 British Standard for the maximum strain (20%) and the maximum test duration (10mm.). However, BS 1377:1990 (part 7, clause 8) recommends that the rate of axial deformation should produce failure within a period of 5—15 mm. The recommendation concerning the maximum axial strain will be kept constant. If criteria for choosing a strain rate are determined by using these guidance, the rate of strain assumed to be 1.5%/mm. It should be

mentioned that the undrained strength is not a principle property of the soil and the recorded strength is dependant to the rate at which the soil is exposed to shear. It is consequently sensible to approve the same rate for all tests of this sort (Clayton et al, 1995). On other hand, Australian standard recommend 0.05mm to 0.5mm per minute. Giving the fact that, clay needs gently increment due to pore pressure inside the soil matrix, the strain selected as 0.5 mm/minute.

Since the major total principal stress (acting in a vertical direction) is composed of two components, i.e.

$$\sigma_1 = \sigma_3 + \frac{P}{A} \quad (5-1)$$

Where:

σ_3 = horizontal total stress (the cell pressure),

P= ram force, and

A = specimen cross-sectional area.

As Clayton et al, 1995 described the principal stress difference (or deviator stress), $\sigma_1 - \sigma_3$, is simply equal to the ram force divided by the cross-sectional area. Because the test is carried out undrained, with no volume change allowed, the specimen diameter increases during the test. In order to calculate the cross-sectional area at any time during testing it is assumed that the specimen deforms as a right cylinder and so:

$$V = A_0 H_0 = AH = AH_0 (1 - \varepsilon_a) \quad (5-2)$$

Where:

V = specimen volume (constant),

A_0 and H_0 are the initial specimen area and height, A and H are the specimen cross section area and height at some time during the test, and ε_a is axial strain at some time during the test. Thus $A = A_0 / (1 - \varepsilon_a)$.

The curves of principal stress difference against strain are plotted with usage of laboratory data. For conditions of maximum principal stress difference (taken as failure) Mohr circles are plotted in terms of total stress. The average undrained shear strength should be cited, and the failure envelope drawn tangential to the Mohr circles in order to find the undrained 'cohesion intercept' and undrained 'angle of shearing resistance'. To measure maximum deviator stress, a correction should be applied to allow for the restraining effect of the membrane. (Clayton et al, 1995)

The compression modulus of the membrane material, M , is anticipated to be equal to its extension 'modulus as Clayton (1995) described. The extension modulus finding method is described by Bishop and Henkel (1962) and Head (1982). In soils which exhibit brittle failure a different membrane correction may be necessary, although not mentioned in the British Standard. This correction is described by Head (1982).

For soils of high strength, such as stiff clays, the effect of the membrane stiffness is minor and is often ignored. For soft and very soft clays the membrane effect can be important and oversight of the correction could cause errors on the hazardous site.

The membrane correction termed above is abstracted from the extreme measured deviator stress. (Clayton et al, 1995)

The size of specimen verified in the undrained triaxial test can have an important effect on the subsequent shear strength (Bishop *et al.* 1965; Agarwal 1968; Marsland and Randolph 1977). While larger specimens may stretch parameters which are more applicable, for instance, to slope stability calculation (Skempton and La Rochelle (1965)) because of their inclusion of fissures or fabric, it is important to recognize that some empirical or semi-design methods were specifically designed on the basis of undrained shear strengths measured on small diameter specimens. Strutted excavations (Peck 1969) and the adhesion on bored piles (Skempton 1959) are examples of this type of problem. (Clayton et al, 1995)

The choice to check large diameter specimens can lead specific difficulties when, as is often the case, deposits are more variable in the vertical than the horizontal direction. From a 450 mm long tube sample, three 204mm high specimens cannot be extruded. In order to overcome the difficulties of shortage of material the aspect ratio of the specimens may be reduced to one by using lubricated end platens (Rowe and Barden 1964) or each specimen may be sheared at three cell pressure levels (Taylor 1950; Parry 1963; Anderson 1974). This latter technique is known as ‘multi-staging’, and has been found to be particularly useful in boulder clay materials where stone content

makes the preparation of undisturbed specimens difficult, and test results from individual specimens typically produce a large strength difference. However, multistage tests are described in Head (1982) and (Clayton et al, 1995), the application of this type of test is not recommended.

Soil mechanical strength parameters (c' and ϕ') can be calculated either from the results of consolidated undrained triaxial compression tests with pore pressure measurement or from consolidated drained triaxial compression tests. The previous test is generally chosen because it can be conducted more rapidly and consequently more economically.

The consolidated undrained triaxial compression test is generally conducted in several stages, involving the following saturation, consolidation and shearing of each of three specimens. The main reason for saturation is carried out to guarantee that the pore fluid in the specimen does not have free air. After saturation, the pore air pressure and pore water pressure will vary owing to surface tension effects: the mean pore pressure cannot be found as it will not be known whether the measured pore pressure is due to the pore air or pore water, and at what level amid the two the mean pressure lies. Possibly more highly, the existence of air in the pore pressure recording system can cause to time lags, which for fairly incompressible over-consolidated clay soils can be very important. Bishop and Henkel (1962) quote theoretical times for 98% equalization of pore pressure for undisturbed 38 mm London clay samples which

can get up to 6hours, depending on the compressibility of the pore pressure recording system.

Saturation phase is typically carried out by leaving the specimens to swell due to elevated back pressure. As Clayton 1995 described the use of a back pressure on dense specimens which are expected to dilate has the extra benefits of extending the range of applied stress for which pore pressure measurements can be made and, in drained tests, of stopping the creation of air locks in the triaxial base and pipework leading to the specimen. “Back pressure (which is simply an imposed pore pressure) is applied through a volume change gauge to the top of the specimen, while a cell pressure of slightly higher value is also applied. Both cell pressure and back pressure are normally increased in increments of about 50 kN/m², allowing time for equalization at each stage”. (Clayton et al, 1995)

Skempton defined the degree of saturation in terms of Skempton’s pore pressure parameter (Skempton 1954):

$$B = \Delta u / \Delta \sigma_3. \quad (5-3)$$

Where:

Δu = change in pore pressure for an applied cell pressure change of $\Delta \sigma_3$.

For a saturated soil, B equals unity. Clayton 1995 pointed out that in practice it was found that B approximates to unity (say $B \geq 0.98$) when a back pressure of 200—300 kN/m² was used on natural clays, but the more back pressure needed for compacted samples. As soon as a reasonable back pressure has been attained the B value can be checked by recording the reply of the pore pressure to an applied cell pressure alteration. The major standards such as British standard recommends that a value of B “greater than or equal to 0.95 must be achieved before the specimen may be considered as fully saturated and the consolidation stage started”. (Clayton et al, 1995)

Due to two reasons, the consolidation stage of an effective stress triaxial test is carried. Firstly, the specimens is tested and consolidated at three different effective pressures, in order to give specimens of different strengths which will create extensively spaced effective stress Mohr circles. Second reason is that the results of consolidation are used to regulate the minimum time to failure in the shear stage. The effective consolidation pressures (i.e. cell pressure minus back pressure) will generally be enlarged by a factor of two between each specimen, with the internal pressure approaching to the vertical effective stress in the ground. (Clayton et al, 1995)

The readings and recording of volume change are conducted using a volume change device in the back pressure line when the consolidation cell pressure and back pressure are applied to the specimen, “The speed at which volume change takes place depends on the effective pressure increment, the coefficient of consolidation of the soil and the drainage conditions at the specimen boundaries”. (Clayton et al, 1995)

Pore pressure usually will be measured at the specimen base, with drainage to the back pressure line conducted through a porous stone casing the top of the specimen. By the application of filter paper drains on the radial boundary of the specimen, the rapidity at which heavy clays consolidate and can be sheared, can be pointedly amplified (Bishop and Henkel 1962 and Clayton et al, 1995).

The coefficient of consolidation of the clay can be determined by plotting volume change as a function of the square root of time. Clayton 1995 pointed that the first 50% of volume change during consolidation stage should indicate a straight line on this plot. Bishop and Henkel expressed that the straight line is “extended down to cut the horizontal line representing 100% consolidation, and the time intercept at this point (termed ‘ t_{100} ’ by Bishop and Henkel) can be used to obtain the coefficient of consolidation as shown below (in fact, t_{100} is equal to $4 \times t_{50}$, and cannot equal the infinite time theoretically required for complete consolidation”.(Clayton et al, 1995)

5-5 Used Triaxial Machine

The LoadTrac-II/FlowTrac-II system for triaxial testing fully automates a triaxial test on a soil specimen. Once a soil specimen is in place and the test conditions selected, the system will run the entire triaxial test from start to finish. Test data will be stored in a file for subsequent reduction and plotting by way of either the report capability built into the control software or the separate triaxial report software. The LoadTrac II/FlowTrac-II system consists of a LoadTrac-II load frame, two FlowTrac-II flow

pumps for controlling volume and pressure for the cell and specimen, a computer with a network card for test control and data acquisition, and Microsoft Windows application software, called TRIAXIAL, for controlling a test and creating a report of

the results. The LoadTrac-II/FlowTrac-II system comes as a complete, self-contained unit with all of the equipment required to perform fully automated triaxial tests. Test chambers from other manufacturers may be used. LoadTrac-II utilizes a high speed, precision micro stepper motor to apply the vertical load to the soil specimen. An embedded control board with a dedicated CPU takes readings from the force transducer and displacement transducer to control the stepper motor. The system is capable of applying a constant rate of strain or stress at any displacement rate from 0.00003 up to 15 mm per minute (0.000001 to 0.6 inches per minute).

Each FlowTrac-II flow pump utilizes a high speed, precision micro stepper motor to regulate pressure and volume to the cell or specimen. The built-in microprocessor controls the micro stepper motor, which drives a piston in and out of a sealed cylinder. A pressure transducer on the end of the cylinder provides the feedback for control of pressure. The number of steps of the motor is used to compute volume change. Two two-way electronic valves are used to control the direction of flow to the cell or specimen (output valve), and the manual fill/drain operation (supply valve). FlowTrac-II is capable of maintaining the desired pressure to within ± 0.35 kPa (0.05 psi) while monitoring volume changes to within ± 0.001 cc. Pressure increments may increase and decrease in any pattern by any amount (without exceeding the system's limits) as specified by the user even during a test.

The TRIAXIAL software contains easy-to-use menus and Property Pages that are used to define the conditions for running a test on the LoadTrac-II/FlowTrac-II system. Specimen-specific information can be entered for inclusion on the tabulated and

graphed results. Once a test has been defined, the test procedure can be started with a single mouse click. During the test, current status information can be shown on the LCD in the front panels of both the LoadTrac-II and the two FlowTrac-II flow pumps. Furthermore, current (real time) data and status information can be displayed on the computer monitor in numeric form or graphical form by accessing menu options. The user can terminate a step in a phase (or the current phase) at any time, thus sending the test to the next step (or phase) rather than waiting for the control program to TRIAXIAL automatically advance the test. Subsequent step information can be modified at any time. This capability allows the user to modify the test specifications based on results from early steps. (An example of this would be selecting the correct shear rate based on consolidation data.)

The user can terminate the test at any time. Data can be written to a storage medium (e.g., CD-ROM, memory stick or external hard drive) at any time during the test so that they can be transferred to another PC (that has the TRIAXIAL software installed) for reduction and plotting while the test continues. While the test is running, current data and status information can be displayed on the monitor. Clicking on an option in the View menu will produce a graph of displacement versus time for the current step of the test.

The LoadTrac-II/FlowTrac-II system requires no special skills to operate other than those used in conventional testing. A person familiar with soil testing can learn to use the system confidently within a few days. Experience with a computer keyboard and the use of the Windows operating system installed on your computer can reduce the

learning time to about one day. The automation of a triaxial and stress path test requires a LoadTrac-II load frame, two Flow Trac-II units, a triaxial cell and a computer. The used triaxial machine is shown in Figure 5-1 and Figure 5-2. FlowTrac-II is an intelligent, versatile unit composed of a flow pump, a pressure sensor and a control board. The flow pump, which regulates pressure and volume in a test cell, contains a high speed, precision micro stepper motor that moves a piston in a water-filled cylinder. An embedded control with a dedicated CPU uses readings from the pressure transducer mounted at the end of the cylinder to determine what signals should be sent to the stepper motor. The software package that fully automates triaxial and stress path test is called TRIAXIAL and is available from Geocomp Corp. The software User's Manual explains the specimen preparation, the positioning of the triaxial cell on the load frame platen, the initialization of the flow pumps, the running of the test and the form of the report generated.



Figure 5-1 Triaxial test machine



Figure 5-2 Triaxial test machine

Test set up was conducted using the procedure as reflected in Manual of Triaxial machine. Figure 5-3 shows the front view and back views of setting up the test.

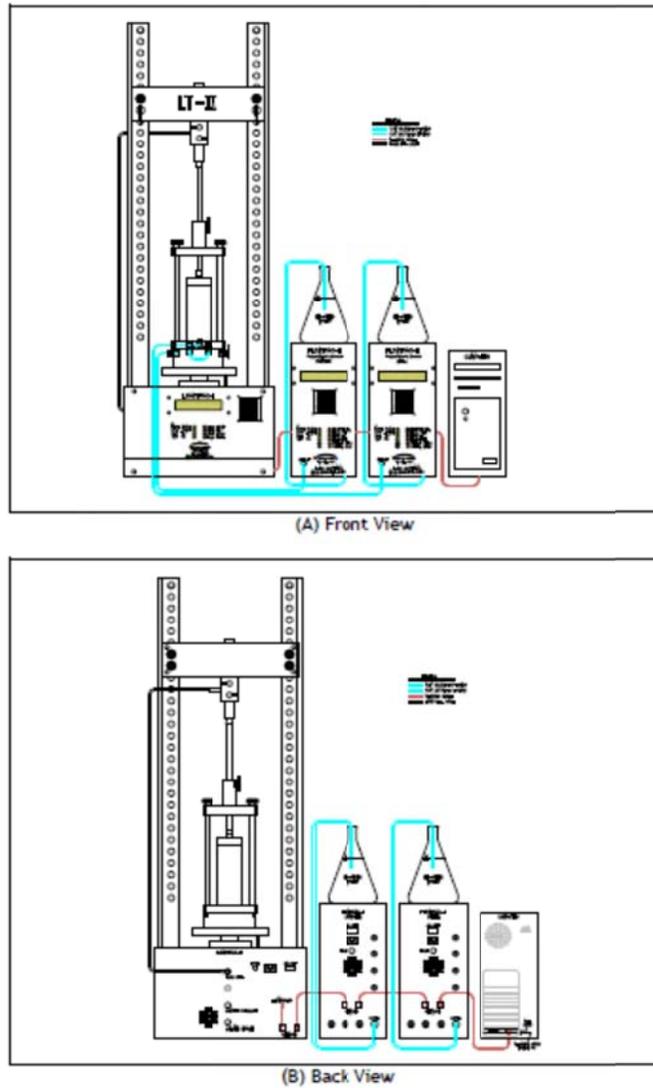


Figure 5-3 Triaxial test Set up-a) Front view b)Back view

This system, especially for clayey soil, can reduce the saturation stage from 2-3 weeks to 4 days. This achievement helps to run the similar test on clay in a quick and very little of time.

5-6 Constants and Variable selection

The constants and variables selected for the triaxial testing program conducted as part of this study include:

5-6-1 Constants

1. **Soil types.** Soil type was Kaolin clay throughout the triaxial test. The details of used kaolin clay are fully explained in chapter 3.
2. **Soil density.** Shear strength of fibre-reinforced soils compacted to same density and the soil density kept constant at 90% of compaction effort.
3. **Fibre type.** Fibres of similar linear densities and shapes (fibrillated fibres) were used as described in chapter 3.
4. **Direction of loading.** triaxial compression tests were conducted to evaluate the potential strength induced by a preferential fibre orientation.

5. Preferential orientation of fibres. For triaxial extension tests, constant preferential orientations of fibres were induced using similar specimen preparation methods to avoid the potential strength anisotropy.

5-6-2 Variables

1. *Fibre content.* Different values of fibre content were used in several of the test series. The fibre contents used in this study ranged from 0% to 0.4%.
2. *Aspect ratio.* The lengths of fibres used were 15 mm and 25 mm, which resulted in a variety of fibre aspect ratios for the different fibre linear densities.

5-7 Sample Preparation

The samples were prepared by mixing clay and three percentage of fibre. Specimen preparation method was the standard compaction method, which was used in an ongoing experimental research on fibre-reinforced clay at Curtin University. The soils were first oven-dried. The dry soils were then crushed using a hammer. A mixer was used to thoroughly mix the soils with water to obtain the desired water moisture content for compaction. The mixing of soil with fibres was performed mostly by hand rather than using the mixer because the mixer caused the fibres to tangle or break. The fibre-soil mixture was placed in a closed container for 24 hours after mixing was completed. A split mold and a specific hammer were used to compact the specimen.

The specimens were prepared in different fibre content (i.e. 0.1%, 0.2%, 0.3%) and different fibre length which were 15mm, 25mm.

5-8 Test Procedure

1. The specimens were prepared in the laboratory with 90% compaction effort, special care was taken during this process
2. The size of samples were checked to be suitable for the test purpose
3. The samples were put in triaxial base with constant confinement pressure
4. The samples were put to be saturated by 96%, the degree of saturation was controlled by computing B values. However the triaxial testing machine was fully automated and therefore any parameter presented on display.
5. The sample left for 2 days to be consolidated. Volume control applied to make sure if sample is consolidated. In this study effective confining pressure kept constant at 100 kpa.
6. The valves double checked to be suitable for undrained condition
7. All of the tests were run at a strain rate of 0.5 mm/minute. The strain rate was selected such that the maximum value of the pore pressure ratio does not

exceed 4%.The data was collected automatically (According to Australian Standard, ASTM and MIT Geotechnical Lab)

8. The stress-strain curve plotted used for different fibre content and length in this investigation

Figure 5-4 and 5-5 show the Automated Triaxial Test which was used in the test program.



Figure 5-4 Initial Triaxial test set up



Figure 5-5 Flow Trac-II



Figure 5-6 Flow Trac-II and Load Trac



Figure 5-7 Connected PC

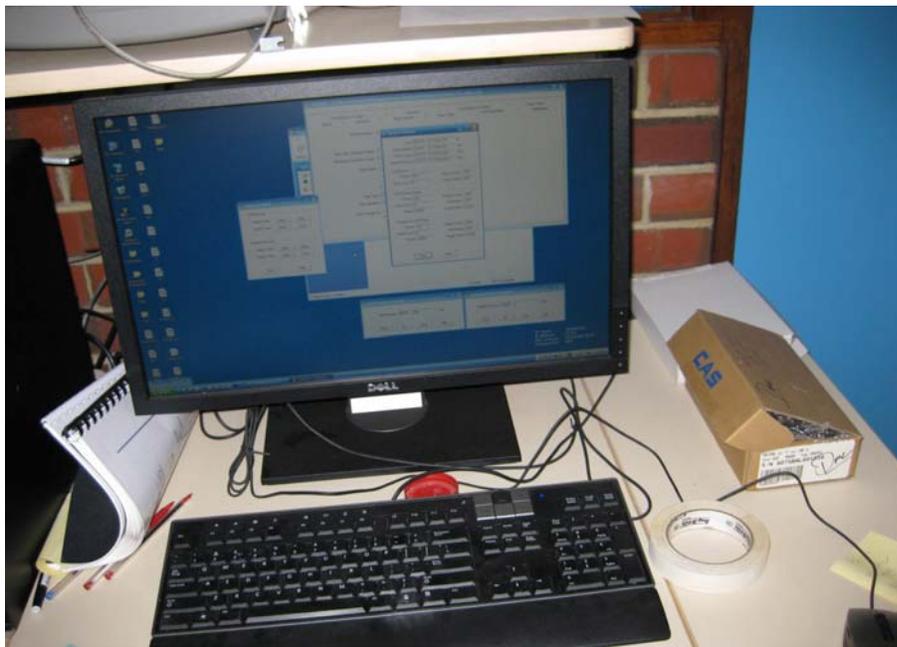


Figure 5-8 PC and Triaxial software



Figure 5-9 Failure of sample at 100 kPa



Figure 5-10 Failure of sample at 200 kPa



Figure 5-11 Failure of sample at 300 kPa



Figure 5-12 Balance used in lab



Figure 5-13 Mixer



Figure 5-14 Sample preparation tools

5-9 Results and Discussion

The consolidated undrained (CU) compression tests were performed in order to determine the effect of plastic fibre inclusion on strength of reinforced clay. The stress-strain curves were derived for different fibre length and content. The tests were conducted on cylindrical specimen of 60 mm diameter and 170 mm height.

While fibre length was 15mm, the maximum deviatoric stress of clayey soil was 170 kPa obtained at fibre content 3% percent. In second consideration, while the fibre content kept constant at 1%, fibre length varied from 15mm to 65mm and the maximum value of deviatoric stress was 140 kpa. It was observed that strength of reinforced clay was increased with increasing in fibre length and fibre content.

Samples response due to failure

The soil sample called fail when the failure plane occurred. Figure 5-9 shows the failure plane which occurred during the tests. The deviatoric stress for failure points of the tests showed that fibre inclusion increased this value and consequently this means that failure shear plane of reinforced samples occurred very slower than that of unreinforced one.

5-9-1 CU test results for different fibre content and length

a) constant length

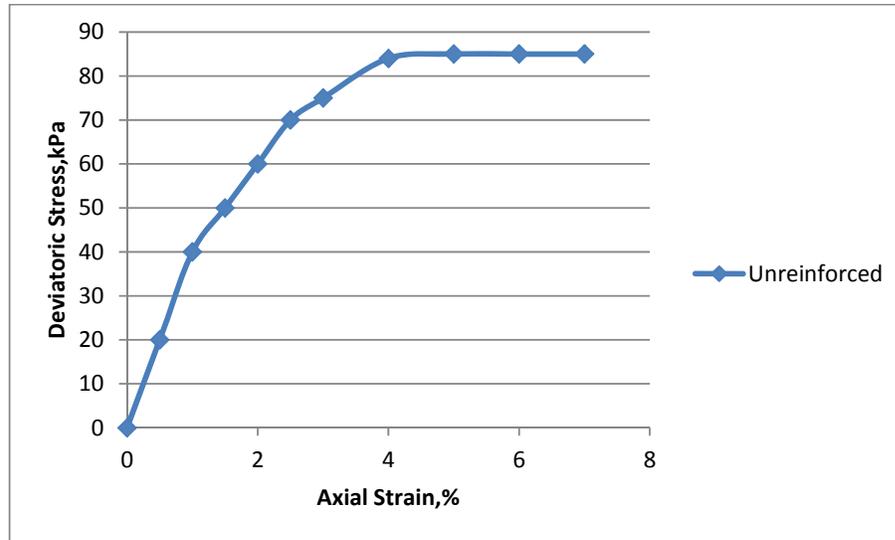


Figure 5-15 Deviatoric stress versus axial strain for pure clay

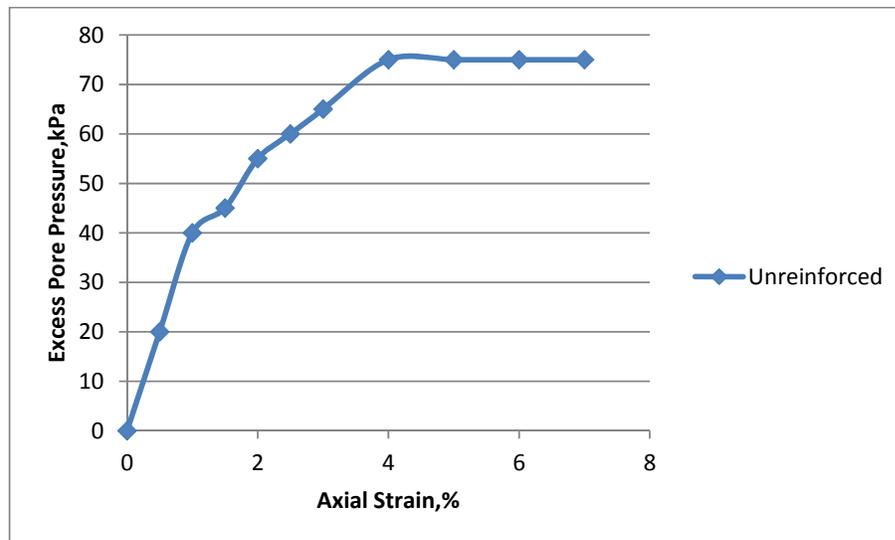


Figure 5-16 Excess pore pressure for pure clay

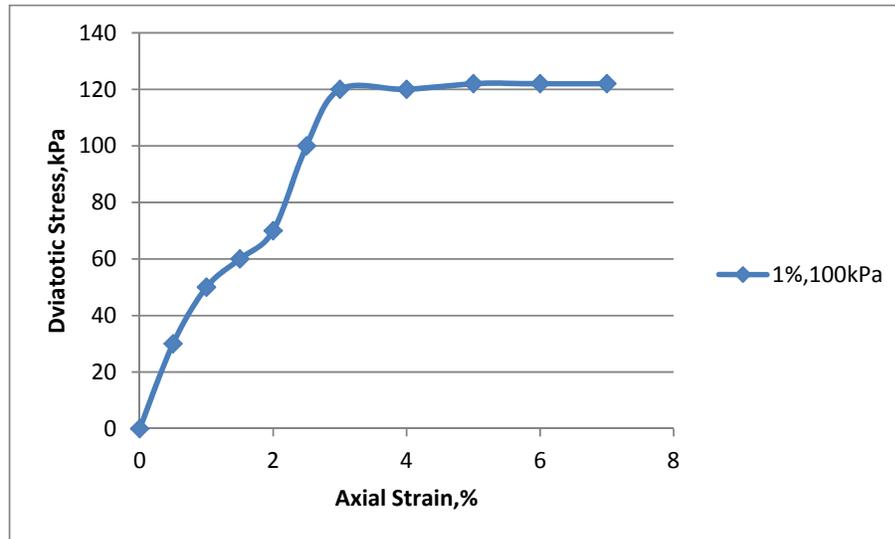


Figure 5-17 Deviatoric stress versus axial strain for 1% fibre content

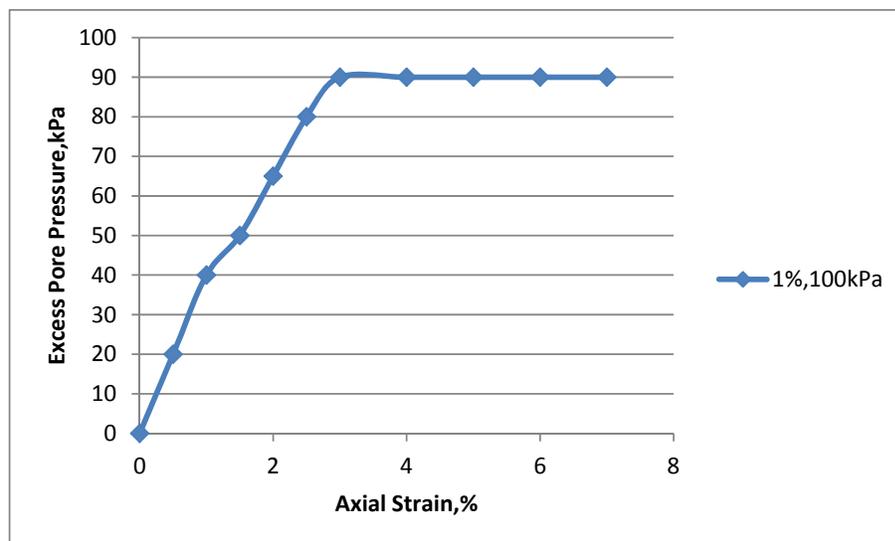


Figure 5-18 Excess pore pressure for 1% fibre content

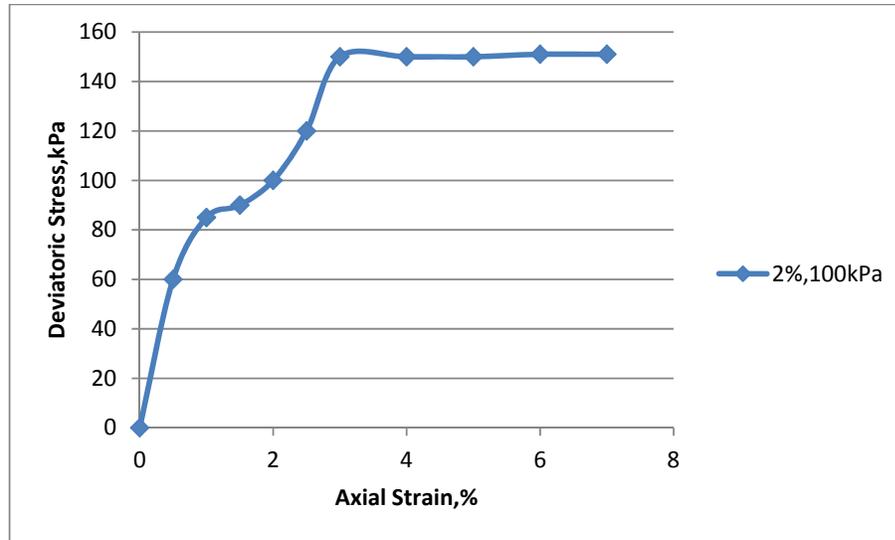


Figure 5-19 Deviatoric stress versus axial strain for 2% fibre content

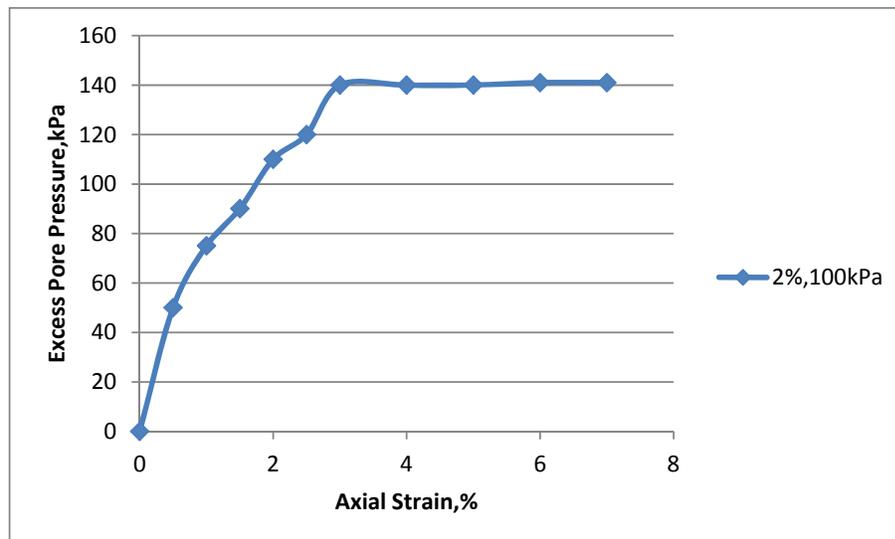


Figure 5-20 Excess pore pressure for 2% fibre content

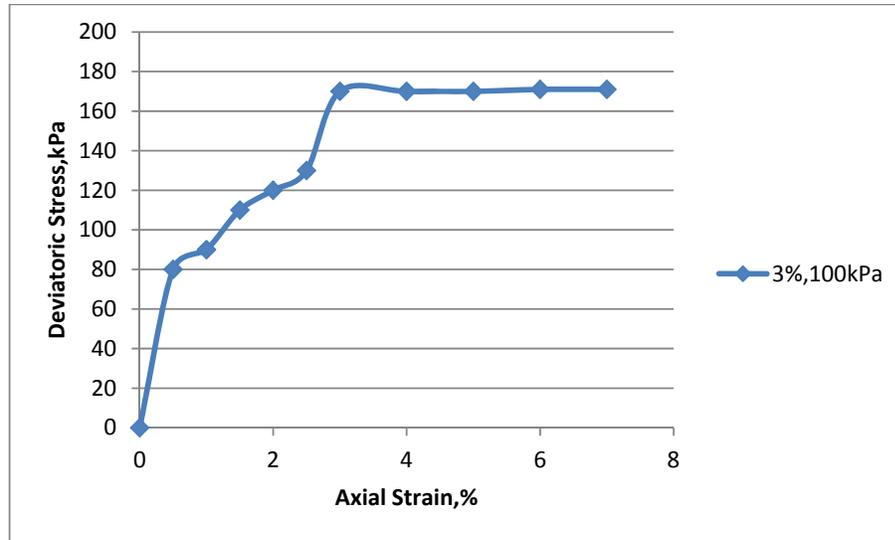


Figure 5-21 Deviatoric stress versus axial strain for 3% fibre content

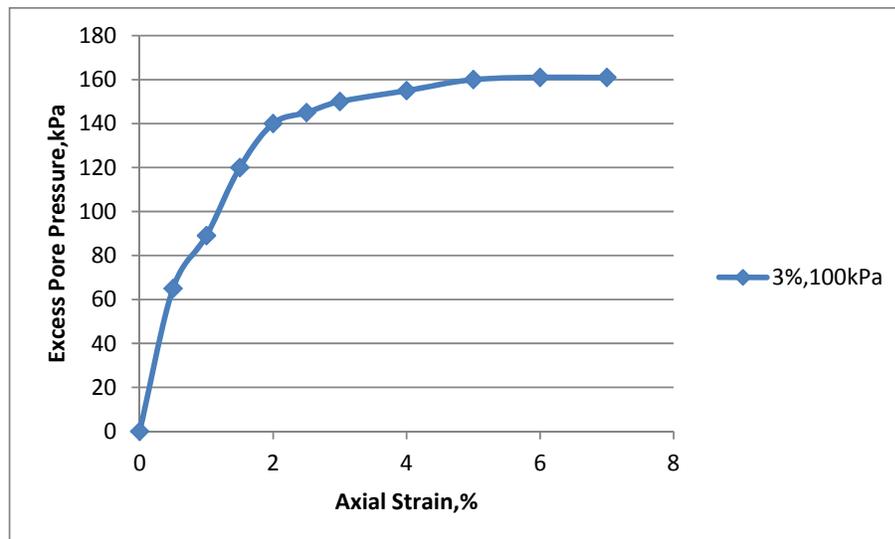


Figure 5-22 Excess pore pressure for 3% fibre content

b) Fibre content constant

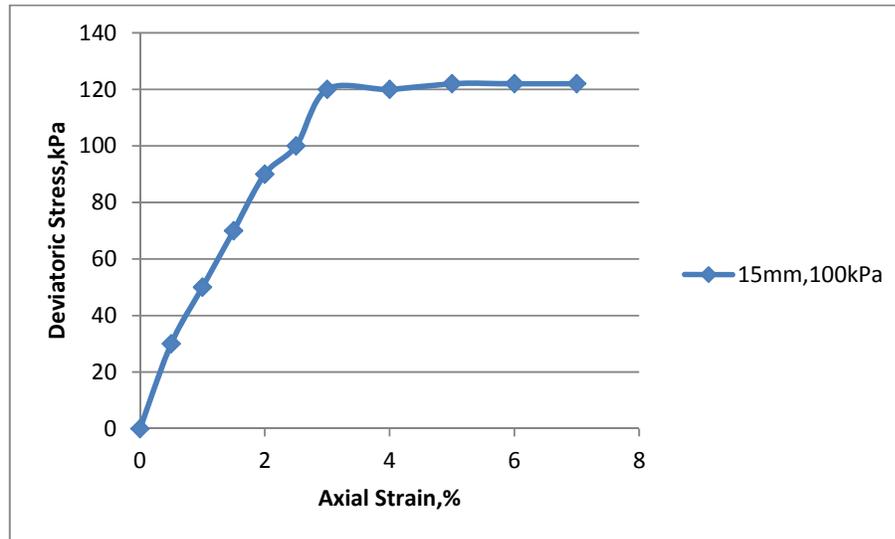


Figure 5-23 Deviatoric stress versus axial strain for 15mm fibre length

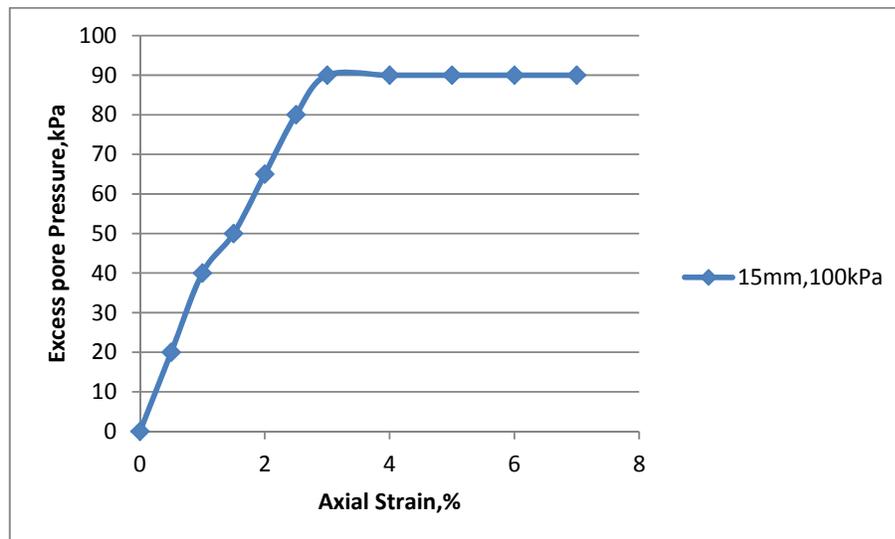


Figure 5-24 Excess pore pressure for 15mm fibre length

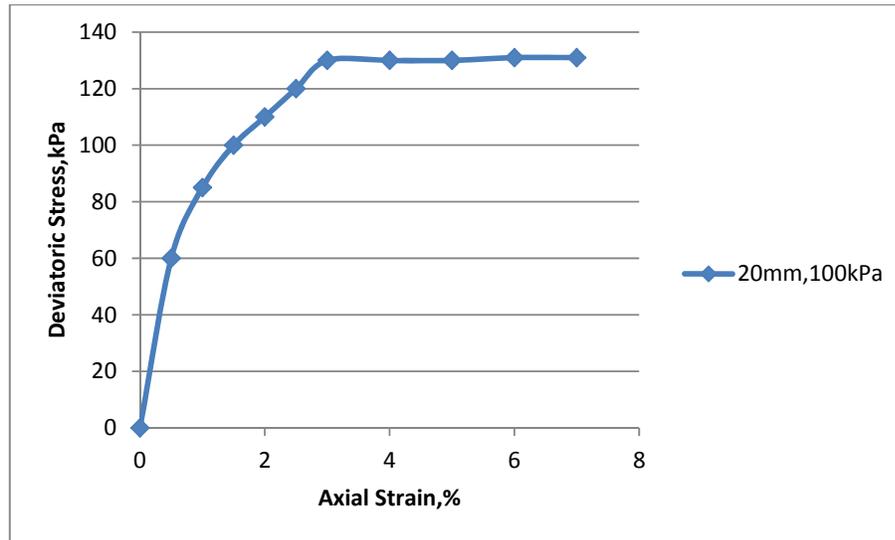


Figure 5-25 Deviatoric stress versus axial strain for 20mm fibre length

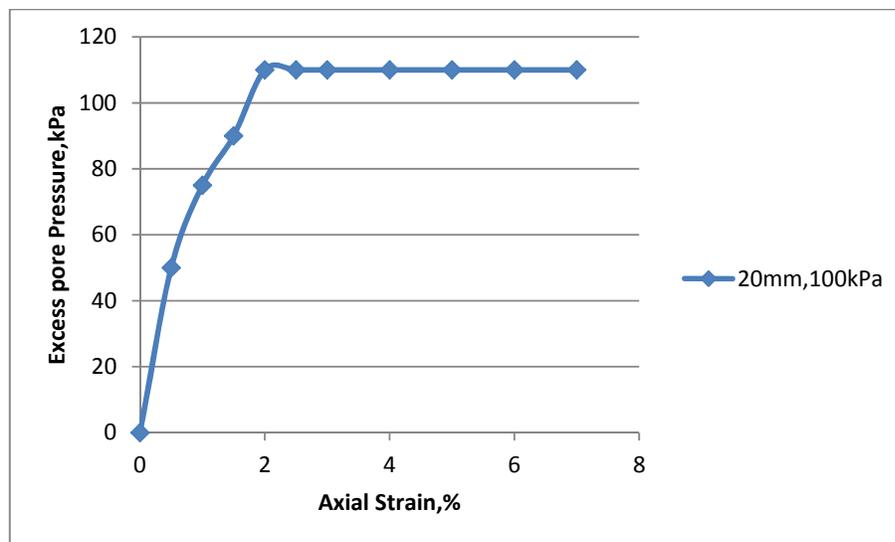


Figure 5-26 Excess pore pressure for 20mm fibre length

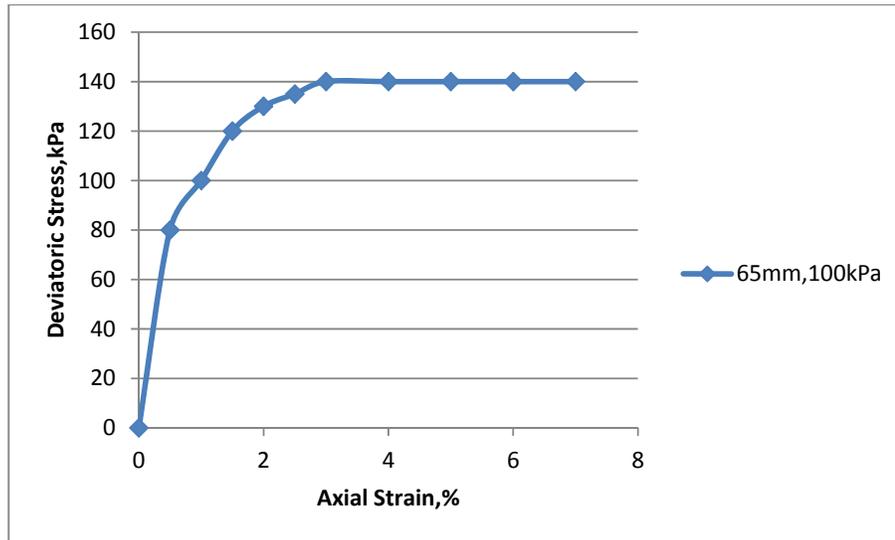


Figure 5-27 Deviatoric stress versus axial strain for 65mm fibre length

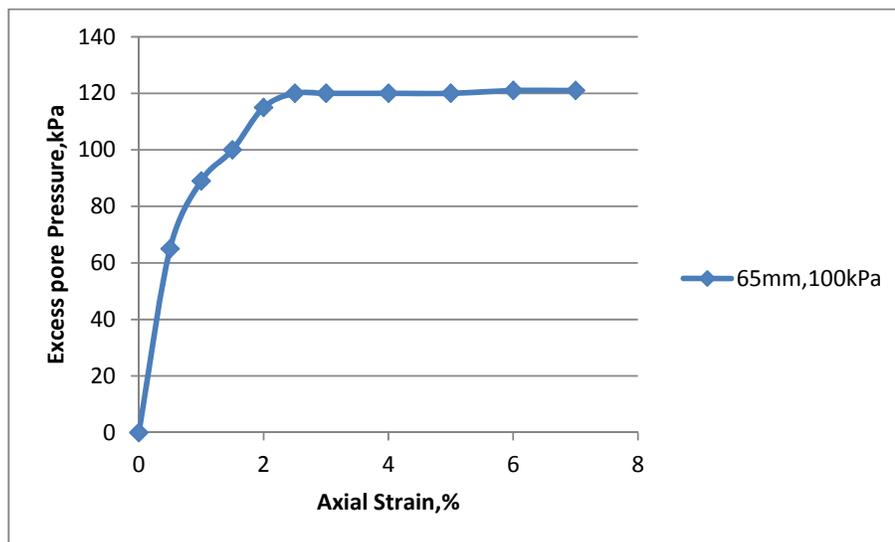


Figure 5-28 Excess pore pressure for 65mm fibre length

5-9-2 CU test results for pure clay

a) 100kPa

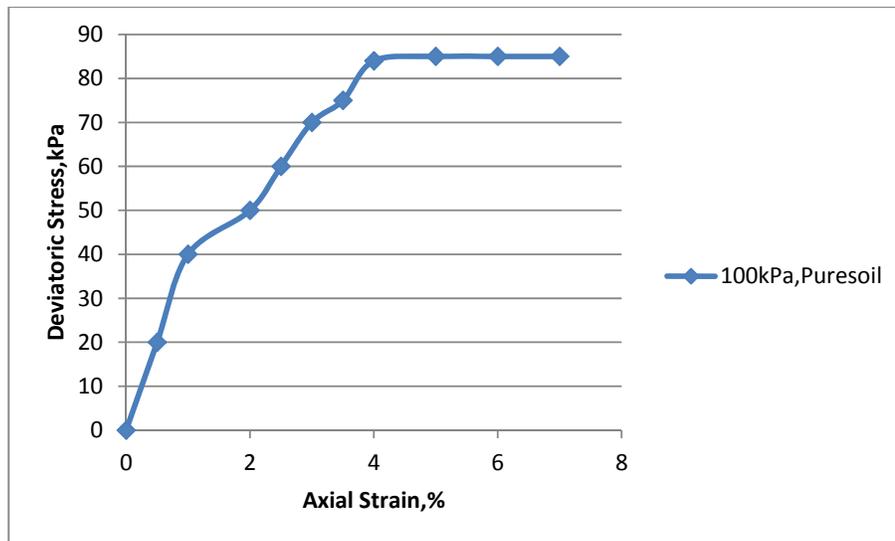


Figure 5-29 Deviatoric stress versus axial strain for pure clay at 100 kPa

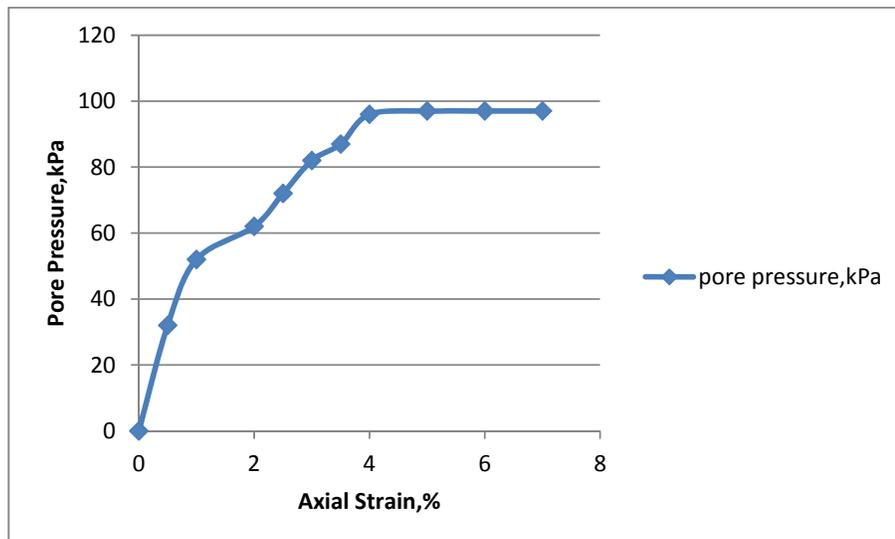


Figure 5-30 Excess pore pressure for pure clay at 100 kPa

b) 200kPa

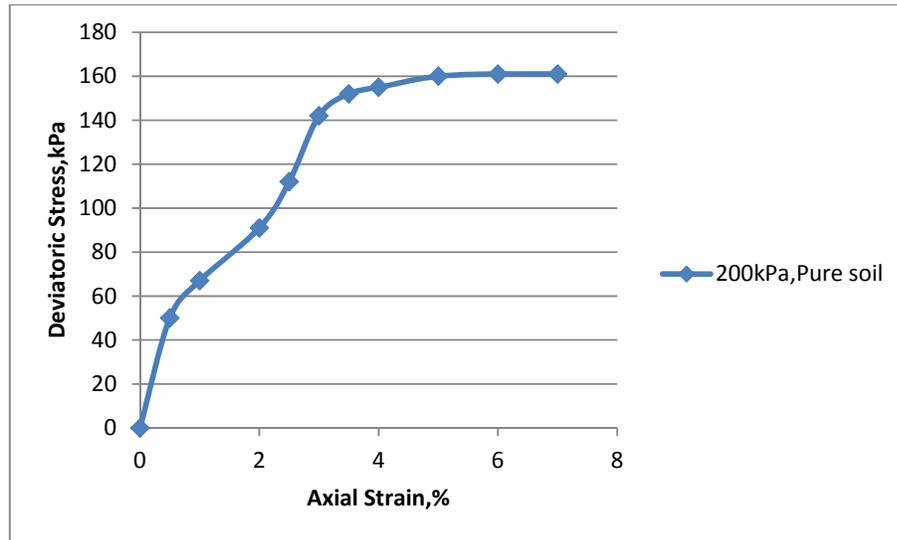


Figure 5-31 Deviatoric stress versus axial strain for pure clay at 200 kPa

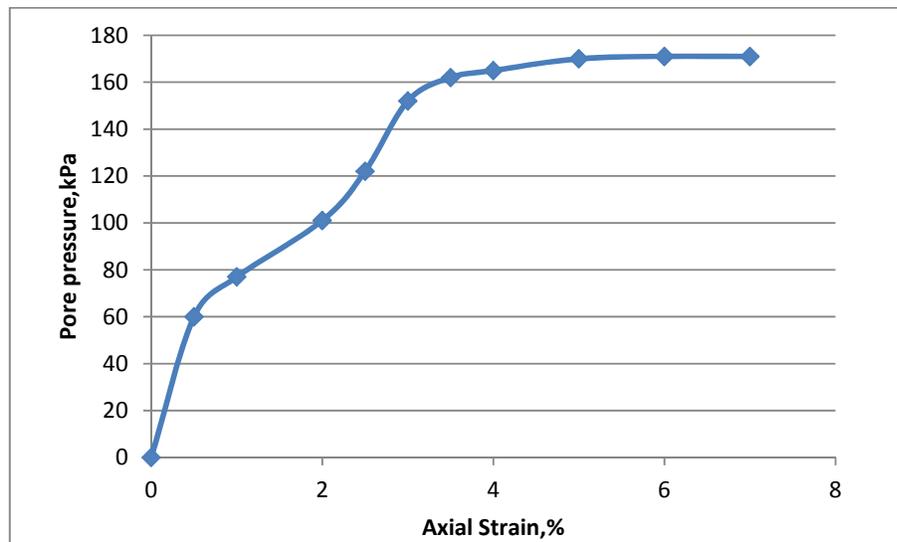


Figure 5-32 Excess pore pressure for pure clay at 200 kPa

c) 300kPa

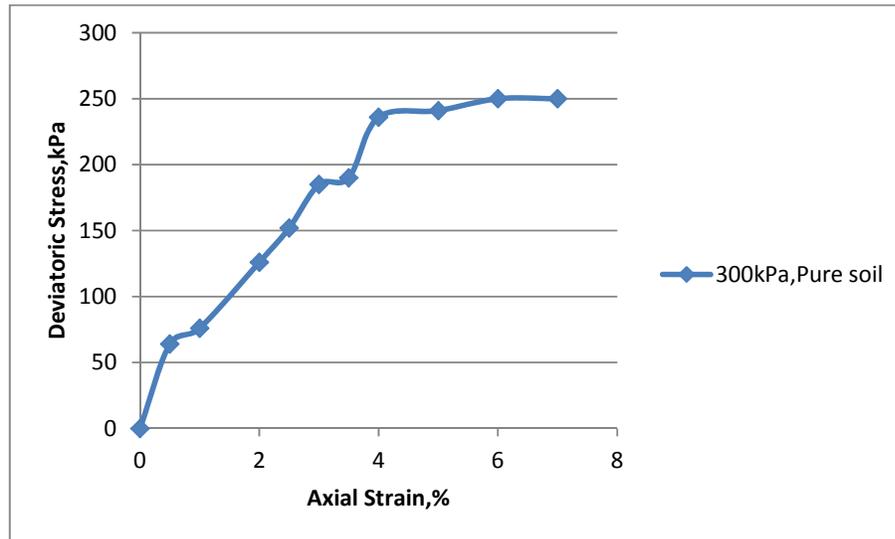


Figure 5-33 Deviatoric stress versus axial strain for pure clay at 300 kPa

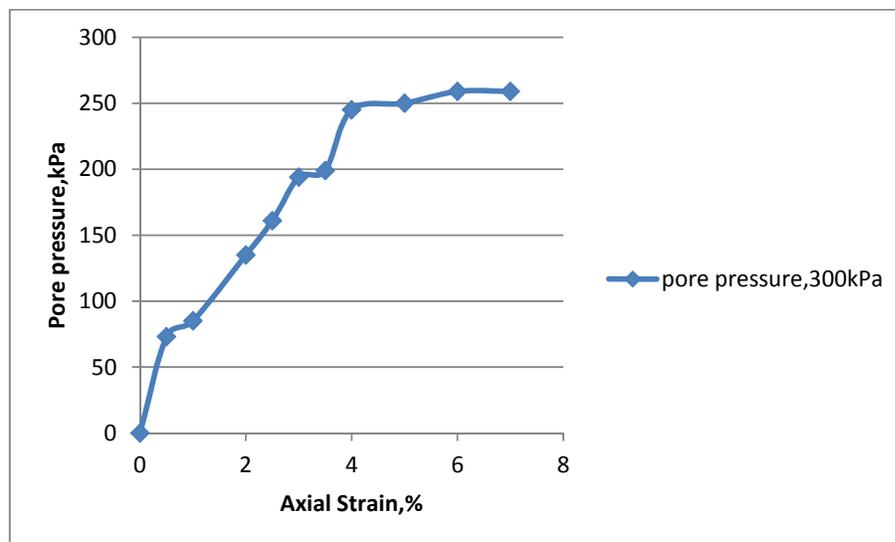


Figure 5-34 Excess pore pressure for pure clay at 300 kPa

5-9-3 CD test results

a) 100kPa

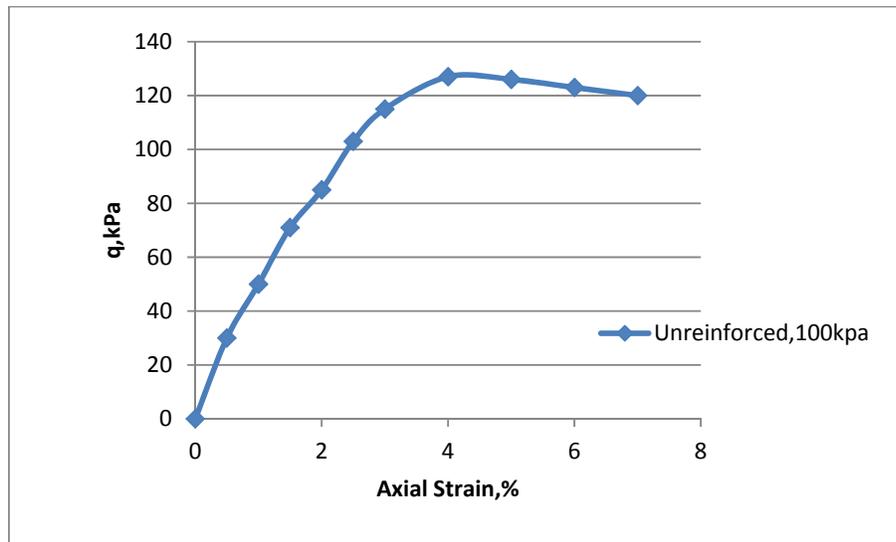


Figure 5-35 Deviatoric stress versus axial strain for pure clay at 100 kPa

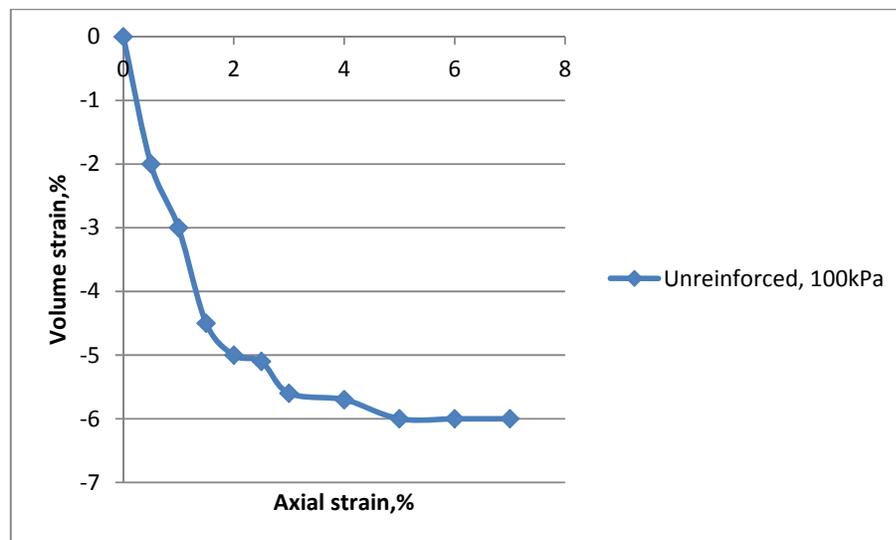


Figure 5-36 Volumetric strain versus axial strain for pure clay at 100 kPa

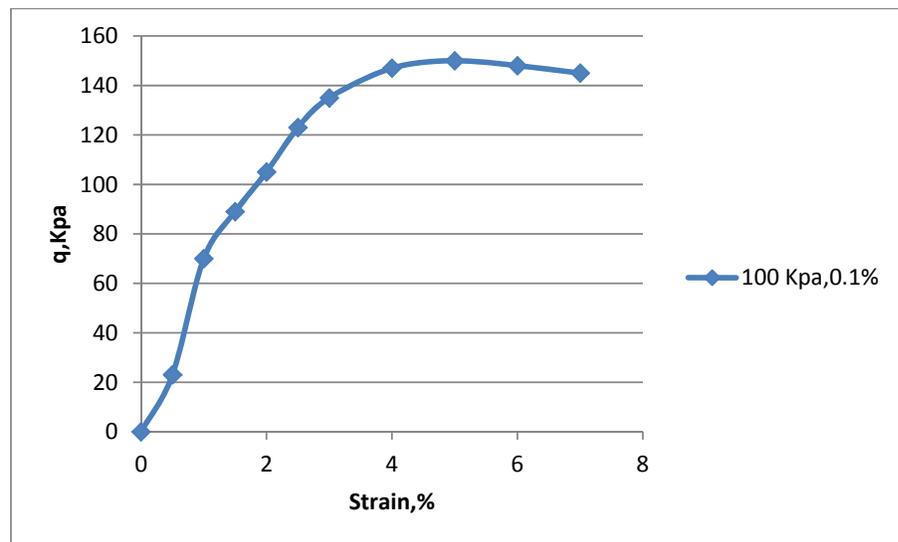


Figure 5-37 Deviatoric stress versus axial strain for 0.1% fibre clay at 100 kPa

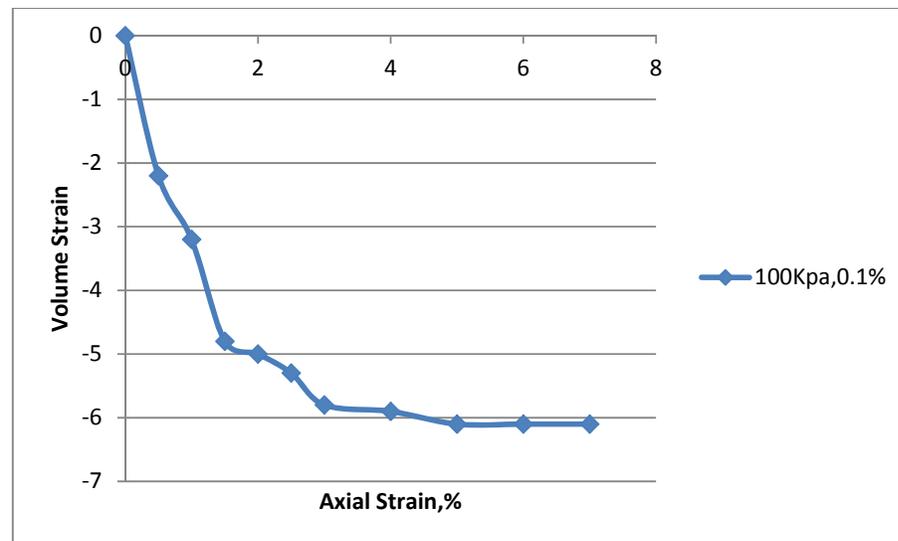


Figure 5-38 Volumetric strain versus axial strain for 0.1% fibre clay at 100 kPa

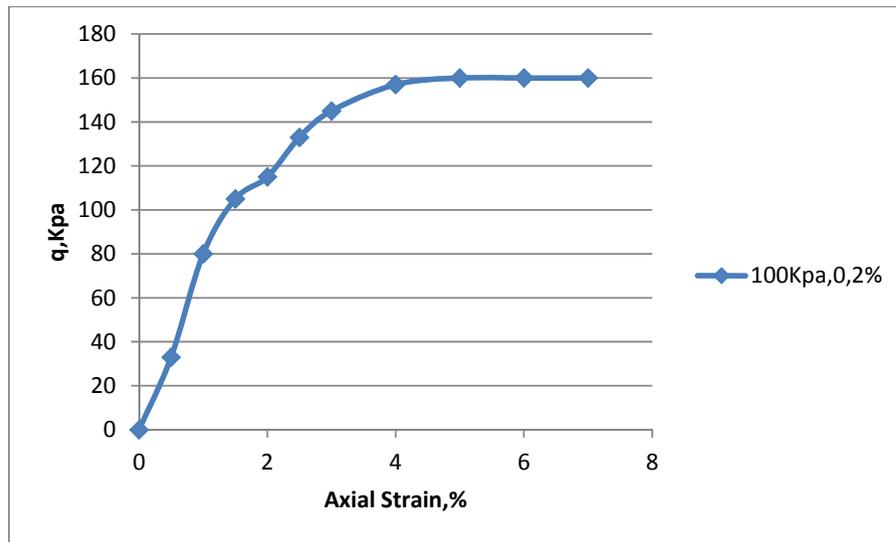


Figure 5-39 Deviatoric stress versus axial strain for 0.2% fibre clay at 100 kPa

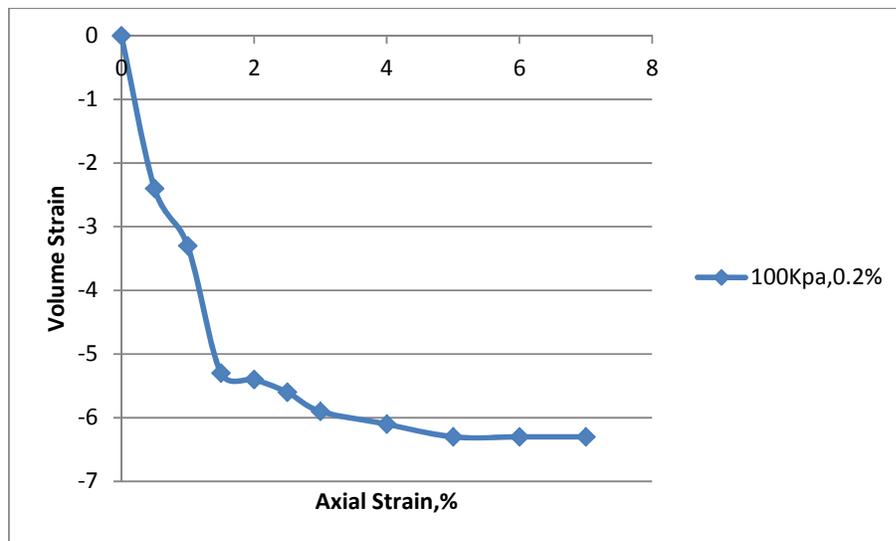


Figure 5-40 Volumetric strain versus axial strain for 0.2% fibre clay at 100 kPa

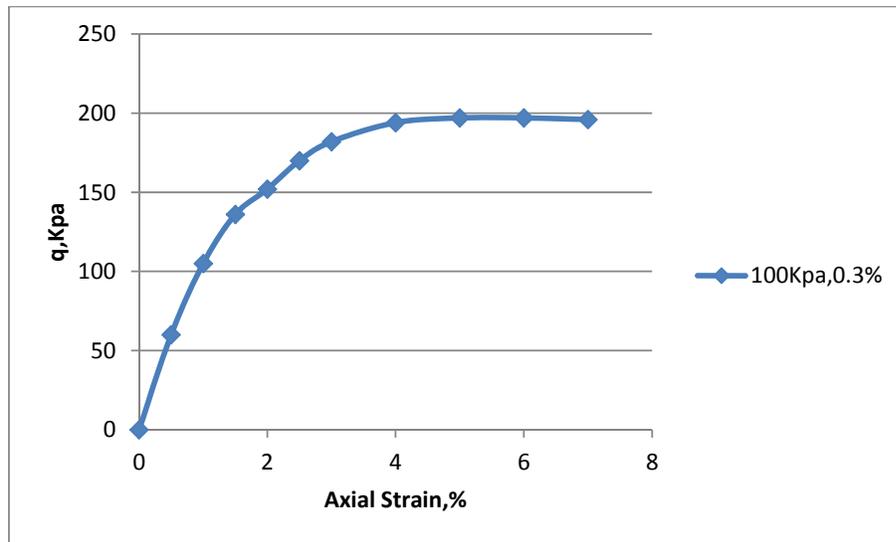


Figure 5-41 Deviatoric stress versus axial strain for 0.3% fibre clay at 100 kPa

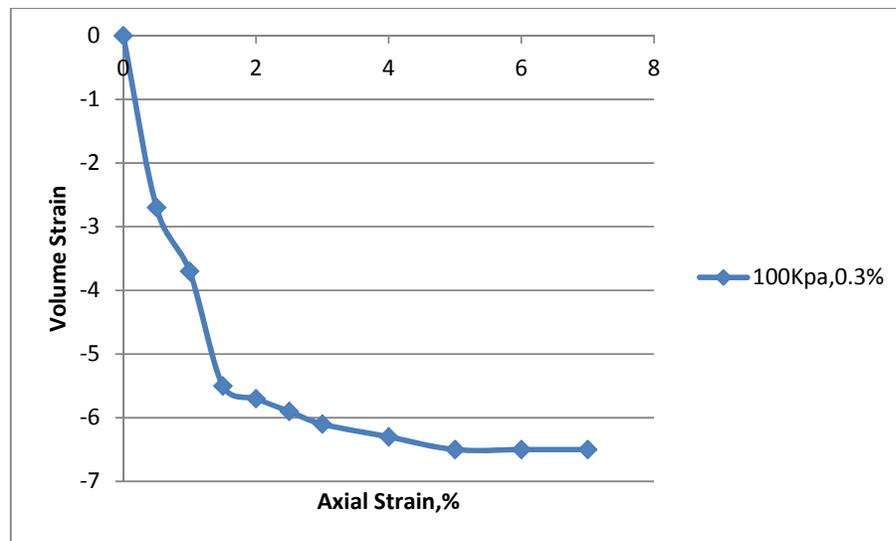


Figure 5-42 Volumetric strain versus axial strain for 0.3% fibre clay at 100 kPa

b)200 Kpa

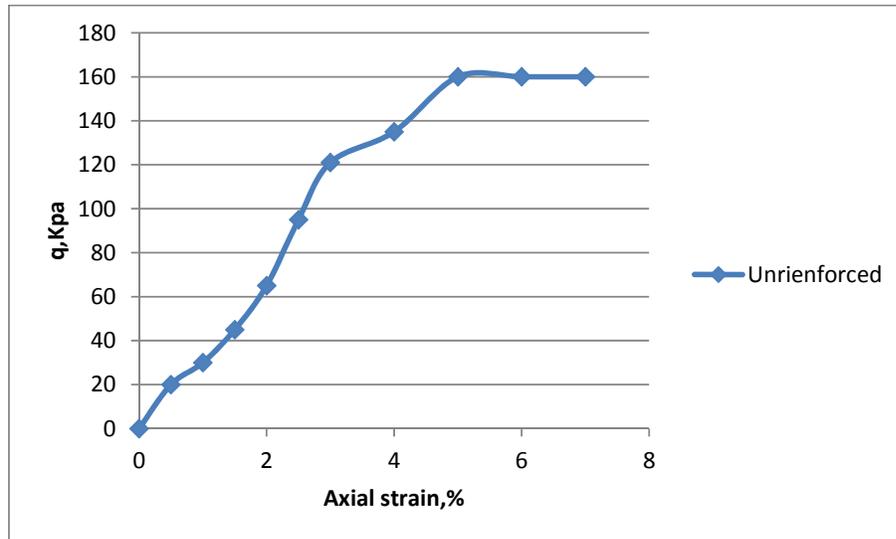


Figure 5-43 Deviatoric stress versus axial strain for pure clay at 200 kPa

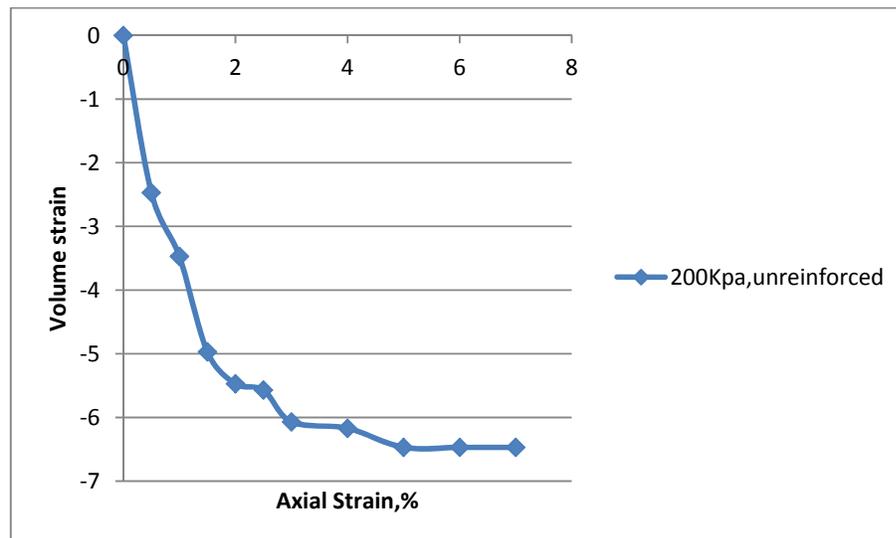


Figure 5-44 Volumetric strain versus axial strain for pure clay at 200 kPa

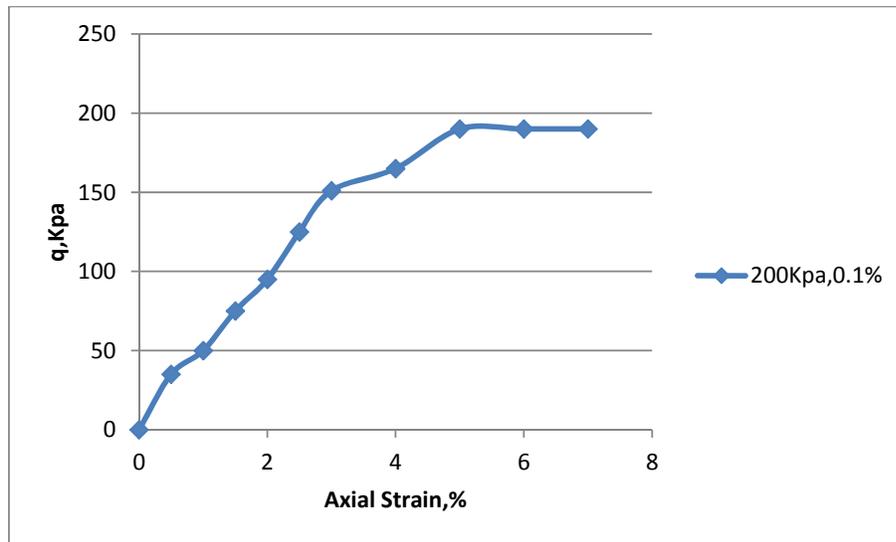


Figure 5-45 Deviatoric stress versus axial strain for 0.1% fibre clay at 200 kPa

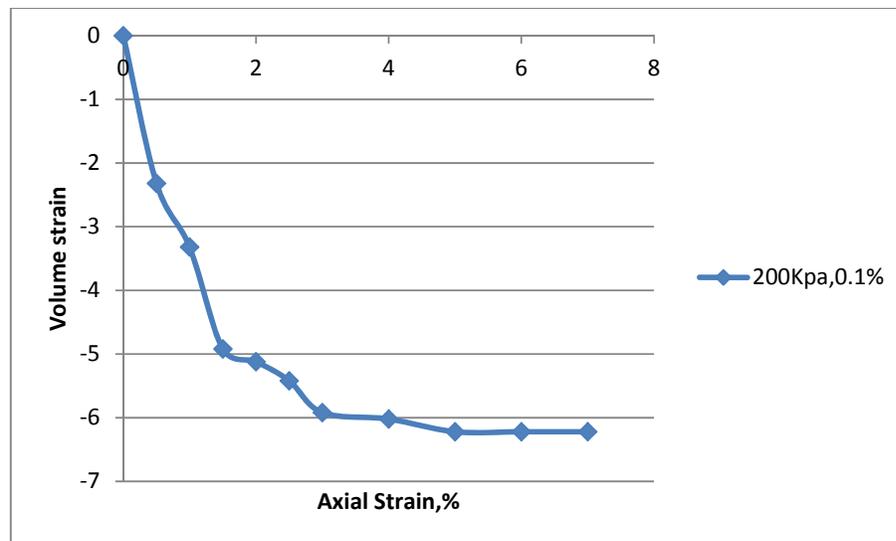


Figure 5-46 Volumetric strain versus axial strain for 0.1% fibre clay at 200 kPa

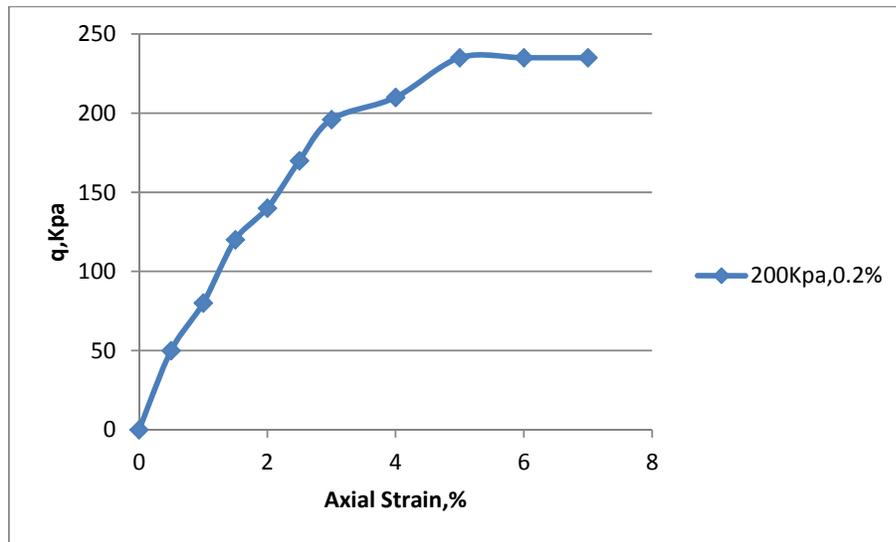


Figure 5-47 Deviatoric stress versus axial strain for 0.2% fibre clay at 200 kPa

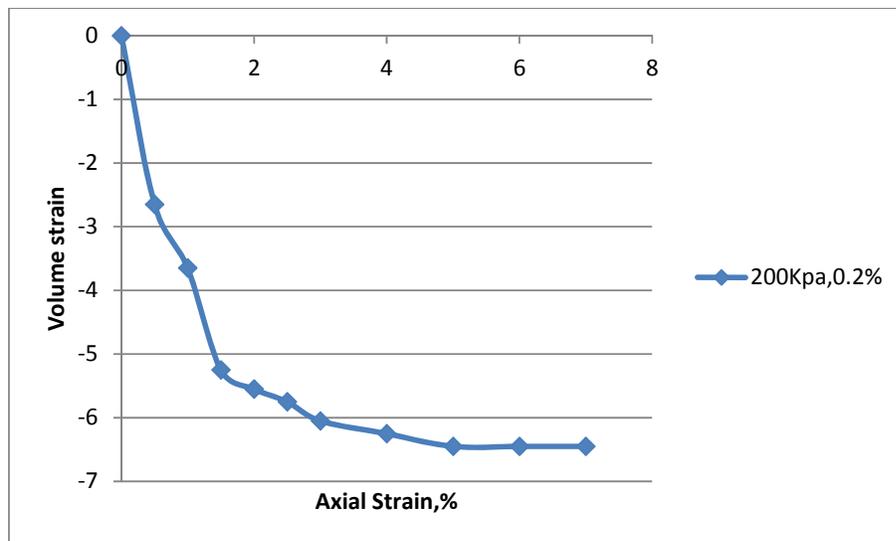


Figure 5-48 Volumetric strain versus axial strain for 0.2% fibre clay at 200 kPa

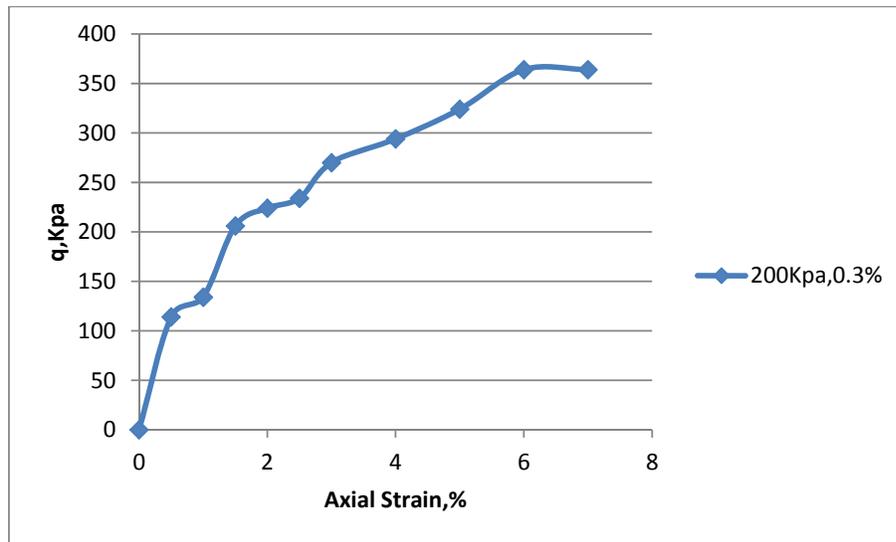


Figure 5-49 Deviatoric stress versus axial strain for 0.3% fibre clay at 200 kPa

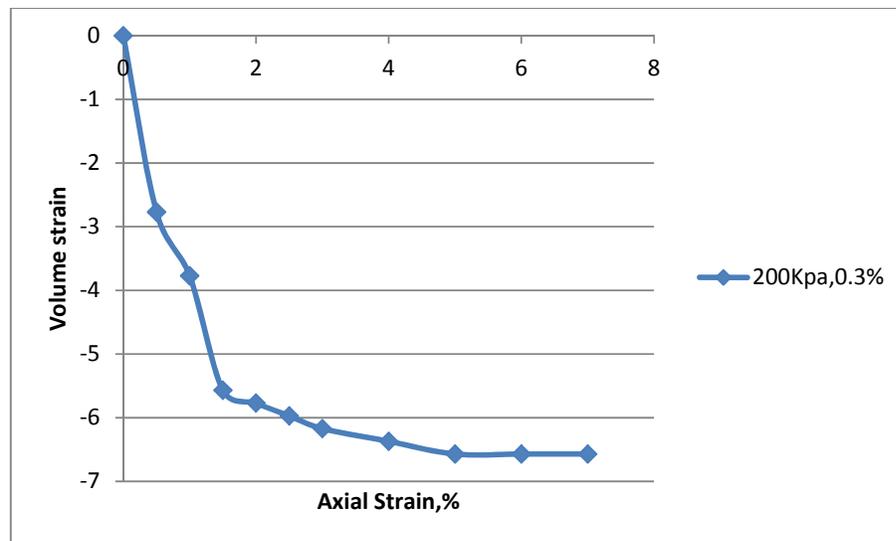


Figure 5-50 Volumetric strain versus axial strain for 0.3% fibre clay at 200 kPa

6. Results Analysis and Discussion

6-1 Raw Results Analysis

In previous chapter, the results of CU tests for different fibre content and length were presented. In this chapter, the raw data obtained from laboratory will be analysed. This section includes two parts. The first part is related to analysing the CU test results and the second part is addressed CD test.

6-2 CU test results analysis

As the tests were designed systematically the effect of variable could be investigated. The first analysis is related to effect of varied parameters (i.e. fibre content and fibre length). The previous section showed results of fibre content change on deviatoric stress of reinforced clay composite samples. The Figure 6-1 presents the effect of this change on samples by compare them in a graph of deviatoric stress and axial strain. Figure 6-2 showed the measured excess pore pressure during the tests.

The second analysis is related to investigate effect of fibre length on the samples by comparing them in a graph similar to first analysis.

6-2-1 Effect of fibre content

In first part of results fibre length and confining pressure kept constant. The values of these parameters were 15mm and 100 kPa respectively.

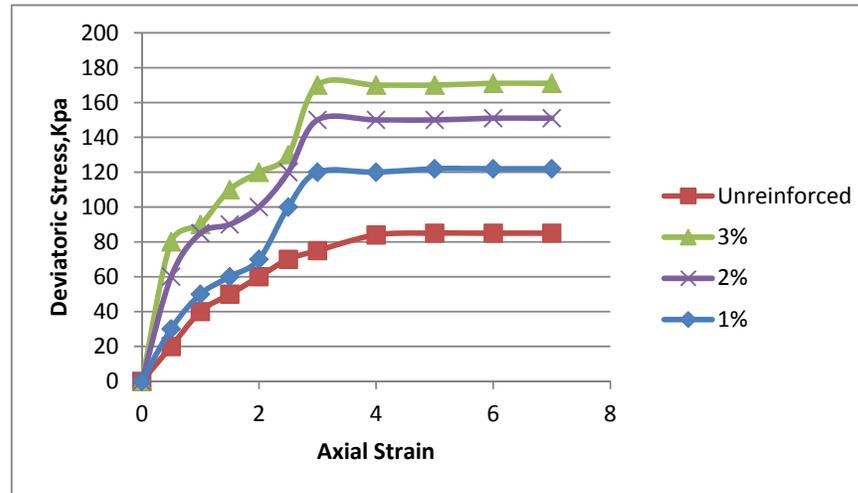


Figure. 6-1 Effect of fibre percentage on strength of reinforced clay (fibre length 15mm, Confining 100kPa)

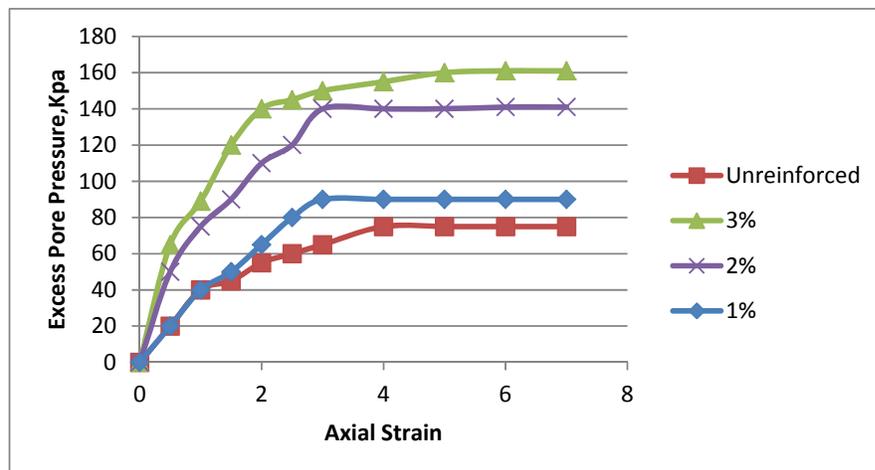


Figure 6-2 Effect of fibre percentage on excess pore pressure of composite clay (fibre length 15mm, Confining 100kPa)

The results of first part proved that inclusion of fibre increased the strength of material and with enhancing fibre content, composite strength dramatically increased.

6-2-2 Effect of fibre length

Triaxial test were run under constant confining pressure 100 kPa and fibre content of 1%. The results can be derived as Figure 6-3 and Figure 6-4.

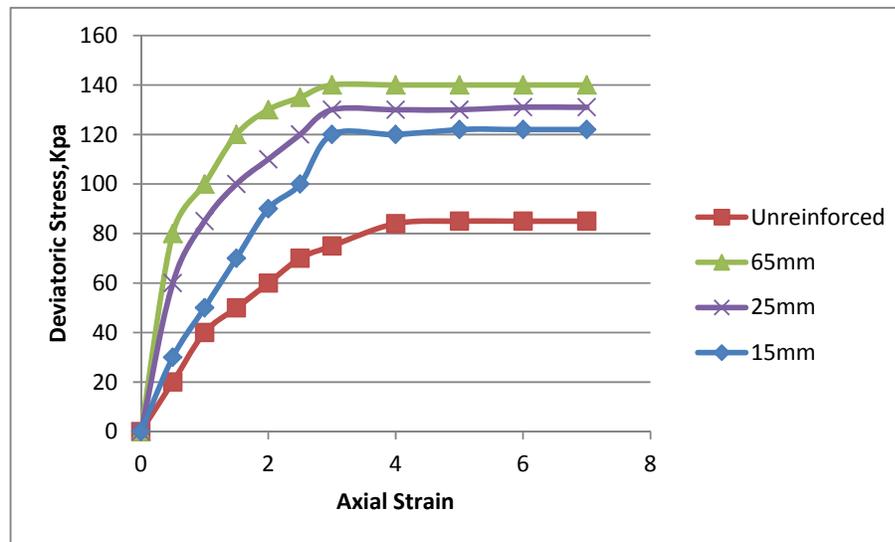


Figure. 6-3 Effect of fibre length on deviatoric stress of composite clay (fibre content 1%, Confining 100kPa)

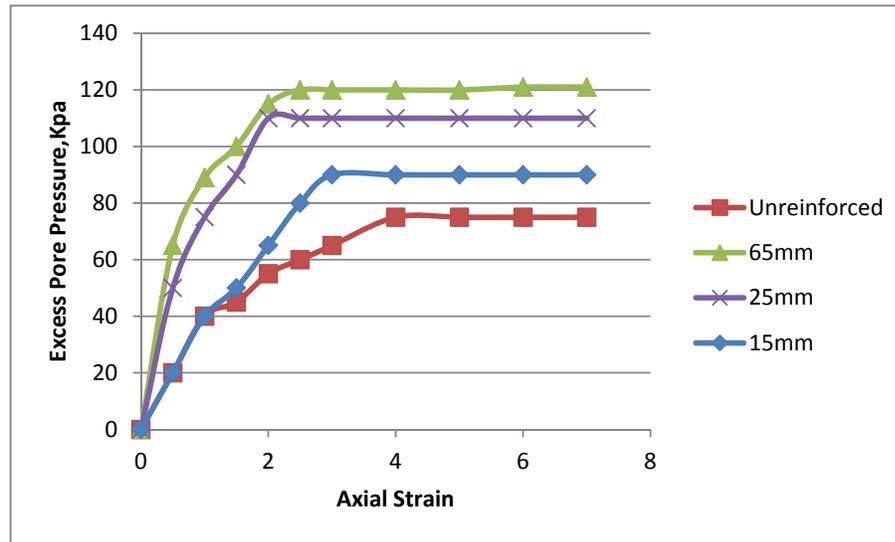


Figure. 6-4 Effect of fibre length on excess pore pressure of composite clay (fibre content 1%, Confining 100kPa)

The results of this part proved that increasing in fibre length caused increasing in strength.

6-2-2 Input data extraction for model from CU tests

The reason for running CU tests for pure kaolin clay is to compute on one of the main input parameter for modified cam clay model. The principle of applying cam clay model is to consider a cap as defines with critical state line slope.

6-2-3 Critical State Line Slope

The Critical State concept is an idealization of the observed behavior of saturated remoulded clays in triaxial compression tests, and it is assumed to apply to undisturbed soils. It states that soils and other granular materials, if continuously distorted (sheared) until they flow as a frictional fluid, will come into a well-defined critical state. At the onset of the critical state, shear distortions ϵ_s occur without any further changes in mean effective stress p' , deviatoric stress q (or yield stress, σ_y , in uniaxial tension according to the von Mises yielding criterion), or specific volume ν :

$$\frac{\partial p'}{\partial \epsilon_s} = \frac{\partial q}{\partial \epsilon_s} = \frac{\partial \nu}{\partial \epsilon_s} = 0 \quad (6.1)$$

Where

$$\nu = 1 + e \quad (6.2)$$

$$p' = \frac{1}{3}(\sigma'_1 + 2\sigma'_3) \quad (6.3)$$

$$q = (\sigma'_1 - \sigma'_3) \quad (6.4)$$

All critical states, for a given soil, form a unique line called the *Critical State Line* (CSL) defined by the following equations in the space (p', q, v) :

$$q = Mp' \quad (6.5)$$

$$v = \Gamma - \lambda \ln(p') \quad (6.6)$$

where M , Γ , and λ are soil constants. The first equation determines the magnitude of the deviatoric stress q needed to keep the soil flowing continuously as the product of a frictional constant M (capital μ) and the mean effective stress p' . The second equation states that the specific volume v occupied by unit volume of flowing particles will decrease as the logarithm of the mean effective stress increases.

6-2-4 Procedure of computing M

Procedure of computing M based on triaxial test results

- 1- Triaxial CU tests were conducted
- 2- In each test, q and P' were calculated according to equations 6-3 and 6-4
- 3- The graph of q - p' were derived and the failure line which pass through each failure point for the tests used to produce the CSL.
- 4- The slope of CSL considered as M value as input for Cam Clay model

The Figure 6-5 shows the presentation of the above procedure.

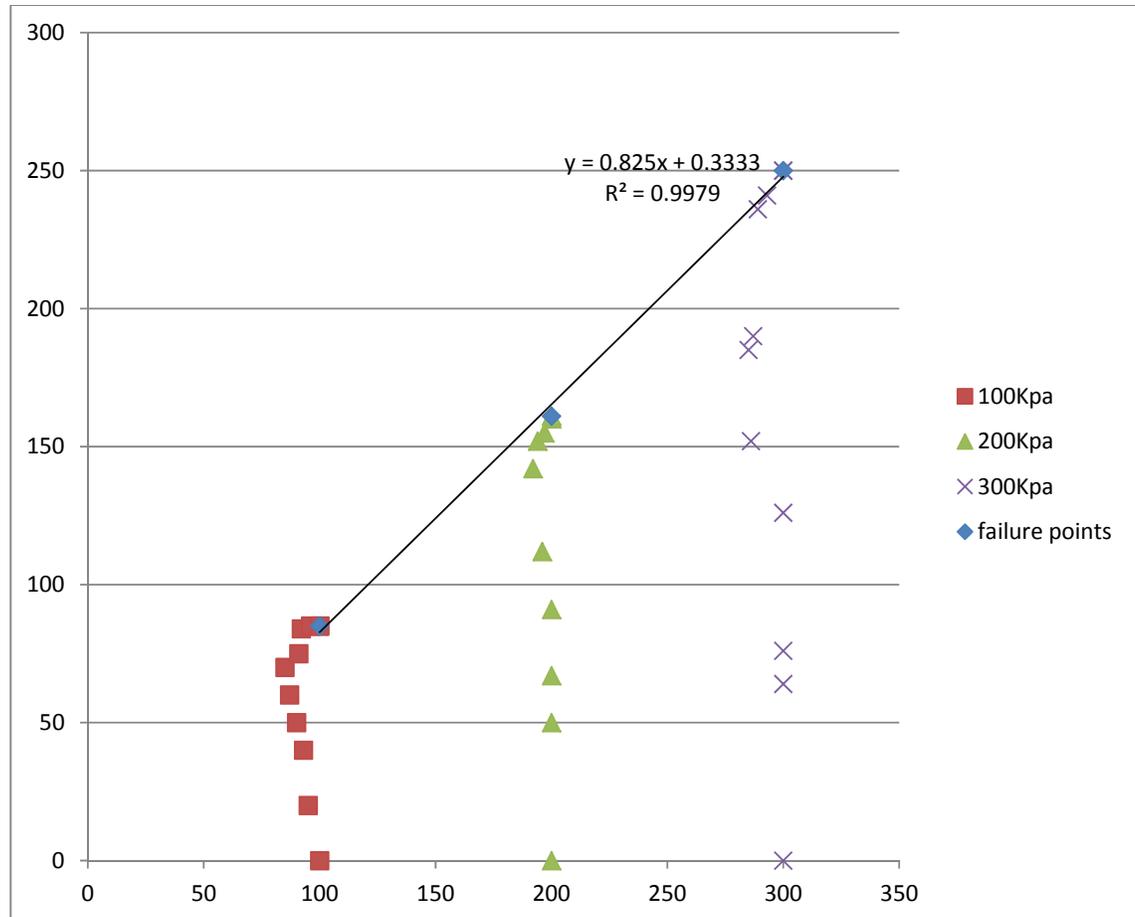


Figure. 6-5 Computing M

6-2-5 Procedure of computing λ and κ

The other two input parameters for Cam Clay model are λ and κ . Figure 6-6 shows the principle of isotropic consolidation and swelling line.

In this study, these two parameters, i.e. λ and κ , found through conducting a consolidation test.

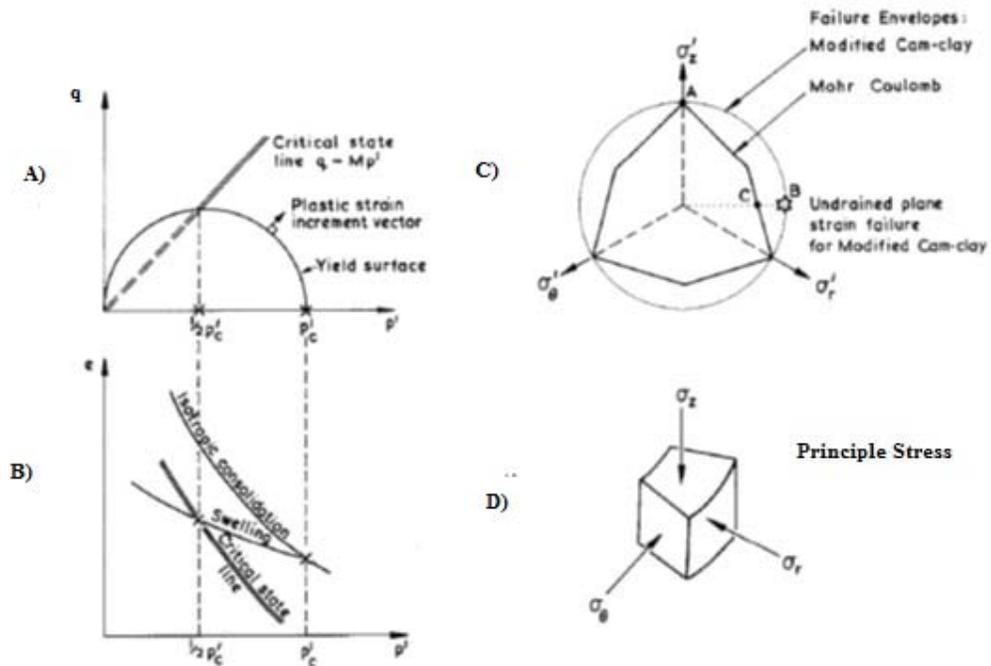


Figure. 6-6 Principle of consolidation and swelling (after Randolph et al, 1979)

6-2-6 Procedure of finding λ and κ

- 1- Consolidation test was conducted
- 2- The results of changing in e (void ratio) versus $\ln p'$ was presented as below
- 3- The slope of consolidation line represents λ
- 4- The slope of unloading phase (swelling line) represent κ
- 5- The value of these two phase are presented as $\lambda= 0.17$ and $\kappa=0.035$

Figure 6-7 presents the computed values of λ and κ within loading and unloading phase.

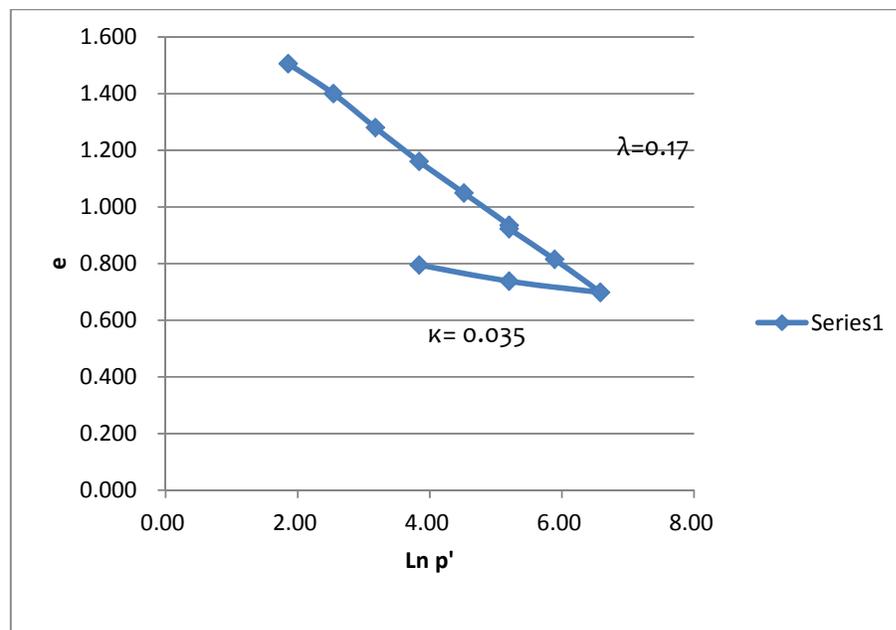


Figure. 6-7 Principle of consolidation and swelling

6-2-7 CD test results

The best way to analyse the results from CD tests and investigate the effect of each changed parameters (i.e. fibre content and fibre length) is to compare them in an engineering graph. This section will focus on effect of length and content in two constant confining pressures.

a) Confining Pressure is kept 100kPa.

The Figure 6-8 shows that with increase in fibre content the deviatoric stress will increase. As it is clear increment of fibre content from 0.1% to 0.3% will increase the deviatoric stress by two times.

The Figure 6-9 shows that at the same time volume strain change in sample shows a slight increase.

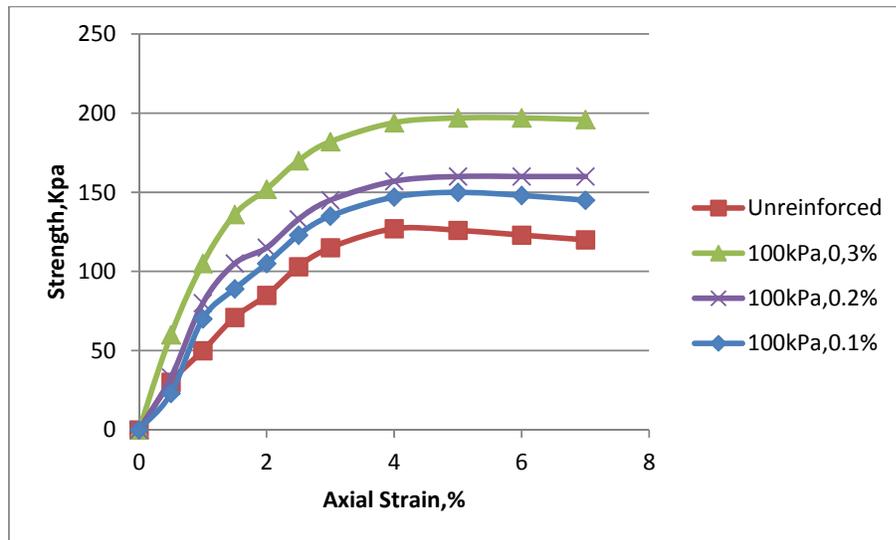


Figure. 6-8 Deviatoric Stress change for different fibre content

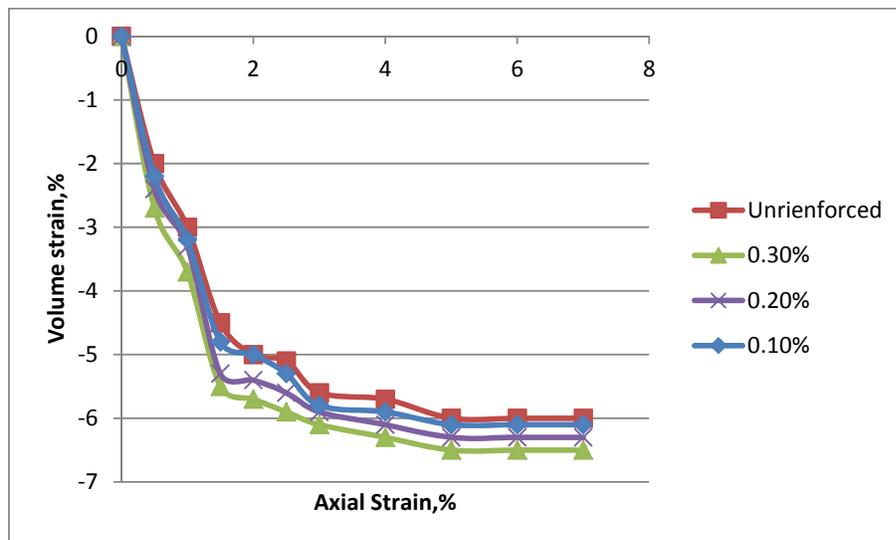


Figure. 6-9 Volume Strain Change for different fibre content

b) Confining Pressure is kept 200kPa

The same results for 200 kPa confining pressure also proved the same trend for fibre content. Figure 6-10 and 6-11 show the evidence for this claim. The results for 200 kPa proved that regardless of confining pressure the behaviour of the composite clay was same.

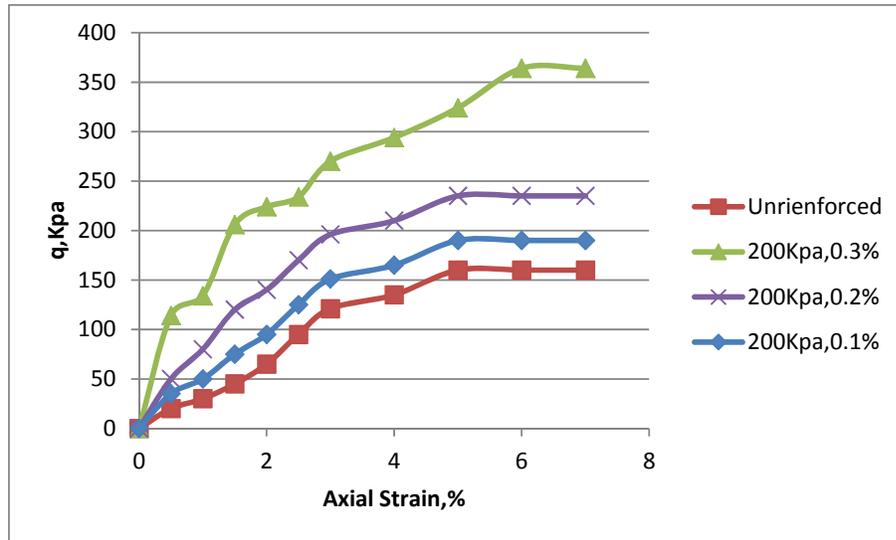


Figure. 6-10 Deviatoric Stress change for different fibre content

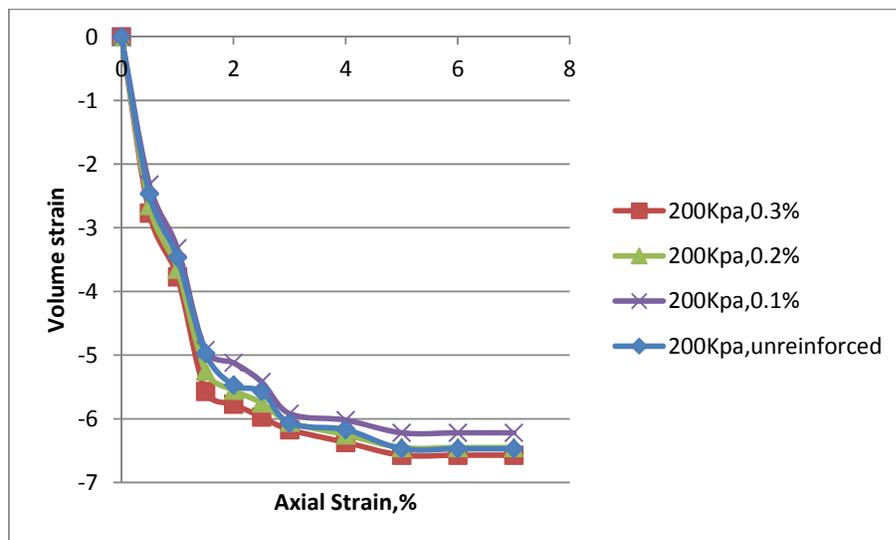


Figure. 6-11 Volume Strain Change for different fibre content

7. Theoretical Model and Simulation

7-1 A Review of Basic Soil Constitutive Models for Geotechnical Application

This section focuses on existing constitutive models.

7-1-1 Introduction

Soil performs non-linearly and sometime displays anisotropic and time dependant behaviour when exposed to stresses, that makes soil a complex material. Normally, soil behaves differently in loading, unloading and reloading. It displays non-linear behaviour well below failure circumstance with stress dependant stiffness. Soil experiences plastic deformation and is changeable in dilatancy. Soil also experiences small strain stiffness at very low strains and upon stress reversal. These general behaviour were not perhaps being considered for in simple elastic-perfectly plastic Mohr-Coulomb model, though the model does offer benefits which makes it a favourable option as soil model.

Brinkgreve (2005) discussed with more explanation and details the five principles of soil behaviour. Brinkgreve (2005) investigated the effect of pore water pressure on the behaviour of the soil on effective stresses. Afterward, he surveyed the effective factor which influenced the soil stiffness such as the stress level, stress path (loading and unloading), strain level, soil density, soil permeability, consolidation ratio and the directional-dependant stiffness (stiffness anisotropy) of the soil. Thirdly, he investigated the process of loading and the irreversible deformation. Then he went

through soil strength with its affecting factors such as loading speed of the tested specimen, age and soil density, undrained behaviour, consolidation ratio and directional dependant shear strength (strength anisotropy). Compaction, dilatancy and memory of pre-consolidation stress were the fifth one.

After understanding of soil behaviour, soil failure in three-dimensional state of stress is extremely complicated. Many efforts were made to explain the condition for failure of a material under such a loading condition. Among these three-, four-, and five-parameter model, Mohr-Coulomb model is a two-parameter model with criterion of shear failure and can also be a three parameter model with criterion of shear failure with a small tension cut-off. Refer Figure 7-1.

In order to signify the stress-strain and failure behaviour of soils enormous diversity of models have been developed which have been suggested in recent research. All of these models have certain benefits and restraints which considerably rely on their use. In this regards, Chen (1985) prepared a criteria for model assessment. Considering the main principle of continuum mechanics, the first measure is theoretical assessment of the models to ensure their steadiness, stability and individuality. The verification of the model by using the experimental data is the second, to fit laboratory data from a different available test and the ease of the resolve of the material parameters from standard test data. Using the numerical and computational assessment of the proposed models according computer implementation ability and calculations abilities is the last one.

As a summary, to have a reliable soil model the balance between the requirements from the continuum mechanics point of view and , the necessities of

realistic picture of soil behaviour from the experimental testing point of view (also the convenience of parameters derivation), and the easy numerical usage should be considered. Figure 7-2 shows the basic parts for material models. The Figure 7-1 simply presents the number of existing constitutive model assumptions and principles.

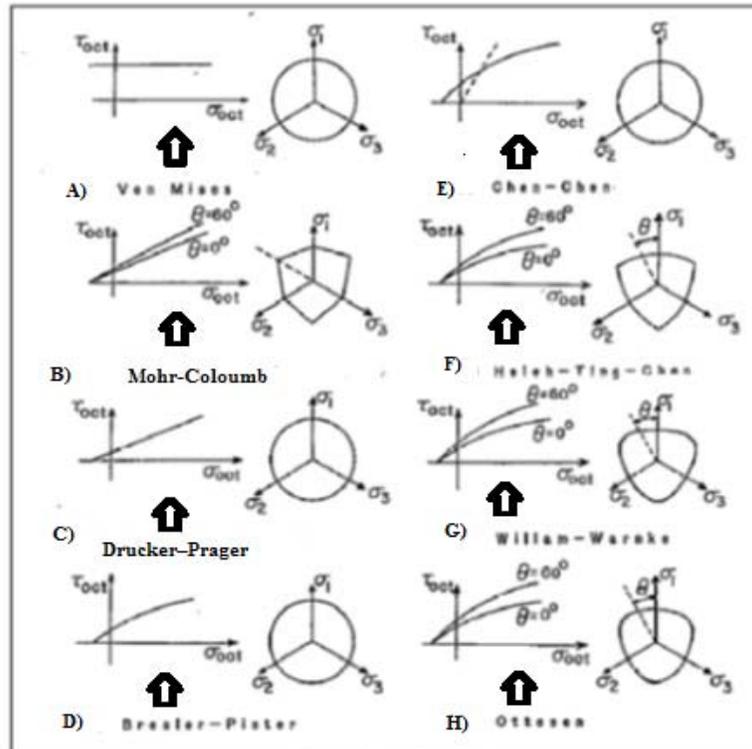


Figure 7-1: Failure models (Chen, 1985)

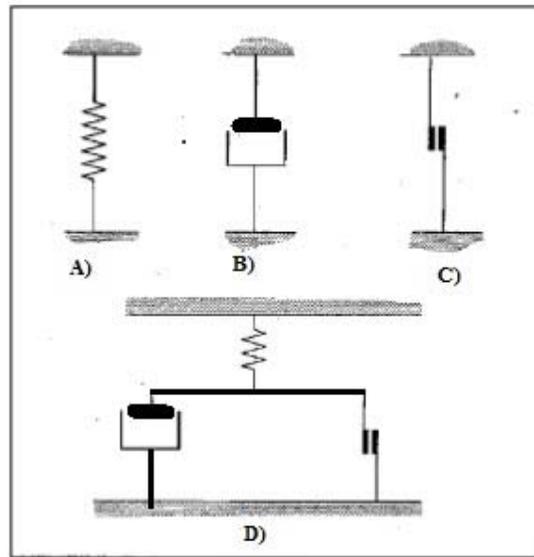


Figure 7-2: Basic components for material models. (A) Spring-reversible linear/nonlinear elasticity.(B) Dashpot-linear/nonlinear creep. (C) Slider-plastic resistance (strain dependant). (D) Possible elastic, viscoplastic assembly.

(Zienkiewicz, 1985).

Brinkgreve (2005) investigated few basic and real soil constitutive models such as Hooke's law, Mohr-Coulomb, Drucker-Prager , Duncan- Chang or Hyperbolic (model), (Modified) Cam Clay, Plaxis Soft Soil (Creep) and Plaxis Hardening Soil Model and the models were summarized according to the model's advantages and limitation." Application of each model was explained briefly in addition to selection of soil parameters from correlation and laboratory testing for application in finite element models. The following sections aims to provide a quick reference on comparison between the soil models collaborated from various researchers in addition to a few more soil models which were not discussed by Brinkgreve (2005); e.g. Hyperelastic model, Hypoelastic model, Viscoelastic model, Viscoplastic model and the Hierarchical Single Surface model". (Kok et al., 2009)

7-1-2 Mohr Coulomb

According to Kok et al., 2009, “Mohr-Coulomb model is an elastic-perfectly plastic model which is often used to simulate soil responses in general and serves as a first-order model (as shown in Figure 7-3). In general stress state, the model’s stress-strain behaves linearly in the elastic range, with two defining parameters from Hooke’s law (Young’s modulus, E and Poisson’s ratio, ν). There are two parameters which construct the Mohr-Coulomb failure criteria (the friction angle, ϕ and cohesion, c) and also a parameter to describe the flow rule (dilatancy angle, which comes from the use of non-associated flow rule which is used to model a realistic irreversible change in volume due to shearing)”.

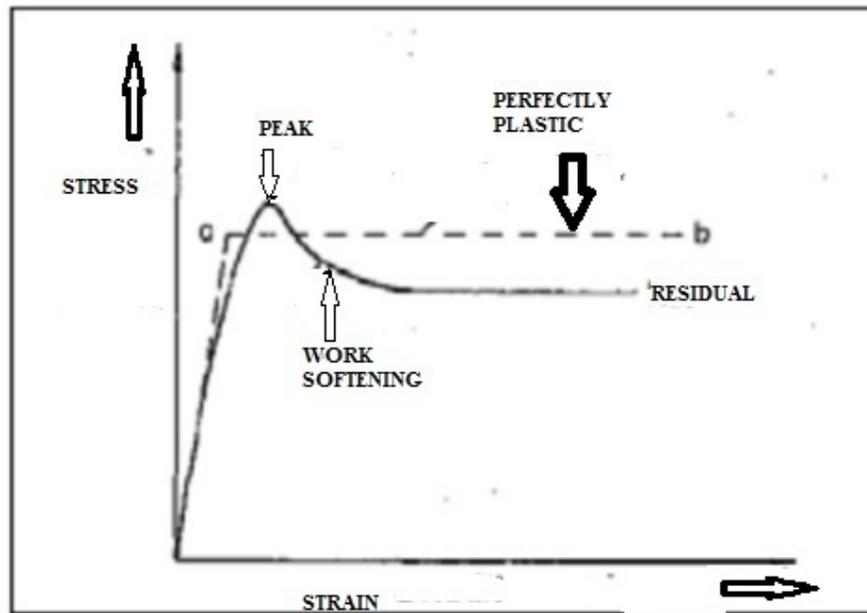


Figure 7-3: Elastic-perfectly plastic assumption of Mohr-Coulomb model. (Kok et al., 2009)

In the conventional plastic theory, the flow rule is used as the evolution law for plastic strain rates. The flow rule is called the associated flow rule and it is different, it is called the non-associated flow rule when the plastic potential function is similar to the yield function. In principles of soil mechanics, associated flow rule has been used to model the behaviour in the region where negative dilatancy is major, for example, the Cam clay model for normally consolidated clay.

According to Kok et al, 2009 “

However, non-associated flow rule is frequently used to describe the behaviour of sands with both negative and positive dilatancy. Mohr-Coulomb model is a simple and applicable to three-dimensional stress space model (Refer Figure 7-4) with only two strength parameters to describe the plastic behaviour. Regarding its strength behaviour, this model performs better. Researchers have indicated by means of true triaxial tests that stress combinations causing failure in real soil samples agree quite well with the hexagonal shape of the failure contour (Goldscheider, 1984). This model is applicable to analyse the stability of dams, slopes, embankments and shallow foundations.” (quoted from Kok et al, 2009)

Kok et al. investigation shows that failure behaviour is generally well captured in drained conditions, the effective stress path that is followed in undrained materials may deviate significantly from observations. It is desirable to use undrained shear parameters in an undrained analysis, with friction angle set equal to zero. The stiffness (hence also deformation) behaviour before reaching the local shear is poorly modelled. For perfect plasticity, model does not include strain hardening or softening effect of the soil. (Kok et al., 2009)

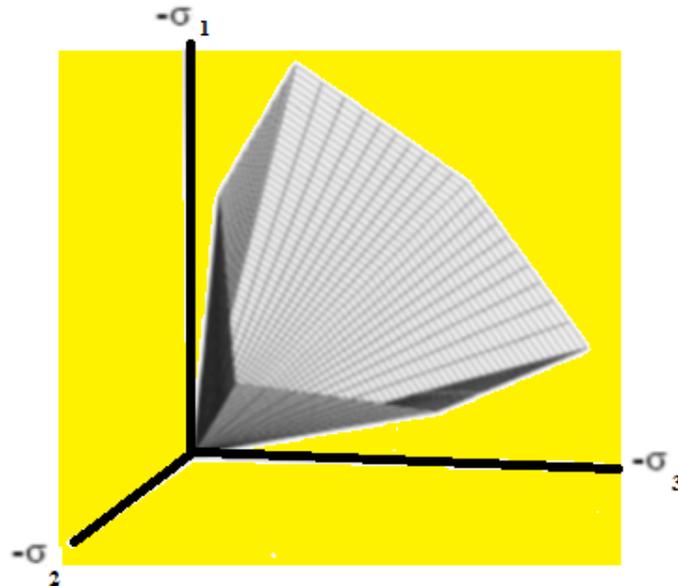


Figure 7-4: The Mohr-Coulomb yield surface in principal stress space ($c = 0$) (Kok et al., 2009)

The overview of Mohr-Coulomb model where the hexagonal shape of the failure cone was replaced by a simple cone was known as the Drucker-Prager model (Drucker and Prager, 1952). As a summary, it has the same advantages and limitations with the Mohr-Coulomb model but at the end model was preferred over this model.

7-1-3 Modified Cam Clay

Some irreversible straining has happened as verified by the fact that reloading leaves a residual strain before the maximum stress has been grasped. Soil might be referred to as a strain hardening material since the onset of plastic yielding is not

synonymous with the maximum stress. A few researchers have investigated the possibility of modelling soil as a strain hardening material, and this has been one of the major thrusts of the soil mechanics group at Cambridge University for the past

thirty years (Roscoe, 1970). Roscoe et al. (1963a) utilized the strain hardening theory of plasticity to formulate a complete stress-strain model for normally consolidated or lightly over-consolidated clay in triaxial test known as the Cam-clay model (Schofield and Wroth, 1968). Burland (1965) suggested a modified version of the Cam-clay model and this model was subsequently extended to a general three-dimensional stress state by Roscoe and Burland (1968).

As Kok et al., 2009 considered in their research, the Modified Cam-clay is an elastic plastic strain hardening model where the non-linear behaviour is modelled by means of hardening plasticity. The model cam clay model is based on Critical State theory and the basic notion that there is a logarithmic association between the mean effective stress, p' and the void ratio, e . Virgin compression and recompression lines are linear in the e - $\ln p'$ space, which is most truthful for near-normally consolidated clays. (Refer Figure 7-5 below).

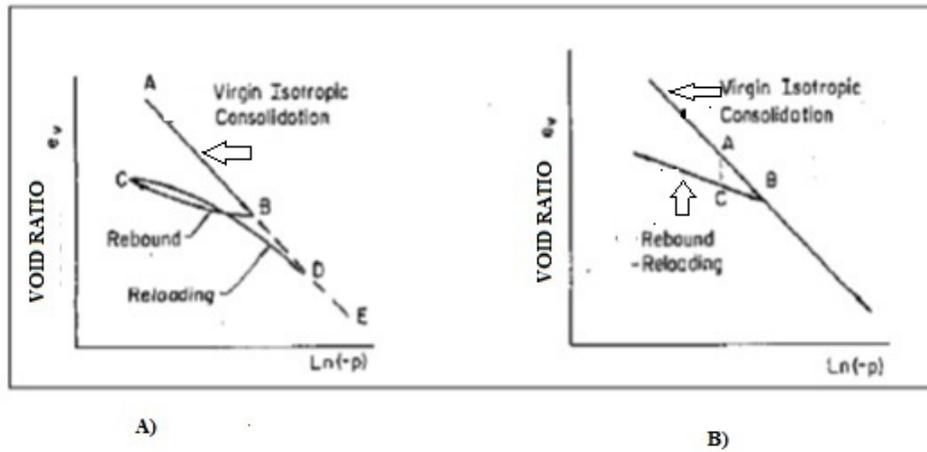


Figure 7-5: (A) Response of real soil to hydrostatic stress; (B) Response of idealized soil to hydrostatic stress. (Kok et al., 2009)

The useful application of Modified Cam Clay model is to label deformation than failure especially for normally consolidated soft soils. One of the model applications is when involving loading conditions such as embankment or foundation. When the case deals with primary undrained deviatoric loading of soft soils, the model prediction is more realistic for undrained shear strength compared to the Mohr-Coulomb model. (Kok et al., 2009)

More over to attain better arrangement between expected and real responses of soil behaviour, a large number of modifications have been made to the standard Cam-clay models over the last two decades. Despite some successes in modifying the standard Cam-clay in the 1980s, the yield surfaces developed in many critical state models considerably overestimate failure stresses on the 'dry side'. These models expected an associated flow rule and therefore were unable to predict an important feature of behaviour that is commonly observed in undrained tests on loose sand and normally

consolidated undisturbed clays, and that is a peak in the deviatoric stress before the critical state is reached. (Kok et al., 2009)

Kok et al.,2009 indicate that the critical state had been much less successful for modelling granular materials due to its inability to predict observed softening and dilatancy of dense sands and the undrained response of very loose sands. The above limitations was indicated by Gens and Potts (1988) where it is also noted that the materials modelled by critical state models appeared to be mostly limited to saturated clays and silts, and stiff over consolidated clays .

The current research is also on clayey soil and therefore according to previous literature, one of the best models to predict the clay behaviour is Modified Cam Clay model. Due to this fact, in this project Modified Cam Clay model will be applied to predict the behaviour of composite clay.

7-2 Modified Cam Clay in details

The following sections investigate the famous Modified Cam Clay model which is used in this project in details.

7-2-1 Introduction

In the previous section, some existing models for soil were discussed. No attempt was made to suggest possible mathematical expressions for the models. In this section, a particular model of soil behaviour is described and used to predict the response of soil specimens in standard triaxial tests. The model was initially called by Roscoe and Burland (1968) as Modified Cam Clay to distinguish it from earlier model of Cam Clay. Both models clarify three important aspects of soil behaviour: (4share.com, 2012)

- (i) Strength
- (ii) Compression or dilatancy, and
- (iii) Critical states in which soil elements can experience infinite deformations without any variations in stress or volume.

A substantial proportion of the volume of a soil contains of voids that may be occupied by air and water. As a consequence, deformations in soil are accompanied by substantial, and often non-reversible, changes in the volume of voids. A major advantage of CC and MCC formulations is their capability to model volume changes more realistically. (4share.com, 2012)

In critical state soil mechanics, the state of a soil sample is characterized by three parameters:

- Specific volume v .
- Effective mean stress p'
- Deviatoric (shear stress) q

The effective mean stress and the deviatoric stress can be defined in terms of principal stresses as: (4share.com, 2012)

$$p' = \frac{1}{3}(\sigma'_1 + \sigma'_2 + \sigma'_3) \quad (7.1)$$

$$q = \frac{1}{\sqrt{2}}\sqrt{(\sigma'_1 - \sigma'_2)^2 + (\sigma'_2 - \sigma'_3)^2 + (\sigma'_3 - \sigma'_1)^2} \quad (7.2)$$

7-2-2 Yield Functions

Under increasing triaxial shear loading, q , Cam Clay and Modified Cam Clay soil assume that behaves elastically until a yield value of q is attained. The yield value is determined by the following equations: (4share.com, 2012)

- a) For Cam-Clay can be expressed as equation (7.3).

$$q + M p' \ln\left(\frac{p'}{p'_0}\right) = 0 \quad (7.3)$$

Where:

M : the slope of CSL (Critical State Line)

p_0' : indicates the size of the current yield locus

b) For Modified Cam-Clay can be expressed as equation (7.4).

$$\frac{q^2}{p'^2} + M^2 \ln \left(1 - \frac{p'}{p_0'} \right) = 0 \quad (7.4)$$

In p' - q space, the CC yield surface is a logarithmic curve while the MCC yield surface plots as an elliptical curve (Figure 7-6). The parameter p_0' (recognized as the yield stress or pre-consolidation pressure) controls the size of the yield surface. The parameter M is the slope of the CSL in p' - q space. A main characteristic of the CSL is that it crosses the yield curve at the point at which the maximum value of q is reached. (4share.com, 2012)

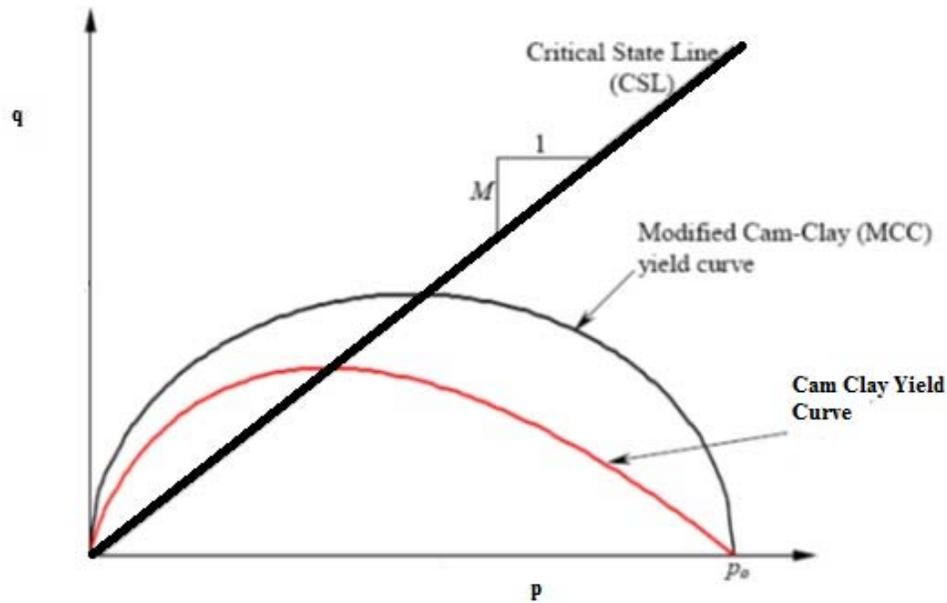


Figure 7-6: Cam-Clay and Modified Cam-Clay yield surfaces in p' - q space.

(4share.com, 2012)

7-2-3 Virgin Consolidation Line and Swelling Lines

The assumption of the models is that when a soft soil sample is gradually compressed under isotropic stress conditions, $\sigma'_1 = \sigma'_2 = \sigma'_3 = p'$, and under fully drained conditions, the association between specific volume, v , and $\ln p'$ is a straight virgin consolidation line (also recognized as the normally consolidated line) and a set of called swelling lines (see Figure 7-7). Swelling lines are also recognized as unloading-reloading lines.

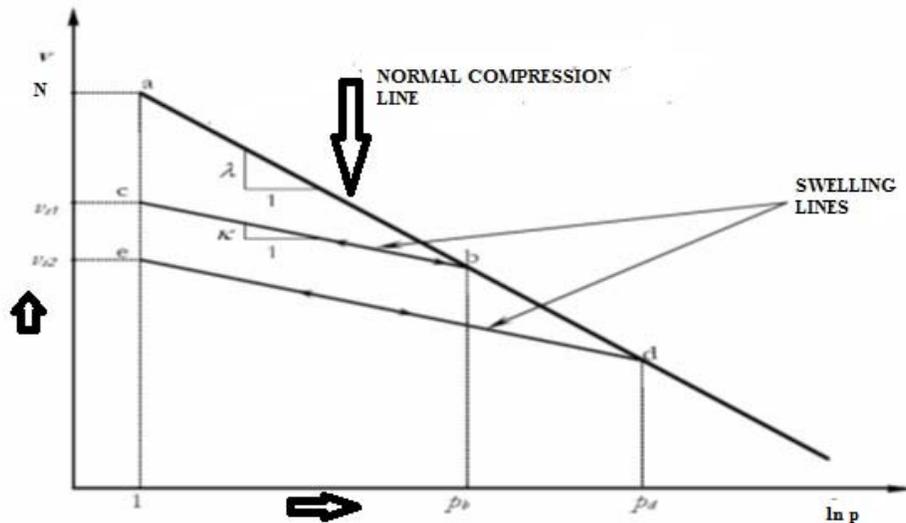


Figure 7-7: Behaviour of sample under loading and unloading (4share.com, 2012))

The loading and unloading behaviour of the CC and MCC models is best explained by an example. When a soil element is first loaded to isotropic stress p'_b , the specific volume is v_b . Upon unloading of the sample, the sample swells and the specific volume changes to v_c which is less than the initial specific volume. This behaviour is shown in $v - \ln p'$ space by ab-bc path. (4share.com, 2012)

If the specimen is reloaded again to a stress p'_d , it will initially move along the swelling line to reach p'_b . Once p'_b is exceeded, the specimen will again move along the virgin consolidation line to point d. If the specimen is then unloaded it will swell and move up along the swelling line to point d. It is obvious that apart of deformation will be irretrievable. (4share.com, 2012)

The virgin consolidation line in Figure 7-7 is expressed by:

$$v = N - \lambda \ln p' \quad (7.5)$$

while a swelling line has a form of:

$$v = v_s - \kappa \ln p' \quad (7.6)$$

The values λ , κ and N are characteristic properties of a particular soil. λ is recognized as the slope of the normal compression (virgin consolidation) line or the critical state line (which is clarified in next section) in v - $\ln p'$ space, while κ is recognized as the slope of the swelling line in v - $\ln p'$ space. N is the specific volume of soil specimen at unit pressure when it is normally consolidated. As can be found on Figure 7-7, v varies for each swelling line, and depends on the loading history of a soil. (4share.com, 2012)

If the current state of a soil specimen is on the virgin consolidation (normal compression) line the soil is defined as being normally consolidated. If the soil is unloaded so that the applied stress on the soil turns out to be less than maximum stress applied on the soil before, the state of the soil is defined to be over-consolidated. (4share.com, 2012)

7-2-4 The Critical State Line

Sustained shearing of a soil sample leads to a state in which further shearing can achieve without any changes in stress or volume. Under this condition, known as the

critical state, the soil deforms at constant stress state. This state is expressed by the Critical State Line (CSL).

The location of this line is under the normal compression line as presented on Figure 7-8. The CSL is parallel to the virgin consolidation line in $v - \ln p'$ space. The parameter Γ is the specific volume of the CSL at unit pressure. (4share.com, 2012)

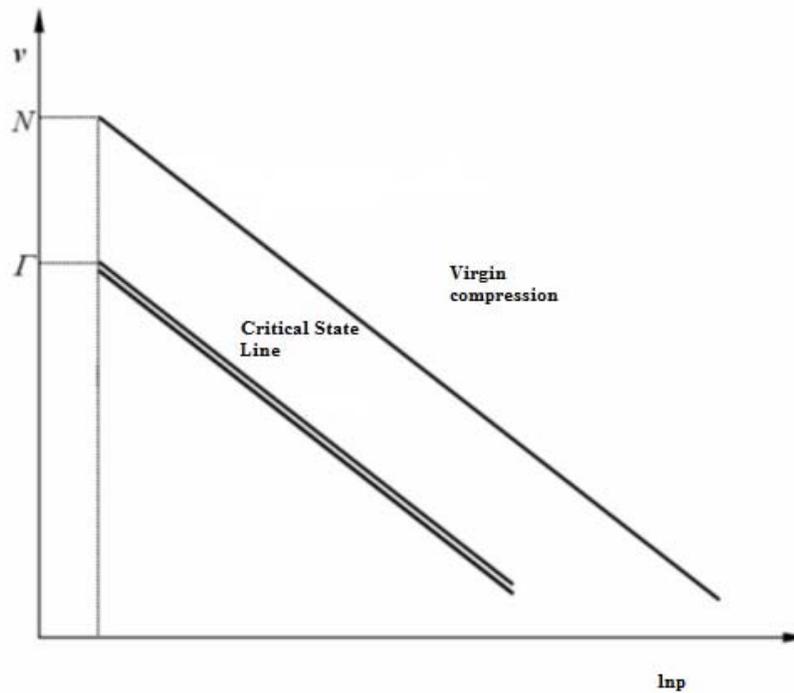


Figure 7- 8: CLS and virgin compression line (4share.com, 2012)

There is a relationship between parameters N and Γ . For the Cam-Clay model the relationship of the two parameters are expressed as equation (7.7)

$$\Gamma = N - (\lambda - \kappa) \quad (7.7)$$

while for the Modified Cam-Clay model the relationship is

$$\Gamma = N - (\lambda - \kappa) \ln 2 \quad (7.8)$$

Due to this relationship between N and Γ , only one of them needs to be known when presenting a Cam-Clay or Modified Cam-Cam material. (4share.com, 2012)

7-2-5 Hardening and Softening Behaviour

If yielding happens to the right of the CSL, hardening behaviour is expected. This side of the yield surface is known as the wet or subcritical side.

Figure 7- 9 explains soil behaviour on the wet side for the case of simple shearing. When a sample is sheared, it behaves elastically until the stress path hits the initial yield surface. From then the size of the yield surface increases and shows hardening behaviour (which results in plastic strain). The Figure 7-9 presents two intermediate changes in the yield surface before failure. At the point C, the sample is at critical state at which it shows continuous shearing under constant load. (4share.com, 2012)

If the stress path hits the yield surface on the left side of the CSL, the soil softens, the size of yield surface shrinks, and the stress path moves toward the CSL (Figure 7- 10).

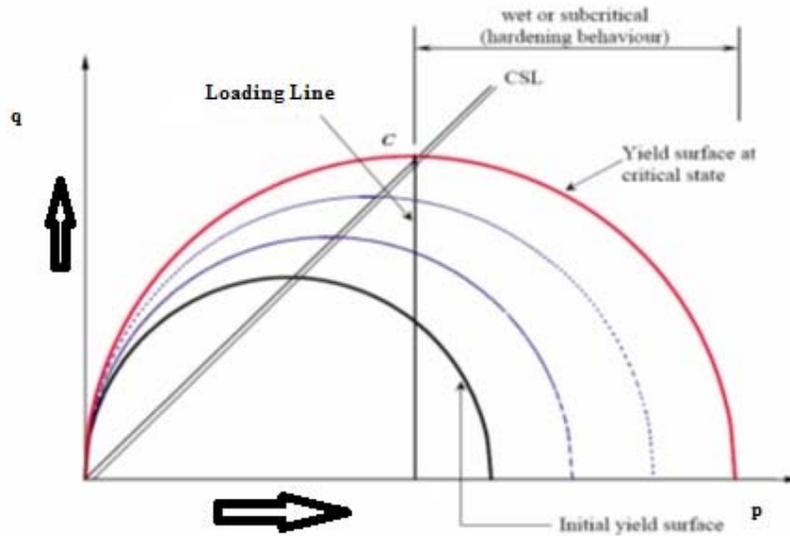


Figure 7- 9: Yield curve on wet side of the modified cam clay (4share.com, 2012)

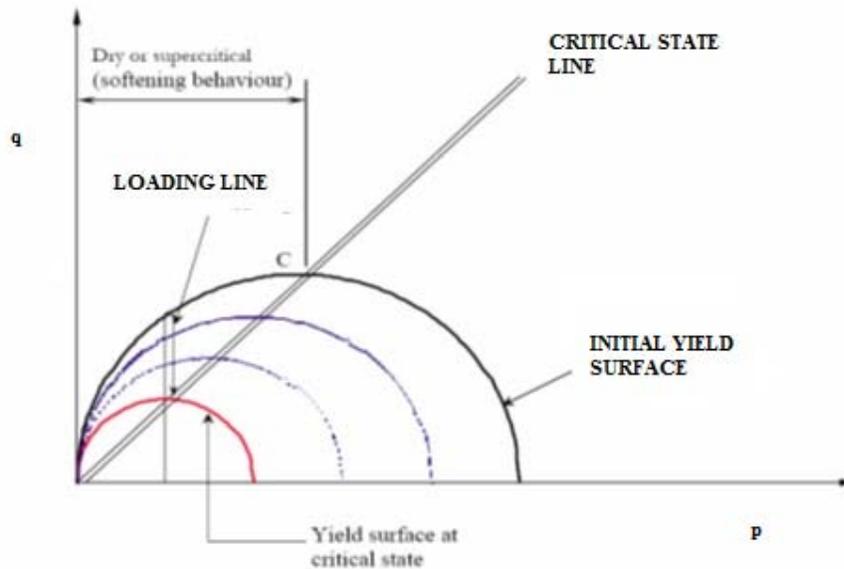


Figure 7- 10: Yield curve on dry side of the modified cam clay (4share.com, 2012)

7-2-6 Elastic Material Constants for Cam-Clay and Modified Cam-Clay

In geotechnical engineering, Young's modulus, E , shear modulus, G , Poisson's ratio, μ , and bulk modulus, K are commonly used to relate stresses to strains, Only two of these properties are sufficient for analysis of deformation. (4share.com, 2012)

For Cam-Clay and Modified Cam-Clay soil models, the deformation moduli are not constant. They depend on mean stress, p' , specific volume, v , and the slope of swelling line, κ . The value of bulk modulus K a stress point can be calculated as: (4share.com, 2012)

$$K = \frac{v p'}{\kappa} \quad (7.9)$$

The Cam-Clay and Modified Cam-Clay formulations also require definition of shear modulus, G , or Poisson's ratio μ . When G is defined the value of μ can be obtained as:

$$\mu = \frac{3K - 2G}{2G + 6K} \quad (7.10)$$

Similar relationship can be established between μ , E and G as:

$$G = \frac{E}{2(1 + \mu)} \quad (7.11)$$

7-2-7 Summary of Input Parameters for Cam-Clay and Modified Cam-Clay

Specification of Cam-Clay and Modified Cam-Clay models needs five soil parameters.

These parameters are presented below. (4share.com, 2012)

1. λ – the slope of the virgin consolidation line or the critical state line (CSL) in v - $\ln p'$ space
2. κ –the slope of a swelling (unloading -reloading) line in v - $\ln p'$ space
3. M – the slope of the CSL in q - p' space
4. Either N or Γ ; where N is the specific volume of the normal compression line at unit pressure and Γ is the specific volume of the CSL at unit pressure
5. Either μ or G where μ is Poisson's ratio and G is shear modulus. (4share.com, 2012)

7-3 Proposed Constitutive Model

The proposed constitutive model will be presented in these sections.

The usual assumptions of the rule of mixtures are:

- each component of a composite satisfies its own constitutive law,
- each component is homogeneously distributed throughout the composite,

- the individual contributions of each component to the overall composite behaviour are scaled according to their volumetric fractions.

Idea of usage of rule of mixture to predict composite clay was derived from its application to metal material, concrete and structural engineering and sandy soil. (Dvorak and Bahei-El-Din, 1982; Dvorak and Bahei-El-Din, 1987 and Voyaiadjis and Thiagarajan, 1995, Diambra et al. 2010)

Based on the literature and physical sens of composite material, the following equation can be derived:

$$v_{total} = v_{soil} + v_{fibre} \quad (7.12)$$

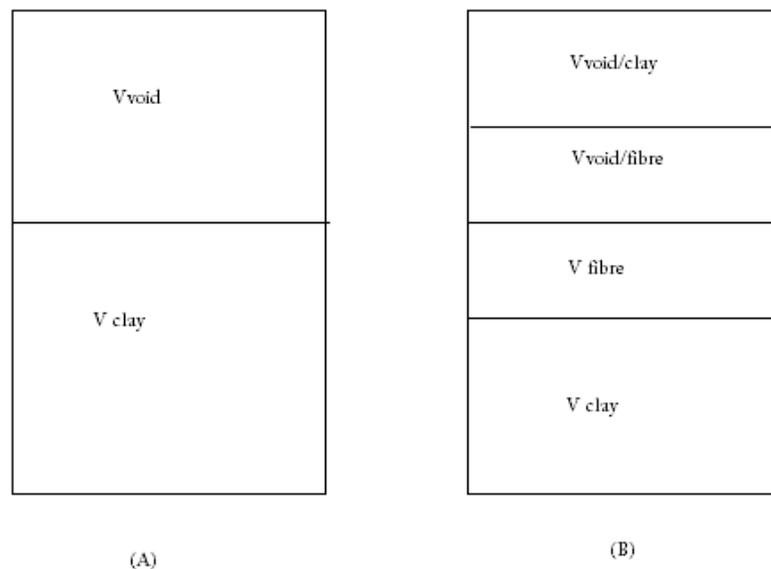


Figure 7- 11: Phase Diagram for (A) Unreinforced Clay (B) Fibre Reinforced Clay

The incremental vector of strain for reinforced clay composite also can be derived as:

$$\varepsilon' = \varepsilon'_{clay} v_{clay} + \varepsilon'_{fibre} v_{fibre} \quad (7.13)$$

The stress state of clay and fibre can be expressed as:

$$\sigma' = [p', q']^T \quad (7.14)$$

$$\sigma_{fibre}' = [p'_{fibre}, q'_{fibre}]^T \quad (7.15)$$

$$\sigma = \sigma'_{clay} v_{clay} + \sigma_{fibre}' v_{fibre} \quad (7.16)$$

The equation (7.14) and (7.15) can be rearranged as:

$$\sigma' = [Clay Matrix] \varepsilon'_{clay} \quad (7.17)$$

$$\sigma_{fibre}' = [Fibre Matrix] \varepsilon'_{fibre} \quad (7.18)$$

Assuming fibre volume of void can be neglected and variation in fibre concentration is zero, then the final incremental stress state equation is:

$$\sigma' = \sigma'_{clay} v_{clay} + \sigma_{fibre}' v_{fibre} \quad (7.19)$$

7-3-1 Clay matrix

An appealing feature of the modelling framework presented here is that any constitutive model for describing the stress–strain behaviour of the sand may be used to obtain the stiffness matrix for unreinforced sand. For the sake of simplicity, the

elastic perfectly plastic Mohr-Coulomb model has been used. In the elastic domain the increments of stresses are related to the increments of strains through the bulk modulus K and the shear modulus G :

$$\begin{bmatrix} \dot{p}' \\ \dot{q}' \end{bmatrix} = \begin{bmatrix} k & 0 \\ 0 & 3G \end{bmatrix} \begin{bmatrix} \dot{\epsilon}_v \\ \dot{\epsilon}_q \end{bmatrix} \quad (7.20)$$

The Cam-Clay and Modified Cam-Clay formulations also require definition of shear modulus, G , or Poisson's ratio μ . When G is defined the value of μ can be obtained as:

$$\mu = \frac{3K - 2G}{2G + 6K} \quad (7.21)$$

Similar relationship can be established between μ , E and G as:

$$G = \frac{E}{2(1 + \mu)} \quad (7.22)$$

$$q' = Mp' \quad (7.23)$$

M is derived from the results of CU tests as presented in Chapter 6.

7-3-2 The fibre stiffness matrix

According to Diambra et al. (2010), the deformation of a single fibre embedded in the composite depends on its orientation. For conventional triaxial conditions, the incremental relationship between the strain at any angle θ from the horizontal (Figure 7-12) can be expressed by:

$$\dot{\epsilon}_{\theta} = \dot{\epsilon}_a \sin(\theta)^2 + \dot{\epsilon}_r \cos(\theta)^2 \quad (7.24)$$

Adopting Voigt's rule along the direction of the fibre, the stress carried by a fibre (behaving elastically with an elastic modulus E_f) oriented at an angle q to the horizontal is then:

$$\sigma_{\theta f} = E_f \dot{\epsilon}_{\theta} \quad (7.25)$$

Applying the above equations into the triaxial condition gives the following equations:

$$\sigma_{af}(\theta) = \sigma_{\theta f} \sin(\theta)^2 \quad (7.26)$$

$$\sigma_{rf}(\theta) = \sigma_{\theta f} \cos(\theta)^2 / 2 \quad (7.27)$$

The equations (7.26) and (7.27) can be rewritten as :

$$\sigma_{af}(\theta) = E_f (\dot{\epsilon}_a \sin(\theta)^4 + \dot{\epsilon}_r \cos(\theta)^2 \sin(\theta)^2) \quad (7.28)$$

$$\sigma_{rf}(\theta) = Ef(\dot{\epsilon}_r \cos(\theta)^4 + \dot{\epsilon}_a \cos(\theta)^2 \sin(\theta)^2)/2 \quad (7.29)$$

The procedure of relating stress of single fibre to fibre distribution will be derived according to Zhu et al. (1994) for single metal-matrix and Diambra et al. (2010) for fibre-sand. The contribution of fibre in clay matrix can be seen in Figure (7-13).

$$\sigma_{af} = \frac{1}{V} \int_V \rho(\theta) \sigma_{af}(\theta) dv \quad (7.30)$$

$$\sigma_{rf} = \frac{1}{V} \int_V \rho(\theta) \sigma_{rf}(\theta) dv \quad (7.31)$$

Then the equation (7.30) and (7.31) can be rewritten as:

$$\sigma_{afibre} = \frac{Ef}{2v_{fibre}} [\dot{\epsilon}_a \int \rho(\theta) \cos(\theta) \sin(\theta)^4 d\theta + \dot{\epsilon}_r \int \rho(\theta) \cos(\theta)^3 \sin(\theta)^2 d\theta] \quad (7.32)$$

$$\sigma_{rfibre} = \frac{Ef}{4v_{fibre}} [\dot{\epsilon}_a \int \rho(\theta) \cos(\theta)^3 \sin(\theta)^2 d\theta + \dot{\epsilon}_r \int \rho(\theta) \cos(\theta)^5 d\theta] \quad (7.33)$$

Equations (7.32) and (7.33) can be written in a matrix format and expanded as:

$$v_{fibre} \begin{bmatrix} \sigma_{af} \\ \sigma_{rf} \end{bmatrix} = E_f f_b \begin{bmatrix} \int_{l_1}^{l_2} \rho(\theta) \cos(\theta) \sin^4(\theta) d\theta & \int_{l_1}^{l_2} \rho(\theta) \cos^3(\theta) \sin^2(\theta) d\theta \\ 1/2 \int_{l_1}^{l_2} \rho(\theta) \cos^3(\theta) \sin^2(\theta) d\theta & 1/2 \int_{l_1}^{l_2} \rho(\theta) \cos^5(\theta) d(\theta) \end{bmatrix} \begin{bmatrix} \dot{\epsilon}_a \\ \dot{\epsilon}_r \end{bmatrix}$$

(7.34)

Where f_b defined according to Machado et al. (2002), Brighenti (2004) and Diambra et al. as a function of bondage between fibre and clay. In this study f_b considered as 1 for fully bonded fibre and 0 for slipped fibre.

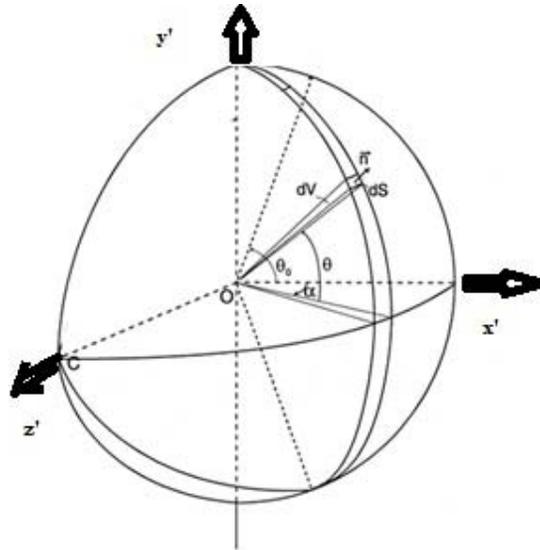


Figure 7-12 Definition of orientation distribution function (after (Michałowski and Čermák, 2002))

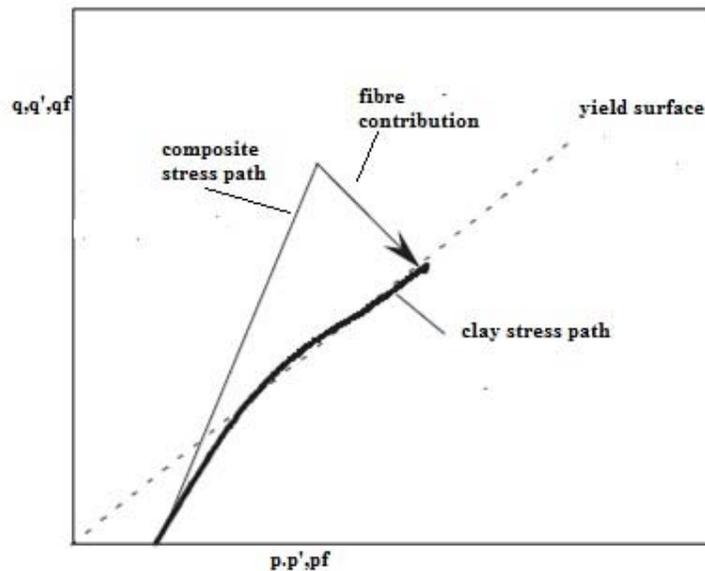


Figure 7- 13 Fibre contribution (after Diambra, 2010)

7-4 Distribution of fibre orientation

The non-uniformity of fibre orientations can affect sample stress–strain behaviour because of the consequent anisotropy. A fibre orientation distribution function may be used to describe this non-uniformity, and can also be used as a modelling tool to explain some of the anisotropic constitutive features of reinforced samples when loaded (Michałowski & Čermač, 2002). One possible form for the fibre orientation distribution function is based on the notion that the distribution is axisymmetric with respect to the axis normal to the compacted layers, which for most practical cases is the vertical axis.

According to Michałowski & Czermańk (2002) and considering same coordinate as Figure 7-12.

$$\rho(\theta) = \rho^-(A + B |\cos \theta^n|) \quad (7.35)$$

where ρ^- is the average volumetric concentration of the fibres, and is defined as the total volume of fibres (V_f) per sample volume (V),

$$\rho^- = \frac{V_f}{V} \quad (7.36)$$

The A and B constant in equation 7.35 can be linked together with (7.37):

$$B = \frac{1-A}{\int_0^{\pi/2} \cos^{n+1}(\theta) d\theta} \quad (7.37)$$

As Michałowski & Czermańk (2002) noted there is no limitation in choosing the orientation function as long as it satisfies the equation of (7.38).

$$\rho^- = \frac{1}{V} \int_V \rho(\theta) dv \quad (7.38)$$

Pattern of solution for orientation function can be seen as Figure (7-14) and (7-15).

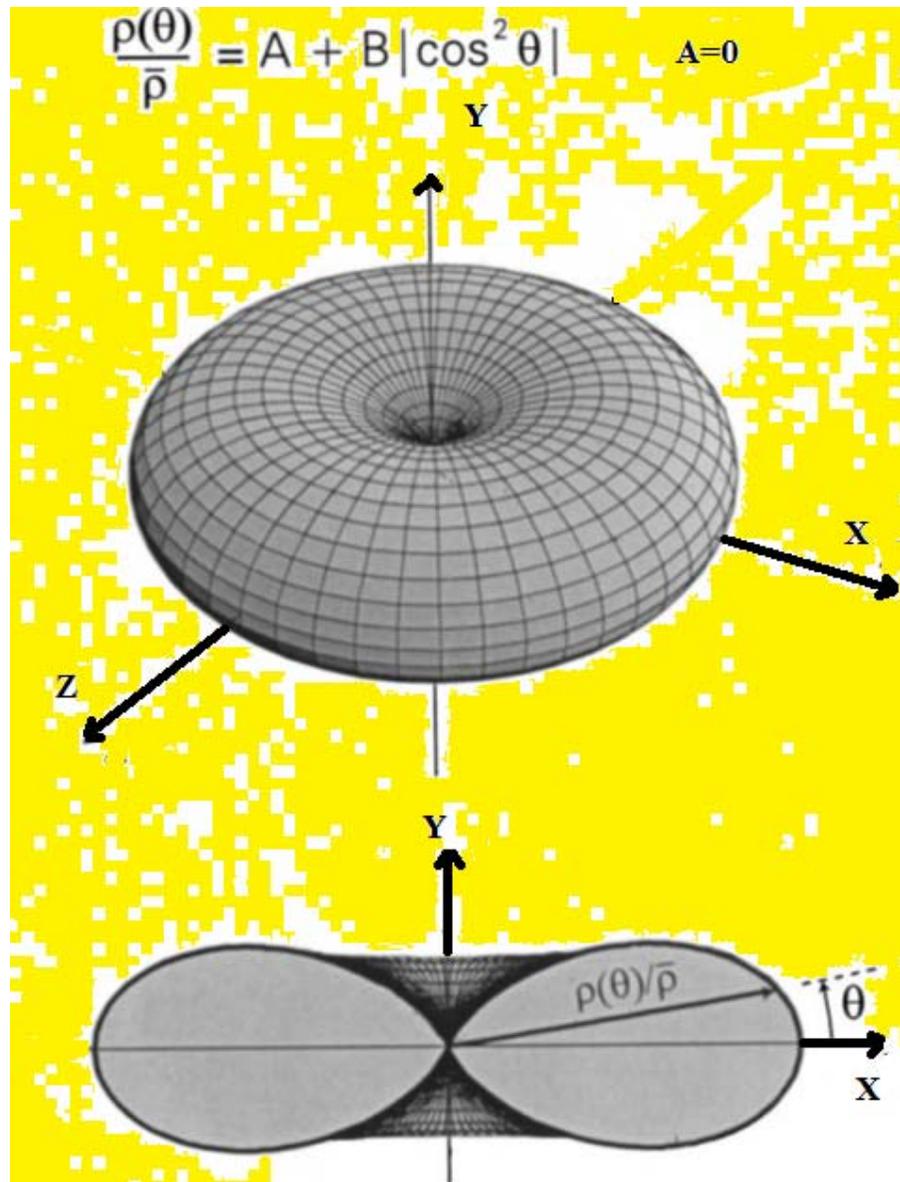


Figure 7- 14 Axisymmetric cosine fibre orientation distribution (after Michałowski & Ċerma'k (2002))

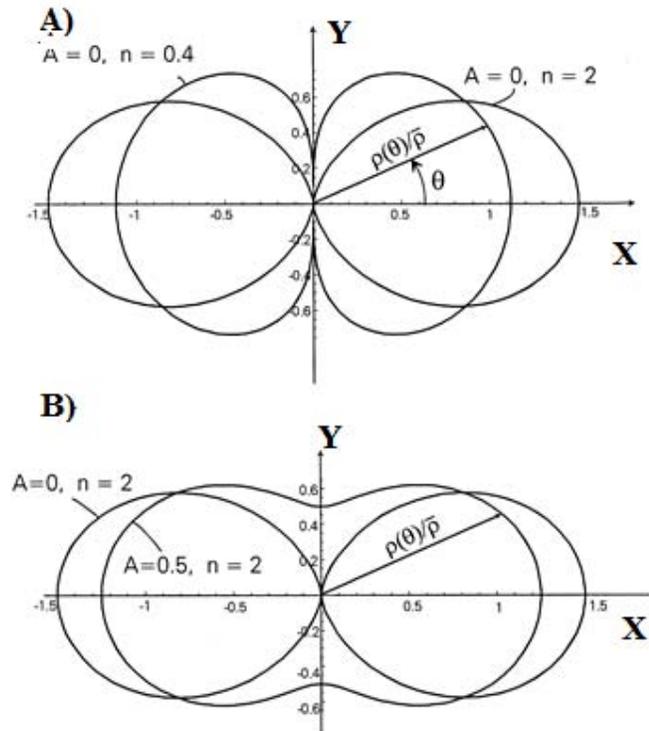


Figure 7- 15 fibre orientation distribution (after Michałowski & C̄erma'k (2002)

A reference sphere is now defined that has a radius R equal to $l_f/2$ and contains only fibres that have a mid-point coinciding with the centre of the sphere. Equation (7.38) can be expanded for this reference sphere by introducing:

$$V = \frac{4}{3} \pi R^3 \quad (7.39)$$

Then volumetric concentration of fibres can be rewritten as:

$$\rho^- = \frac{1}{\frac{4}{3}\pi R^3} \int_{-\pi/2}^{\pi/2} \int_0^{2\pi} \rho(\theta) R^3 \cos(\theta) d\alpha d\theta \quad (7.40)$$

To complete the definition of fibre stiffness task, determination of A and n is vital. The value of B was calculated automatically using equation (7.37).

From the lab samples two cutting plane provided and the number of horizontal and vertical fibre counted the ratio of these two values was used to find the best match with analytical solution similar to Michałowski & Čermač (2002) provided.

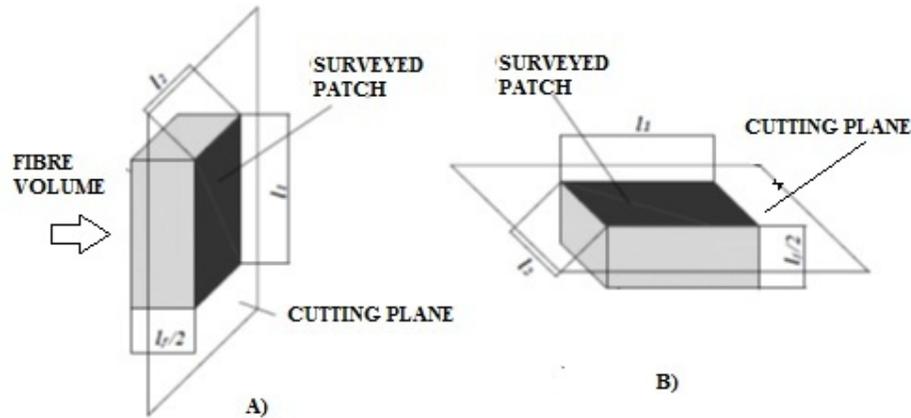


Figure 7- 16 Horizontal and vertical Cutting Plane (after Diambra et al., 2010)

As Diambra et al., 2010 noted the number of horizontal and vertical fibre number can be calculated as:

$$N^H = \frac{4l_1l_2}{V_{1fibre}} \left[\int_0^{l_f/2} \frac{1}{V_{Sphere}} \int_{\pi/2 - \arccos(b/R)}^{\pi/2} \int_0^{2\pi} \rho(\theta) \frac{R^3}{3} \cos(\theta) d\alpha d\theta \right] db \quad (7.41)$$

$$N^V = \frac{16l_1l_2}{V_{1fibre}} \left[\int_0^{\frac{l_f}{2}} \frac{1}{V_{Sphere}} \int_0^{\arccos\left(\frac{b}{R}\right)} \int_0^\alpha \rho(\theta) \frac{R^3}{3} \cos(\theta) d\alpha d\theta \right] db \quad (7.42)$$

Where l_1 and l_2 defined as shown in Figure (7-16).

Diambra et al. (2010) expanded the orientation function for sand as:

$$\rho(\theta) = \rho^- \left(\frac{2AB^2 |\cos \theta|}{(\cos^2 \theta (B^2 - A^2) + A^2)} \right) \quad (7.43)$$

Both functions (i.e. Michałowski & Čermač and Diambra et al.) applied in model and Diambra et al. function performs better for clayey soil. Applying the above principles for the clay reinforced samples prepared in Curtin University laboratory, A calculated to be 0.1 and B=3 for computing $\rho(\theta)$

7-5 Simulation

This section focuses on modelling of the constitutive model and compares the results with laboratory results. According to “MATLAB user manual 2010b,” the MATLAB capabilities and interfaces are:

“

7-5-1 Software overview

MATLAB (matrix laboratory) is a numerical computing environment and fourth-generation programming language. Developed by MathWorks, MATLAB allows matrix manipulations, plotting of functions and data, implementation of algorithms, creation of user interfaces, and interfacing with programs written in other languages, including C, C++, Java, and Fortran.

Although MATLAB is intended primarily for numerical computing, an optional toolbox uses the MuPAD symbolic engine, allowing access to symbolic computing capabilities. An additional package, Simulink, adds graphical multi-domain simulation and Model-Based Design for dynamic and embedded systems.

In 2004, MATLAB had around one million users across industry and academia. MATLAB users come from various backgrounds of engineering, science, and economics. MATLAB is widely used in academic and research institutions as well as industrial enterprises.

Cleve Moler, the chairman of the computer-science department at the University of New Mexico, started developing MATLAB in the late 1970s. He designed it to give his students access to LINPACK and EISPACK without them having to learn Fortran. It soon spread to other universities and found a strong audience within the applied

mathematics community. Jack Little, an engineer, was exposed to it during a visit Moler made to Stanford University in 1983. Recognizing its commercial potential, he

joined with Moler and Steve Bangert. They rewrote MATLAB in C and founded MathWorks in 1984 to continue its development. These rewritten libraries were known as JACKPAC. In 2000, MATLAB was rewritten to use a newer set of libraries for matrix manipulation, LAPACK. MATLAB was first adopted by researchers and practitioners in control engineering, Little's specialty, but quickly spread to many other domains. It is now also used in education, in particular the teaching of linear algebra and numerical analysis, and is popular amongst scientists involved in image processing". (quoted in MATLAB user manual,2012b)

7-5-2 Overview of the MATLAB Environment (quoted in Matlab User Manual,2010b)

According to "MATLAB user manual 2010b," the MATLAB interfaces and environment are:

“

MATLAB is a high-level technical computing language and interactive environment for algorithm development, data visualization, data analysis, and numeric computation. Using the MATLAB product, you can solve technical computing problems faster than with traditional programming languages, such as C, C++, and Fortran.

You can use MATLAB in a wide range of applications, including signal and image processing, communications, control design, test and measurement, financial modeling

and analysis, and computational biology. Add-on toolboxes (collections of special-purpose MATLAB functions, available separately) extend the MATLAB environment to solve particular classes of problems in these application areas.

MATLAB offers a number of structures for recording and distribution the work. The MATLAB code can be combined with other languages and uses, and MATLAB algorithms and applications can be spread in any language. MATLAB Structures include:

- High-level language for technical computing
- Development environment for managing code, files, and data
- Interactive tools for iterative exploration, design, and problem solving
- Mathematical functions for linear algebra, statistics, Fourier analysis, filtering, optimization, and numerical integration
- 2-D and 3-D graphics functions for visualizing data
- Tools for building custom graphical user interfaces
- Functions for integrating MATLAB based algorithms with external applications and languages, such as C, C++, Fortran, Java™, COM, and Microsoft® Excel®”

7-5-3 The MATLAB System

The MATLAB system consists of these main parts. According to “MATLAB user manual 2010b,” MATLAB system consists of the following:

a) Desktop Tools and Development Environment

This part of MATLAB is the set of tools and facilities that help you use and become more productive with MATLAB functions and files. Many of these tools are graphical user interfaces. It includes: the MATLAB desktop and Command Window, an editor and debugger, a code analyzer, and browsers for viewing help, the workspace, and folders.

b) Mathematical Function Library

This library is a vast collection of computational algorithms ranging from elementary functions, like sum, sine, cosine, and complex arithmetic, to more sophisticated functions like matrix inverse, matrix eigenvalues, Bessel functions, and fast Fourier transforms.

c) The Language

The MATLAB language is a high-level matrix/array language with control flow statements, functions, data structures, input/output, and object-oriented programming features. It allows both "programming in the small" to rapidly create quick programs you do not intend to reuse. "Programming in the large" can be conducted to create complex application programs intended for reuse.

d) Graphics

MATLAB has extensive facilities for displaying vectors and matrices as graphs, as well as annotating and printing these graphs. It includes high-level functions for two-dimensional and three-dimensional data visualization, image processing, animation, and presentation graphics. It also includes low-level functions that allow you to fully customize the appearance of graphics as well as to build complete graphical user interfaces on your MATLAB applications.

e) External Interfaces

The external interfaces library allows you to write C/C++ and Fortran programs that interact with MATLAB. It includes facilities for calling routines from MATLAB (dynamic linking), for calling MATLAB as a computational engine, and for reading and writing MAT-files.”(quoted in MATLAB user manual,2012b)

7-6 Model Verification

In this section, the results of simulation and constitutive model are compared with laboratory results for two tests. Generally, the results shows good agreement with laboratory results and the differences in some parts are related to limitation in modelling. (Figure 7-17 to 7-20).

Figure 7-17 is for confining pressure of 100 kPa and 0.2% fibre content which shows that deviatoric stress from the laboratory and the model has a good agreement in general. The Figure 7-18 shows a good prediction of volume strain in model which match with laboratory results. Figure 7-19, again proved the capability of model to predict deviatoric stress for the 200 kPa confining pressure and 0.2% fibre content. Finally, Figure 7-20 proved the ability of the model to predict the volume strain of the composite properly.

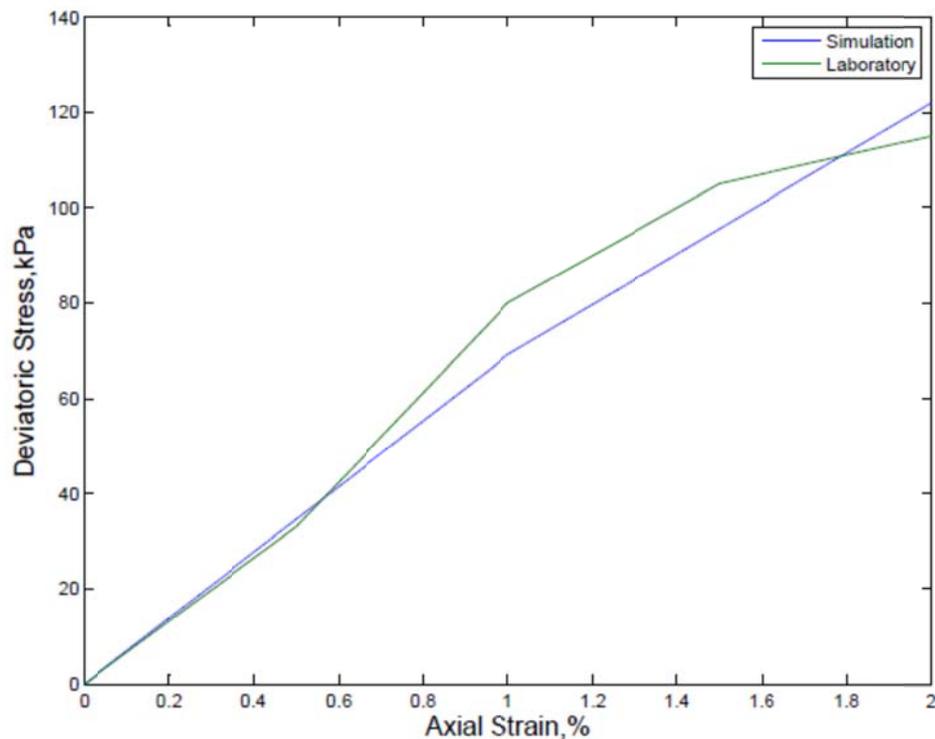


Figure 7- 17 Deviatoric Stress from Simulation and Experimental results for 100 kPa confining pressure and 0.2% fibre

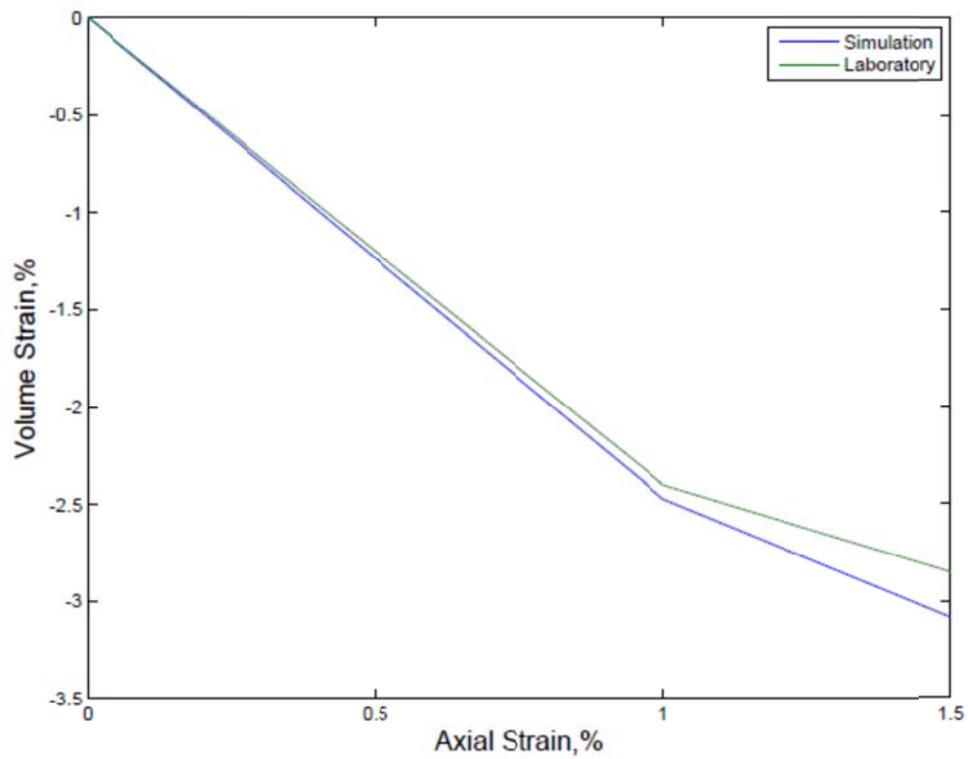


Figure 7- 18 Volume Strain from Simulation and Experimental results for 100 kPa confining pressure and 0.2% fibre

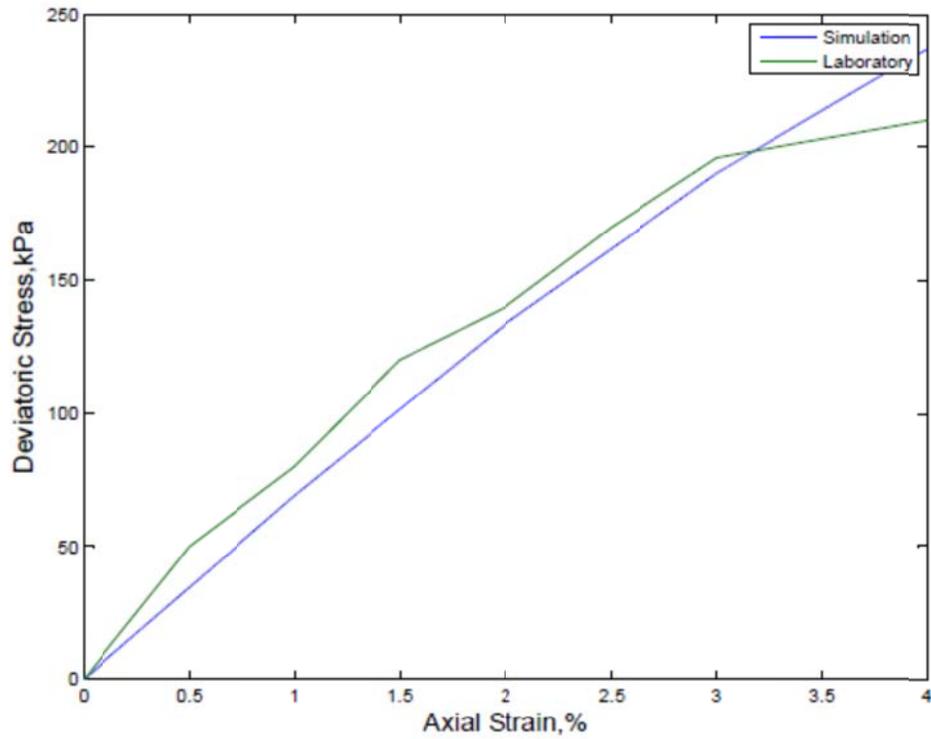


Figure 7- 19 Deviatoric Stress from Simulation and Experimental results for 200 kPa confining pressure and 0.2% fibre

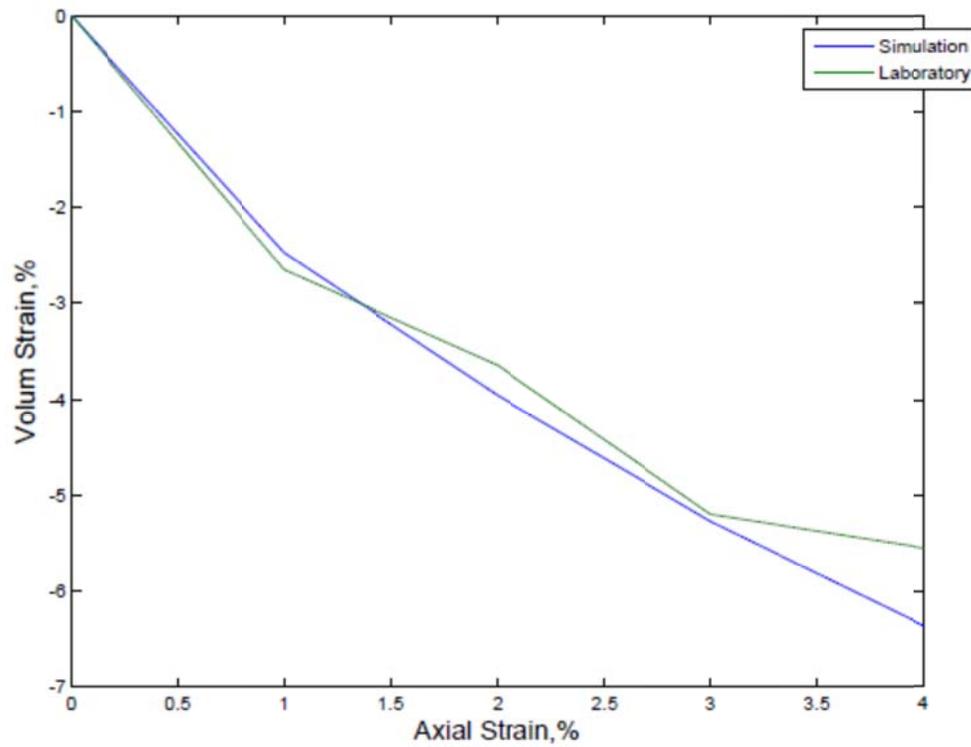


Figure 7- 20 Volume Strain from Simulation and Experimental results for 200 kPa confining pressure and 0.2% fibre

8. Conclusion

8-1 Conclusion

The studied research project investigated the experimental behaviour of the fibre reinforced clay and the offered a constitutive model able to predict samples mechanical response. The experimental tests consisted on testing specimens made up with Prestigious Kaolin Clay in Western Australia and reinforced with short discrete BASF polypropylene fibres which currently widely used in concrete structures. Apart from automated triaxial apparatus, direct shear test, consolidation tests were used to complete the investigation. The summary of conclusions drawn from the research will be presented in following sections.

8-2 Preliminary tests evaluation

As there are little works on reinforced clay due to complexity of the clay behaviour, the preliminary tests provided a good background for further research on reinforced clay. These sets of tests proved that, there are significant effects on behaviour of composite samples due to usage of fibre. Effect of fibre length and fibre content was clearly drawn through the tests and confirmed that usage of plastic fibre will increase the compressive strength of samples dramatically. The results from the consolidation tests also showed that the λ and κ changed due to usage of fibre.

8-3 Triaxial tests evaluation

- More than 20 triaxial tests were performed on clay composite. Results from the drained and undrained triaxial confirmed that shear strength characteristic of the soil in compression are increased.
- There was not significant change in volumetric behaviour of the composite clay samples. However, the volumetric strain was increased slightly due to putting fibre inside the samples.

8-4 Constitutive Modelling evaluation

Constitutive behaviour of fibre reinforced clay in conventional triaxial conditions has been developed. Rule of mixtures applied to derive the constitutive model according to which each constituent follows its own constitutive law. Behaviour of clay has been predicted by use of strong and reliable model of Cam Clay.

A stress-strain relationship for the fibre fraction has been developed by considering a linear elastic model for the describing the tensile behaviour of a single plastic fibre. The stiffness matrix for the fibres requires the calibration of three different components: the fibre elastic modulus, the orientation distribution of fibre, the amount of sliding between fibres and clay. Any distribution of the fibre orientation can be incorporated in the stiffness matrix; however calibration needs to be performed to make it applicable to any special case.

This study proved that application rule of mixture for clayey soil is a reliable procedure which can be taken account as a first step to solve complexity of reinforced clay composite.

8-5 Further Work

Author believes that this research is a significant step to start working on reinforced clay which is hardly acknowledged in literature due to complexity of clay by itself. On other hand, due to degree of freedom of this problem, some of the future works can be conducted to improve the state of art of geotechnical science. The following list addressed some of them:

- To investigate the fibre orientation effect in more detail
- To run triaxial extension tests on clay composite and validate the model
- To improve the constitutive modelling with altering some other factors such as relative density
- To introduce the new sliding function with conducting a new set of experiments
- To examine and run the tests for different types of clay

References

Abdi, M.R., Parsapajouh, Ali and Arjmandi, M. (2004) “Effects of random fibre inclusion on consolidation, hydraulic conductivity, swelling, shrinkage limit and desiccation cracking of clays”, *International Journal of civil engineering* 6 (4), pp. 284–292.

Abdulla, A. and Kioussis, P.D. (1997) “Behaviour of cemented sands-II. Modelling”, *International Journal for Numerical and Analytical Methods in Geomechanics*, 21, pp. 549–568.

Akbulut, S., Arasan, S. and Kalkan, E. (2007) “Modification of clayey soils using scrap tire rubber and synthetic fibres”, *Journal of Applied Clay Science* 38, 23-32.

Allan, M. L., Kukacka, L. E. (1995) “Permeability of microcracked fibre-reinforced containment barriers.” *Waste Management* 15 (2), pp. 171-177.

Al Refeai, T.O. (1991) “Behaviour of granular soils reinforced with discrete randomly oriented inclusions”, *Journal of Geotextiles and Geomembranes* 10, pp. 319–333.

Andersland, O. B. and Khattack, A. S. (1979) “Shear strength of kaolinite/fibre soil Mixture”, *Proc. 1st Int. Conf. on Soil Reinforcement I*, Paris, France, pp. 11-16.

Al Wahab, R. M., and El-Kedrah, M. A. (1995) “Using fibres to reduce tension cracks and shrink/swell in compacted clay”, *Proc. Geoenvironment 2000, ASCE*, New Orleans, 791–805.

- Ang, E.C. and Loehr, J.E. (2003) “Specimen size effects for fiber-reinforced silty clay in unconfined compression”, *Geotechnical Testing Journal* 26 (2), pp. 1–10.
- Attard, M. and Setunge, S. (1996) “Stress–strain relationship of confined and unconfined concrete”, *ACI Material Journal* 93, pp 432–442.
- Bolton, M.D. (1986) “The strength and dilatancy of sands”, *Géotechnique* 36 (1), pp. 65–78.
- Brighenti, R. (2004) “A mechanical model for fibre reinforced composite materials with elasto-plastic matrix and interface debonding”, *Computational Materials Science* 29, pp. 475–493.
- Cai, Y., Shi, B., Charles, W.W. Ng. & Tang, C. (2006) “Effect of polypropylene fibre and lime admixture on engineering properties of clayey soil”, *Engineering Geology* 87, 230–240.
- Car, E., Oller, S. and Oñate, E. (2000) “An anisotropic elastoplastic constitutive model for large strain analysis of fibre reinforced composite materials”, *Computer Methods in Applied Mechanics Engineering* 185, pp. 245–277.
- Consoli, N.C., Prietto, P.D.M. and Ulbrich, L.A. (1998) “Influence of fibre and cement addition on behavior of sandy soil”, *Journal of Geotechnical and Geoenvironmental Engineering* 124 (12), pp. 1211–1214.

- Consoli, N.C., Vendruscolo, M.A., Fonini, A. and Dalla Rosa, F. (2009) “Fibre reinforcement effects on sand considering a wide cementation range”, *Geotextiles and Geomembranes* 27, pp. 196–203.
- Davis, R.O. and Selvadurai, A.P.S. (2002) “*Geotechnic and Plasticity*”, Cambridge University Press
- Di Prisco, C. and Nova, R. (1993) “A constitutive model for soil reinforced by continuous threads”, *Geotextiles and Geomembranes* 12, pp. 161–178.
- Diambra, A., Russell, A.R., Ibraim, E. and Muir Wood, D. (2007) “Determination of fibre orientation distribution in reinforced sands”, *Geotechnique* 57 (7), pp. 623–628.
- Ding, D. and Hargrove, S.K. (2006) “Nonlinear stress–strain relationship of soil reinforced with flexible geofibres”, *Journal of Geotechnical & Geoenvironmental Engineering, ASCE* 132 (6), pp. 791–794.
- Diambra, A., Russell, A.R., Ibraim, E., Muir Wood, D. (2007a) “Determination of fibre orientation distribution in reinforced sand”, *Geotechnique* 57 (7), 623–628.
- Diambra, A., Bennanni, Y., Ibraim, E., Russell, A.R., Muir Wood, D. (2008) “Effect of sample preparation on the behaviour of fibre reinforced sands”,. *In: Proceedings of the 4th International Symposium on Deformation Characteristic of Geomaterials, Atlanta*, pp. 629–636.

- Diambra, A., Ibrahim, E., Muir Wood, D., Russell, A.R. (2010) “Fibre reinforced sands: Experiments and modelling”, *Journal of Geotextiles & Geomembranes. Engineering*, in press
- Dvorak, G.K. and Bahei-El-Din, Y.A. (1982) “Plasticity analysis of fibrous composites”, *Journal of Applied Mechanics* 49, pp. 327–335.
- Fletcher, C. and Humphries, W. K. (1991) “California bearing ratio improvement of remolded soils by the addition of polypropylene fibre reinforcement.”, *National Research Council*, Washington D.C., pp. 80–86.
- Foster, S. and Attard, M. (2001) “Strength and ductility of fibre reinforced high strength concrete column”, *Journal of structural engineering* 127(1), pp. 28–35.
- Freitag, D.R. (1986) “Soil randomly reinforced with fibres”, *Journal of Geotechnical Engineering ASCE* 112 (8), pp. 823–826.
- Fukuda ,H. and Choi, T. (1982) “A probabilistic theory of strength of short-fibre composites with variable fibre length and orientation”, *Journal of Materials Science* 17, pp. 1003–1011
- Gray, D. H. (1970) “Role of woody vegetation in reinforcing soils and stabilizing slopes” *Proc., Symp. on Soil Reinforcement and Stabilizing Techniques*, pp. 253-306.
- Gray, D.H. and Ohashi, H. (1983) “Mechanics of fibre reinforcement in sand”, *Journal of Geotechnical Engineering ASCE* 109 (3), pp. 335–353.

- Gray, D.H. and Alrefeai, T. (1986) “Behavior of fabric-reinforced versus fibre-reinforced sand”, *Journal of Geotechnical Engineering ASCE* 112 (8), pp. 804–820.
- Gregory, G. H. (1999) “Theoretical shear-strength model of fibre-soil composite.” *Proc., ASCE Texas Section Spring Meeting, ASCE, Longview, Tex.*, pp.1–10.
- Harianto, T., Hayashi, S., Du, Y. and Suetsugu, D. (2008) “Effects of fibre additives on the desiccation crack behavior of the compacted akaboku Soil as a material for landfill cover barrier”, *journal of Water Air Soil Pollut* 194, pp. 141–149
- Hoare, D.J. (1979) “Laboratory study of granular soils reinforced with randomly oriented discrete fibres”, *Proceedings of the International Conference on Soil Reinforcement Paris, France* 1, pp. 47–52.
- Ibraim, E., Fourmont, S. (2006) “Behaviour of sand reinforced with fibres”, *In: Ling, H., Callisto (Eds.), Soil Stress–Strain Behaviour: Measurement, Modelling and Analysis, Geotechnical Symp.*
- Ibraim, E., Maeda, K. (2007) “ Numerical analysis of fibre-reinforced granular soils”. *In: Taylor, Francis (Eds.), Proceedings of 5th International Symposium on Earth Reinforcement. Balkema*, pp. 387–393.
- Jewell, R.A. and Wroth, C.P. (1987) “Direct shear tests on reinforced sand”, *Géotechnique* 37 (1), pp. 53–68.

- Jang, B. Z.; *Advanced Polymer Composites: Principles and Applications*, ASM International, Materials Park, OH, 1994.
- Kaniraj, S. R., Havanagi, V. G. (2001). "Behaviour of cement-stabilized fibre reinforced fly ash-soil Mixtures", *Journal of Geotech. and Geoenvironmental. Engineering* 127 (7), pp. 574-584.
- Kok Sien Ti, Bujang B.K. Huat, Jamaloddin Noorzaei, Moh'd Saleh Jaafar, A Review of Basic Soil Constitutive Models for Geotechnical Application, *EJGE journal*, 2009
- Kumar, S. and Tabor, E. (2003) "Strength characteristics of silty clay reinforced with randomly oriented nylon fibres.", *Electronic Journal of Geotechnical Engineering (EJGE)*.
- Li, C., and Zornberg, J.G. (2003) "Validation of discrete framework for fibre-reinforcement", *Proceedings of the 2003 North American Conference on Geosynthetics*. Winnipeg, Canada, pp. 285-293
- Miller, J. and Rifai, S. (2004) "Fiber reinforcement for waste containment soil liners", *Journal of Environmental Engineering* 130(8), pp. 891-896
- Mizanur Rahman, M., Mubarak, A.K.M. and Khan, A. (2007) "Influences of various surface pretreatments on the mechanical and degradable properties of photografted oil palm fibres", *Journal of Applied Polymer Science* 105 (5), pp. 3077–3086.
- Maher, M.H. and Gray, D.H. (1990) "Static Response of sands reinforced with randomly distributed fibres", *Journal of Geotechnical Engineering ASCE* 116 (11), pp. 1661–1677.
- Maher, M.H. and Ho, Y.C. (1994) "Mechanical properties of kaolinite/fiber soil composite", *Journal of Geotechnical Engineering* 120 (8) (1994), pp. 1381–1393.

- Michalowski, R.L. and Zhao. (1996) “A. Failure of unidirectionally reinforced composites with frictional matrix”, *Journal of Engineering Mechanics ASCE* 122 (11), pp. 1086–1092.
- Michalowski, R.L. and Cermák, J. (2003) “Triaxial compression of sand reinforced with fibres”, *Journal of Geotechnical and Geoenvironmental Engineering* 129 (2), pp. 125–136.
- Montoya, E., Vecchio, F., Sheikh, sh. (2006) “Compression field modelling of confined concrete: constitutive models” *Journal of Materials in Civil Engineering*, 18(4), pp.52-63
- Nataraj, M.S. and McManis, K.L. (1997) “Strength and deformation properties of soils reinforced with fibrillated fibres”, *Geosynthetics International* 4 (1), pp. 65–79.
- Odian, George; Principles of Polymerization, 3rd ed., J. Wiley, New York, 1991.
- Ozkul, Z. H., and Baykal, G. (2007) “Shear behavior of compacted rubber fibre–clay composite in drained and undrained loading.”, *Journal of Geotechnical and Geoenvironmental Engineering ASCE* 7, pp. 767–781.
- Park, S.S. (2009) “Effect of fibre reinforcement and distribution on unconfined compressive strength of fibre-reinforced cemented sand”, *Geotextiles and Geomembranes* 27, pp. 162–166.
- Prabakar, J. and Sridhar, R.S. (2002) “Effect of random inclusion of sisal fibre on strength behaviour of soil”, *Construction and Building Materials* 16 (2), pp. 123–131.

- Puppala, A. J. and Musenda, C. (2000) "Effects of fibre reinforcement on strength and volume change in expansive soils", *Transportation Res. Rec.*(1736), pp.134- 140.
- Ranjan, G., Vasan, R.M. and Charan, H.D. (1996) "Probabilistic analysis of randomly distributed fibre-reinforced soil", *Journal of Geotechnical Engineering ASCE* 122 (6), pp. 419–426.
- Rifai, S. and Miller, C. (2009) "Theoretical assessment of increased tensile strength of fibrous soil undergoing desiccation", *Journal of Geotechnical and Geoenvironmental Engineering* 135(12), pp. 1857-1862
- Soil mechanics, T. William Lambe, Robert V. Whitman, 1961, Wiley and Sons
- Sivakumar Babu, G.L., Vasudevan, A.K. and Haldar, S. (2008) "Numerical simulation of fibre-reinforced sand behaviour", *Geotextiles and Geomembranes* 26, pp. 181–188.
- Tang, C.S., Shi, B., Gao, W., Chen, F.J. and Cai, Y.S. (2007) "strength and mechanical behavior of short polypropylene fibre reinforced and cement stabilized clayey soil", *Geotextiles and Geomembranes* 25 (3), pp. 194–202.
- Villard, P., Jouve, P., Riou, Y. (1990) " Mode lisation du compertment mecanique du Texsol." *Bulletin liaison Labo. P et Ch* 168, pp. 15–27.
- Viswanadham, B., Phanikumar, B.R., Mukherjee, R., (2009) "Swelling behaviour of a geofiber-reinforced expansive soil", *Geotextiles and Geomembranes* 27, pp.73–76
- Waldron, L. J. (1977). "Shear resistance of root-permeated homogeneous and stratified soil." *Soil Society. Of American Journal*41 (5), pp. 843–849.
- Wu, T. H., Beal, P. E., Lan, C. (1988) "In situ shear test of soil-root system." *Journal of*

Geotech Engineering ASCE 114 (12), pp. 1376-1394.

Yetimoglu, T. and Salbas, O. (2003) “A study on shear strength of sands reinforced with randomly distributed discrete fibres”, *Geotextiles and Geomembranes* 21 (2), pp. 103–110.

Ziegler, S., Leshchinsky, D., Ling, H. I. and Perry, E. B. (1998) “Effect of short polymeric fibres on crack development in clays”, *Soils and Foundations* 38 (1), pp. 247–253.

Zornberg, J. G., Cabral, A. R. and Viratjandr, C. (2004) “Behavior of tire shred-sand mixtures”, *Canadian Geotechnical Journal* 41 (2), pp. 227–241.

Zornberg, J. G. (2002) “Discrete framework for limit equilibrium analysis of fibre-reinforcement”, *Geotechnique Journal* 52 (8), pp. 227–241.

Mechanical Properties of Polymers, viewed 1 January 2012, <http://pslc.ws/macrog/mech.htm>

Site Investigation by C.R.I. Clayton, M.C. Matthews and N.E. Simons, Viewed 1 January 2012, <http://www.geotechnique.info/SI/SI%20Book%20Chapter%208.pdf>

Site Investigation, C.R.I. Clayton, M.C. Matthews and N.E. Simons, 1995, Oxford [England]; Cambridge, Mass., USA: Blackwell Science, 1995. vii, 584 p. , ISBN 0632029080

Permeability Test, Lecture note, Viewed December 2011, http://faculty.fullerton.edu/btiwari/geotech_Lab/mainpage_files/other/Permeability.pdf

Compaction test , Lecture Note, Viewed November 2011,
http://www.uta.edu/ce/geotech/lab/Main/Soil%20Lab/06_Standard%20and%20modified%20compaction%20test/Standard%20Proctor%20Compaction%20Test.pdf

Description of Cam-Clay and Modified-Cam-Clay Critical State Strength, viewed January 2012, Models http://dc196.4shared.com/doc/VwXbnCT_/preview.html

Every reasonable effort has been made to acknowledge the owners of copyright material. I would be pleased to hear from any copyright owner who has been omitted or incorrectly acknowledged

Investigation On Compaction Characteristics Of Reinforced Soil

Amin Chegenizadeh ^{1, a}, Prof. Hamid Nikraz ^{2, b}

¹PhD candidate, Department of Civil Engineering, Curtin University of Technology, Perth, Australia; Tel: +61-413165961; Fax: +61 8 9266 2681

²Prof. Hamid Nikraz, Head of the Department of Civil Engineering, Curtin University of Technology, Perth, Australia; Tel: +61 8 9266 7573; Fax: +61 8 9266 2681

a Email: amin.chegenizadeh@postgrad.curtin.edu.au,

b Email: H.Nikraz@curtin.edu.au

Keywords: Reinforced soil, Compaction, Fiber.

Abstract. Composite soils have been widely used in civil engineering applications, especially in slopes, embankment dam and landfills. This paper aims to investigate effect of fiber inclusion on compaction characteristic of composite soil (i.e. clay composite). A series of laboratory tests carried out to evaluate fiber effect on optimum water content and maximum dry unit weight of composite soils. Clay was selected as soil part of the composite and plastic fiber was used as reinforcement. The fiber parameters differed from one test to another, as fiber length varied from 10 mm to 35mm and fiber content were selected as 0.1% and 0.4%. For each test, compaction curved derived and the results were compared. The results proved that inclusion of fiber affected compaction behaviour of samples so that increasing in fiber content and length caused increasing in Optimum Moisture Content (OMC) and slightly decreased maximum dry unit weight.

Introduction

Fletcher and Humphries (1991) investigated influence of fiber inclusion on compaction of silty clay soil. Unlike the case of sandy gravel reported by Hoare (1977), the test results indicated that increasing the fiber content causes a modest increase in the maximum dry unit weight. The optimum water content was found to decrease by increasing fiber content. Other researchers (Nataraj and McManis, 1997; Al Wahab and El-Kedrah, 1995; Puppala et al., 2006; Miller and Rifai, 2004; Ozkul et al., 2007; Kumar Tabor, 2003) also reported similar results. Figure 21 shows results from Miller and Rifai (2004). In contrast, other researcher such as Ozkul et al, 2007 reported not significant changes on compaction parameter by fiber inclusion. Therefore, the problem of effect of fiber inclusion needs to be investigated precisely. Authors believe that different results are due to different material each researcher has used. This paper aims to investigate influences that are induced by fiber inclusion.

Material

Composite materials consist of two parts. The first part is soil part which can be dealt as normal soil. The second part is reinforcement part which can be made up of any material which helps soil to have better performance. Reinforcement expects to work in tensile.

Soil Type

The soil type in this study was kaolin clay. The properties of kaolin clay are presented in table 1.

No.	Type	
1	Soil type	Clay
2	Liquid Limit	49
3	Plastic Limit	23
4	Pl. Index	26

Fiber Type

The plastic fiber has been used for this investigation. Figure1 shows the used fiber. Good adhesion with soil part can be named as major advantage of this plastic fiber.



Fig. 1 Plastic fiber

Test program

A series of compaction tests have been conducted. The results of the tests have been presented and well discussed.

Compaction Test Principle

Soil compaction is a mean to increase the density of soil. In geotechnical projects, soil density is a important parameter. Any difficulty related to compaction may cause settlement of the soil and as a consequence unnecessary maintenance costs or structure failure will be needed. Therefore, all types of construction sites and construction projects use mechanical compaction method Figure 2 shows the difference between compacted and loose soil.

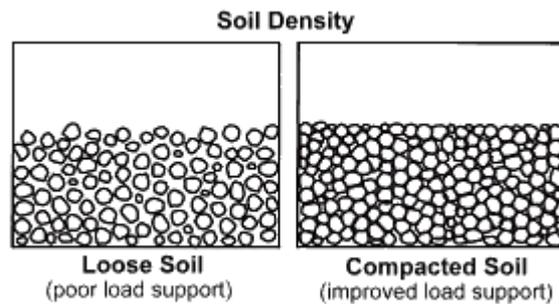


Fig. 2 Structure of loose and compacted soil (Online compaction handbook, 2010)

Effect of Moisture on Compaction Procedure

To compact properly moisture content is vital. Moisture plays as a lubricant within soil, sliding the particles together. If moisture content is very low amount that means inadequate compaction - the particles cannot slip well to achieve density. In contrast, if moisture is too high then weakens the load-bearing ability. The maximum density for most soils is at a specific water content for a given compaction effort. Therefore, the drier the soil is more unsuitable for compaction.

Compaction Methods

The standard compaction Test determines the maximum density of a soil needed for a specific project. Standard compaction method is widely used in geotechnical engineering. Figure 3 shows the technical specification for standard compaction method.

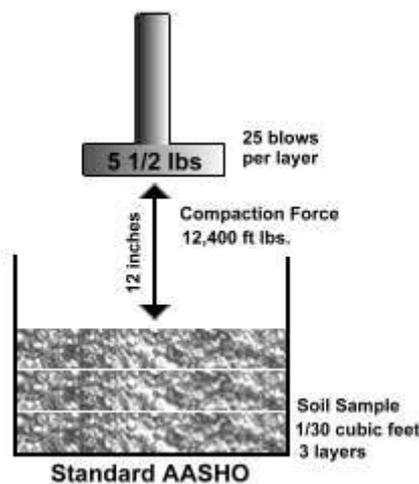


Fig. 3 Standard compaction sketch (Online compaction handbook,2010)

Main Equipments

1. Proctor mould with a detachable collar assembly and base plate.
2. Manual rammer weighing 2.5 kg and equipped with height of drop to a free fall of 30 cm.
3. Sample Extruder.
4. A sensitive balance.
5. Straight edge.

8. Moisture cans.
9. Drying Oven

Test Methodology and Procedure

- About 4.5 kg of air-dried soil was put in the mixing pan so that it could pass No. 4 sieve.
- The moisture content was increased by about 5%.
- The weight of empty mould without the base plate and the collar was recorded as W1(gr).
- The collar and base plate was fixed and the first soil part was compacted with 25 blows in proctor mould
- Some scratches were put with a spatula forming a grid to ensure uniformity in distribution of compaction energy to the subsequent layer. The second and third layer was placed and 25 blows were applied.
- The final layer was placed so that the compacted soil is just above the rim of the compaction mould when the collar is still attached.
- The collar carefully was detached without disturbing the compacted soil inside the mould and edge was used to trim the excess soil leveling to the mould.
- The weight of the mould with the moist soil W2, (gr) was determined.
- Sample was extruded the sample and evaluated for water content in some cans
- The rest of the compacted soil was broken with hand to pass US Sieve No.4. and moisture content was increased by 2%.
- Repeat previous steps for different moisture contents.
- The dry density plotted versus moisture contents.

Results and discussions

The results of laboratory investigation are presented in this section. As the tests were designed systematically the effect of each fiber parameter can be observed in this study. The first engineering graph is related to effect of fiber dosage on compaction curve of composite soil. Respectively, second part is focused on effect of fiber length (aspect ratio) on soil composite compaction characteristics.

The results from laboratory compaction test were interpreted and figure 4 shows the effect of fiber content on maximum dry density and optimum moisture content while the fiber length kept constant at 10mm. Respectively, figure 5 indicates effect of fiber length on maximum dry density and optimum moisture content while the fiber content is constant at 0.4%.

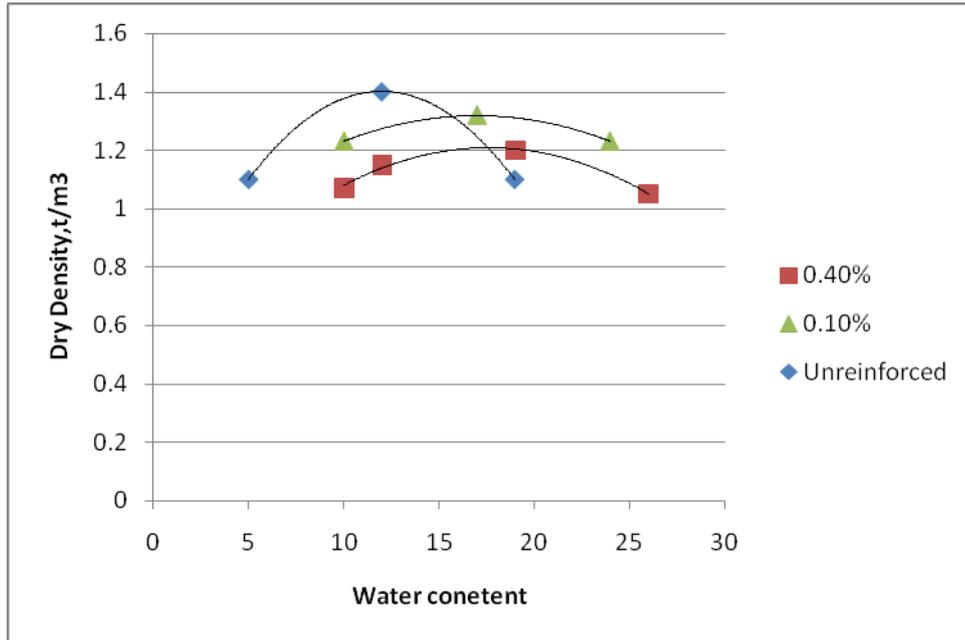


Fig. 4 Effect of fiber content on compaction curve (fiber length 10mm)

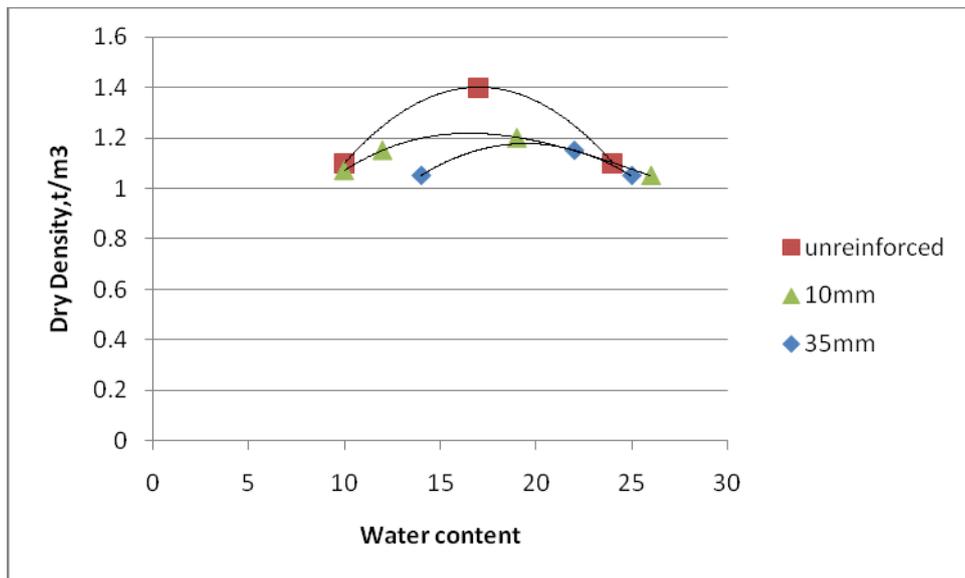


Fig. 5 Effect of fiber length on compaction curve (at fiber content 0.4%)

Conclusion

Compaction tests were performed on composite clay. This investigation proved that:

- 1- Induction of fiber caused decrease in maximum dry density
- 2- Optimum Moisture Content (OMC) increased with increasing in fiber content
- 3- Increasing in compaction effort causes increasing maximum dry density; this fact was observed for composite soil as well.

4-Plastic fiber showed to be good material to be used in practical projects

Acknowledgement

The technical support from the Curtin University Laboratory is gratefully acknowledged.

Reference

- [1] AlWahab, R.M. and Al Quirma, H.H. (1995) Fiber Reinforced Cohesive Soils for Application in Compacted Earth Structures, Proceedings of Geosynthetics '95, IFAI, Vol. 2, Nashville, Tennessee, USA, March 1995, pp. 433-476.
- [2] Al Wahab, R. M., and El-Kedrah, M. A. (1995) Using fibers to reduce tension cracks and shrink/swell in compacted clay, Proc. Geoenvironment 2000, ASCE, New Orleans, 791–805.
- [3] Fletcher, C.S. and Humphries, W.K. (1991) California Bearing Ratio Improvement of Remoulded Soils by the Addition of Polypropylene Fiber Reinforcement, Transportation Research Record 1295, Washington, DC, USA, pp. 80-86.
- [4] Gray, D.H. and Ohashi, H. (1983) Mechanics of Fiber Reinforcement in Sand, Journal of Geotechnical Engineering, Vol. 109, No. 3, pp. 335-353.
- [5] Kumar, Kanaujia and Chandrad (1983) Fiber-Reinforced Pond Ash and Silty Sand , Geosynthetic international S 1999, VOL. 6, NO. 6
- [6] Maher, M.H. and Gray, D.H. (1990) Static Response of Sands Reinforced with Randomly Distributed Fibers, Journal of Geotechnical Engineering, Vol. 116, No. 11 pp. 1661-1667.
- [7] Maher, M.H. and Ho, Y.C. (1964) Mechanical Properties of Kaolinite/Fiber Soil Composite, Journal of Geotechnical Engineering, Vol. 120, No. 8, pp. 1981-1993.
- [8] Nataraj, M.S. and McManis, K.L. (1997) Strength and Deformation Properties of Soils Reinforced with Fibrillated Fibers, Geosynthetics International, Vol. 4, No. 1, pp. 65-79.
- [9] Ozkul, Z. H., and Baykal, G. (2007) Shear behavior of compacted rubber fiber–clay composite in drained and undrained loading, Journal of Geotechnical and Geoenvironmental Engineering ASCE 7, pp. 767–781.
- [10] Online Compaction handbook, http://www.concrete-catalog.com/soil_compaction.html, 2010
- [11] Sivakumar Babu, G.L., Vasudevan, A.K. and Haldar, S. (2008) Numerical simulation of fiber-reinforced sand behaviour, Geotextiles and Geomembranes 26, pp. 181–188.
- [12] Yetimoglu, T. and Salbas, O. (2003) A study on shear strength of sands reinforced with randomly distributed discrete fibers, Geotextiles and Geomembranes 21 (2), pp. 103–110.

- [13] Ziegler, S., Leshchinsky, D., Ling, H. I., and Perry, E. B. (1998) Effect of short polymeric fibers on crack development in clays. *Soils and Foundations*, Vol. 38, No. 1, pp. 247-253.
- [14] Zornberg, J. G., Cabral, A. R. and Viratjandr, C. (2004) Behavior of tire shred-sand mixtures, *Canadian Geotechnical Journal* 41 (2), pp. 227–241.
- [15] Zornberg, J. G. (2002) discrete framework for limit equilibrium analysis of fiber-reinforcement, *Geotechnique Journal* 52 (8), pp. 227–241

Modulus of Elasticity of Reinforced Clay

Amin Chegenizadeh^{1, a}, Prof. Hamid Nikraz^{2, b}

¹PhD candidate, Department of Civil Engineering, Curtin University of Technology, Perth, Australia; Tel: +61-413165961; Fax: +61 8 9266 2681

²Prof. Hamid Nikraz, Head of the Department of Civil Engineering, Curtin University of Technology, Perth, Australia; Tel: +61 8 9266 7573; Fax: +61 8 9266 2681

a Email: amin.chegenizadeh@postgrad.curtin.edu.au,

b Email: H.Nikraz@curtin.edu.au

Abstract. Reinforced soil has been among the most effective soil modification materials. Its use has been expanded rapidly into civil engineering, geotechnical engineering and pavement engineering. Reinforcing subgrade in pavement systems has always been an issue. This study focuses on effect of fibre inclusion on the modulus of elasticity of subgrade material. Plastic fibre was used for this investigation. Fibre contents and aspect ratio have been changed during these tests. The fibre percentage varied from 0 % (for unreinforced samples) to 3%. Clay was used as sub grade material. Unconfined compression tests were carried out to investigate behaviour of the composite under different condition. The fibre length and fibre content found to play important rule on the modulus of elasticity of fibre. Furthermore it was observed that ductility of sample increased by fibre inclusion.

Keywords: Reinforced soil, Unconfined, Strength, Fibre.

INTRODUCTION

In conventional application of reinforcement in soil, the inclusion of tire, bars, grids etc are usually in a preferred orientation. The advances of these materials have usually been considered by an increase in their applications. The randomly discrete fibers are easily added and mixed randomly with soil part, the same way as cement, lime or other additives. Some researches have been done on cement additive (Consoli et.al. 2009; Cai et.al 2006; Lorenzo and Bergado, 2004) and can be used as a pattern of additive usage in soil. Fibre reinforced composite shows more ductility and small losses of peak strength i.e. in compared to unreinforced material. Therefore, fiber-reinforced soil composite is a practical solution in civil engineering projects. The main application of composite soil can be in embankment, subgrade, subbase, and slope stability problems. However, the data concerning the effects of fiber inclusion on the characteristics of compacted native or virgin soils are limited, (Maher and Ho, 1993). This shortage is more considerable in pavement engineering therefore research on fibre inclusion in pavement systems needs to be more performed. As in pavement engineering modulus of elasticity has considerable effect on the design procedure, this study is mainly focused on changes in this parameter due to random fibre inclusion.

MATERIAL

Composite materials consist of two parts. The first part is soil part which can be dealt as normal soil. The second part is reinforcement part which can be made up of any material which helps soil to have better performance.

Soil Type

The soil type in this study was kaolin clay. The properties of kaolin clay are presented in table 1.

Table1. Clay properties

No.	Type	
1	Soil type	Clay
2	Liquid Limit	49
3	Plastic Limit	23
4	Pl. Index	26

Fibre Type

The plastic fibre has been used for this investigation. The fibre properties are presented in table 2. The fibre is commercially available and is called fibre Meyco FIB SP 65 macro structural synthetic polypropylene fibre which generates a very high energy absorption rate when used in the matrix. Figure 1 shows the used fibre.



Fig. 1 Plastic fibre

Table2. fibre properties

No.	Type	
1	Material	Polypropylene
2	Specific Gravity	0.92
3	Width	1.6825 mm

TEST PROGRAM

A series of unconfined compression tests have been conducted to verify effect of fibre content on elasticity modulus.

Unconfined Compression Test Principle

Aim of Unconfined Compression test is to obtain unconfined compressive strength of soil. This can be applied to fine grade and cohesive soil and will represent very fast response in practical condition as the test time is very quick in respect to confined one. This test is widely used for slope stability and embankment dam applications.

Equipment

- Unconfined compression testing machine (Triaxial Machine) as shown in figure 2
- Specimen preparation equipment
- Sample extruder
- fibre
- Balance



Fig. 2 Triaxial machine

Sample Preparation

The samples were prepared by mixing clay and four percentage of fibre. Specimen preparation method was the standard compaction method, which was used in an ongoing experimental research on fiber-reinforced clay at Curtin University. The soils were first oven-dried. The dry soils were then crushed using a hammer. A mixer was used to thoroughly mix the soils with water to obtain the desired water moisture content for compaction. The mixing of soil with fibers was performed mostly by hand rather than using the mixer because the mixer caused the fibers to tangle or break. The fiber-soil mixture was placed in a closed container for 24 hours after mixing was completed. A split mold and a specific hammer were

used to compact the specimen. The specimens were prepared in different fibre content (i.e. 0.5%, 1%, 2%, 3%) and different fibre length (aspect ratio) which were 15mm, 30mm, 65mm.

Test Procedure

1. The specimens were prepared in the laboratory with 90% compaction effort, special care was taken during this process
2. The size of samples were checked to be suitable for the test purpose
3. The samples were put for 24 hours in geotxtile and packed
4. Special attention was applied for preventing any moisture loose
5. The samples were put in triaxial base without any confinement pressure
6. According to ASTM 1.27 mm/min were applied through the tests
7. The data was collected automatically
8. The stress-strain curve plot used for modulus elasticity investigation

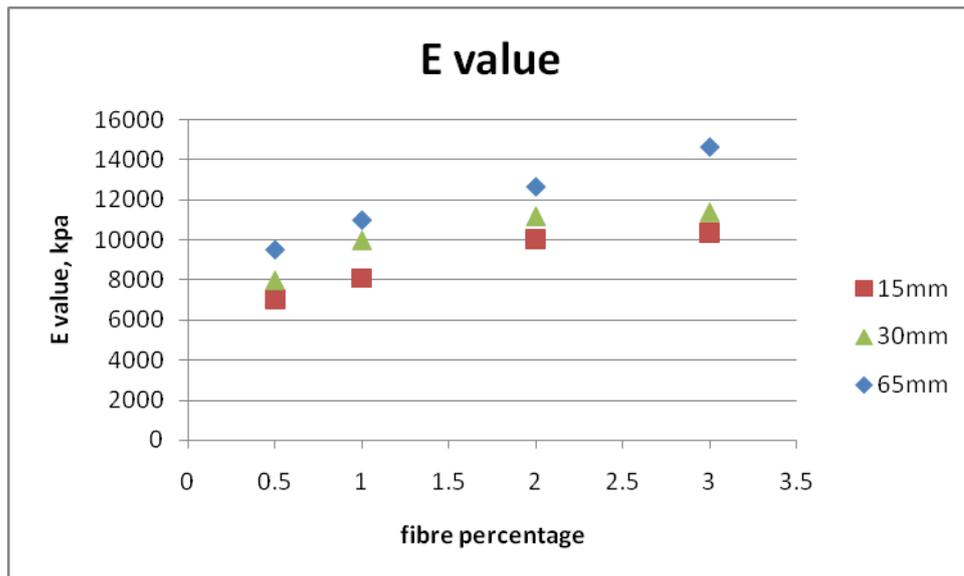
Results and Discussion

The unconfined compression tests were performed in order to determine the modulus of elasticity (E-value). The E values were calculated based on the initial tangent of the stress-strain curve. The tests were conducted on cylindrical specimen of 60 mm diameter and 170 mm height.

Table 3 provides values of elastic modulus of soil with and without fiber reinforcement. The maximum E-value of clayey soil was 14620 kPa obtained at the aspect ratio of 65mm and fiber content 3% percent. It was observed that modulus of elasticity was increased with increasing in fibre length and fibre content.

Table 3 E-Values (kPa) for Reinforced and Unreinforced Soils

Fibre length(mm)	Fiber content %	E value
----	0.00	5500
15	0.5	7000
	1	8068
	2	10000
	3.0	10340
30	0.5	8000
	1	10000
	2	11200
	3.0	11400
65	0.5	9540
	1	11000
	2	12650
	3.0	14620



CONCLUSION

A series of Unconfined Compression tests were performed and conclusions can be summarized as:

- Increasing in fibre percentage increased modulus of elasticity
- Increasing in fibre aspect ratio increased modulus of elasticity
- During the test, it was observed that ductility behavior of reinforced clay increased because of fibre inclusion.
- Short and randomly fibre inclusion showed to be reliable solution to enhance strength of the composites.

ACKNOWLEDGEMENTS

Authors would like to thank Curtin laboratory staff for their kind assistance.

REFERENCES

- [1] Akbulut, S., Arasan, S. and Kalkan, E. (2007) Modification of clayey soils using scrap tire rubber and synthetic fibres, *Journal of Applied Clay Science* 38, 23-32.
- [2] Al Refeai, T.O. (1991) Behaviour of granular soils reinforced with discrete randomly oriented inclusions, *Journal of Geotextiles and Geomembranes* 10, pp. 319–333.
- [3] Cai, Y., Shi, B., Charles, W.W. Ng. & Tang, C. (2006) Effect of polypropylene fibre and lime admixture on engineering properties of clayey soil, *Engineering Geology* 87, 230– 240.
- [4] Consoli, N.C., Vendruscolo, M.A., Fonini, A. and Dalla Rosa, F. (2009) Fibre reinforcement effects on sand considering a wide cementation range, *Geotextiles and Geomembranes* 27, pp. 196–203.
- [5] Freitag, D.R. (1986) Soil randomly reinforced with fibres, *Journal of Geotechnical Engineering ASCE* 112 (8), pp. 823–826.

- [6] Lorenzo, G. A. and Bergado, D. T. (2004). Fundamental parameters of cement-admixed clay – New approach. *Journal of Geotechnical and Geoenvironmental Engineering*, Vol. 130, No. 10, pp. 1-9.
- [7] Michalowski, R. L., Cermak, J. (2002), Strength anisotropy of fiber-reinforced sand. *Computers and Geotechnics*, Vol. 29, No. 4, pp. 279-299.
- [8] Maher, M. H., Ho, Y. C. (1994), Mechanical-properties of kaolinite fiber soil composite. *J. of Geotech. Engrg, ASCE*, Vol. 120, No. 8, pp. 1381-1393.
- [9] Nataraj, M. S., Mcmanis, K. L. (1997), Strength and deformation properties of soils reinforced with fibrillated fibers. *Geosynthetics Int.*, Vol. 4, No. 1, pp. 65-79.
- [10] Sivakumar Babu, G.L., Vasudevan, A.K. and Haldar, S. (2008) Numerical simulation of fibre-reinforced sand behaviour, *Geotextiles and Geomembranes* 26, pp. 181–188.
- [11] Yetimoglu, T. and Salbas, O. (2003) A study on shear strength of sands reinforced with randomly distributed discrete fibres, *Geotextiles and Geomembranes* 21 (2), pp. 103–110.
- [12] Ziegler, S., Leshchinsky, D., Ling, H. I., and Perry, E. B. (1998) Effect of short polymeric fibers on crack development in clays. *Soils and Foundations*, Vol. 38, No. 1, pp. 247-253.
- [13] Zornberg, J. G., Cabral, A. R. and Viratjandr, C. (2004) Behavior of tire shred-sand mixtures, *Canadian Geotechnical Journal* 41 (2), pp. 227–241.
- [14] Zornberg, J. G. (2002) discrete framework for limit equilibrium analysis of fibre-reinforcement, *Geotechnique Journal* 52 (8), pp. 227–241.

Automated Shear Test on Reinforced Clayey Sand

Amin Chegenizadeh ^{1, a}, Prof. Hamid Nikraz ^{2, b}

¹PhD candidate, Department of Civil Engineering, Curtin University of Technology, Perth, Australia; Tel: +61-413165961; Fax: +61 8 9266 2681

²Prof. Hamid Nikraz, Head of the Department of Civil Engineering, Curtin University of Technology, Perth, Australia; Tel: +61 8 9266 7573; Fax: +61 8 9266 2681

a Email: amin.chegenizadeh@postgrad.curtin.edu.au,

b Email: H.Nikraz@curtin.edu.au

Abstract. Composite soils have been widely used in civil engineering applications, especially in slopes, embankment dam and landfills. This paper aims to investigate effect of fiber inclusion on shear stress of composite soil (i.e. sand composite). A series of laboratory direct shear tests carried out to evaluate fiber effect on strength behavior of composite sand. Clayey sand was selected as soil part of the composite and natural fiber was used as reinforcement. The fiber parameters differed from one test to another, as fiber length were changed from 20 mm to 50 mm and fiber content were varied from 0.5% and 6%. Normal stress kept constant at 200 kpa. For each test, stress_ displacement graph derived and the results were compared. The results proved that inclusion of fiber affected strength behaviour of sand composite so that increasing in fiber content and length caused increasing in shear stress.

Keywords: Direct shear, Reinforced, Fiber, Sand

INTRODUCTION

The direct shear test is one of the oldest strength tests for soils. In this study, a direct shear device will be used to determine the shear strength of a fiber reinforced soil. Applications of soil strengthening or stabilization range from the mitigation of complex slope hazards to enhancing the subgrade stability. Together with the many applications for improving soil, there are several widely varied methods. The mixing of randomly oriented fibers to a soil sample may be considered same as other admixtures used to stabilize soil. Material used to make fibers for reinforcement may be obtained from paper, metal, nylon, polyester and other materials having widely varied physical properties. There have been numerous past papers published on the topic of fiber strengthening of soils. Examples include Lee et al., 1973, Hoare, 1979, Andersland and Khattac, 1979, Freitag, 1986, Gray and Ohashi, 1983, Gray and Rafeai, 1986, Maher and Gray 1990, Maher and Ho, 1994, Michalowski and Zhao 2002, Ranjan et al. 1996, Kaniraj and Havanagi 2001, Consoli et al. 2009.

All of the papers listed above have generally shown that; strength of the soil was improved by fiber reinforcement. The investigation on clayey sand is very limited. The purpose of this survey is to evaluate clayey sand behaviour induced by fiber inclusion.

MATERIAL

Composite soils consist of two parts. The first part is soil part which can be dealt as normal soil. The second part is reinforcement part which can be made up of any material which helps soil to have better performance.

Soil Type

The soil type in this study was Western Australian sand. The properties of clay are presented in table 1. The sand distribution curve is presented in Fig 1. The soil part was reconstituted in lab by using sand with 10% of kaolin clay.

Table1. Clay properties

No.	Type	
1	Soil type	Clay
2	Liquid Limit	49
3	Plastic Limit	23
4	Pl. Index	26

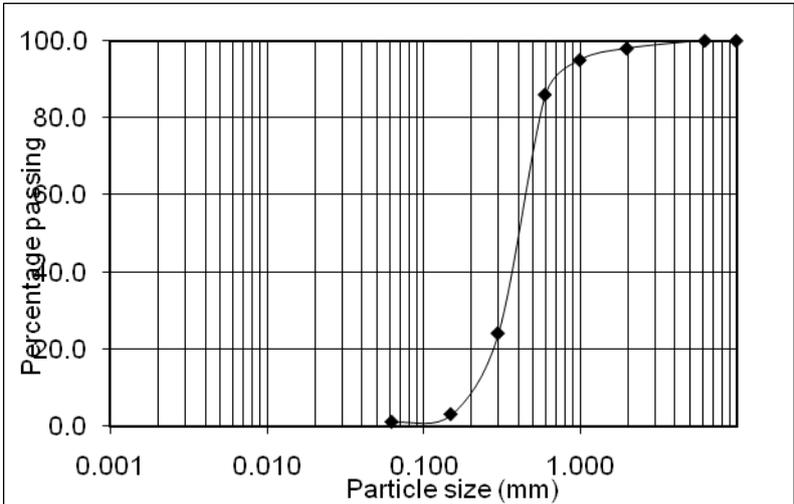


Fig. 1 Sand Particle Distribution

Fibre Type

The plastic fibre has been used for this investigation. The fibre properties are presented in table 2. The fibre is commercially available and is called fibre Meyco FIB SP 65 macro structural synthetic polypropylene fibre which generates a very high energy absorption rate when used in the matrix. Figure 1 shows the used fibre.



Fig. 1 Plastic fibre

Table2. fibre properties

No.	Type	
1	Material	Polypropylene
2	Specific Gravity	0.92
3	Width	1.6825 mm

TEST PROGRAM

A series of direct shear tests have been conducted on reinforced sand composite.

DIRECT SHEAR TEST

The test is carried out on either undisturbed samples or remoulded samples. To facilitate the remoulding purpose, a soil sample may be compacted at optimum moisture content in a compaction mould. Then specimen for the direct shear test could be obtained using the correct cutter provided. Alternatively, sand sample can be placed in a dry state at a required density, in the assembled shear box.

A normal load is applied to the specimen and the specimen is sheared across the pre-determined horizontal plane between the two halves of the shear box. Measurements of shear load, shear displacement and normal displacement are recorded. From the results, the shear strength parameters can be determined.

Equipment

- Direct Shear Test Machine
- Specimen preparation equipment
- fiber
- Balance

Figure 3 shows automated direct shear which was used to run shear test. The device is fully automated so the results easily transferred without any user interference.



Fig. 3 Direct Shear Test Machine

Sample Preparation

The samples were prepared by mixing clayey sand and four percentage of fiber (i.e. 0.5%, 1%, 4%, 6%) The soil was first dried under laboratory air-dried conditions then ground and passed through a 2 mm sieve. The dry powder was carefully wetted with a spray gun to the standard optimum moisture content. The moist soil was then put in sealed plastic bags in a humidity room for about two days before use. The moist residual soil was then compacted in a 300 mm x 300 mm shear box mould by machine compaction to the appropriate height and unit weight at the optimum moisture content.

Test Procedure

1. The shear box was assembled and the specimen was put into the shear box. Special care was made that the alignment screws working well.
2. The shear box was placed into the shearing device.
3. Normal load was applied to the specimen using the load transfer plate and the loading hanger.
4. Set the shearing device the advance at a rate of 0.50 mm/min.
7. The data acquisition system was run.
8. Once data acquisition has begun, the shearing device was started.
9. The Shear Stress-Displacement curve plot used for strength behavior investigation

RESULTS AND DISCUSSION

The direct shear tests were performed in order to determine effect of fiber inclusion on shear strength of reinforced clayey sand. Figure 4 showed the stress-displacement curve obtained from the tests at 20mm fiber length and constant normal stress of 200 kpa.

Figure 4 proved increasing in fiber content will increase the strength. Figure 5 shows the effect of fiber length on strength of composite clayey sand at constant fiber content of 1% and normal stress of 200 kpa.

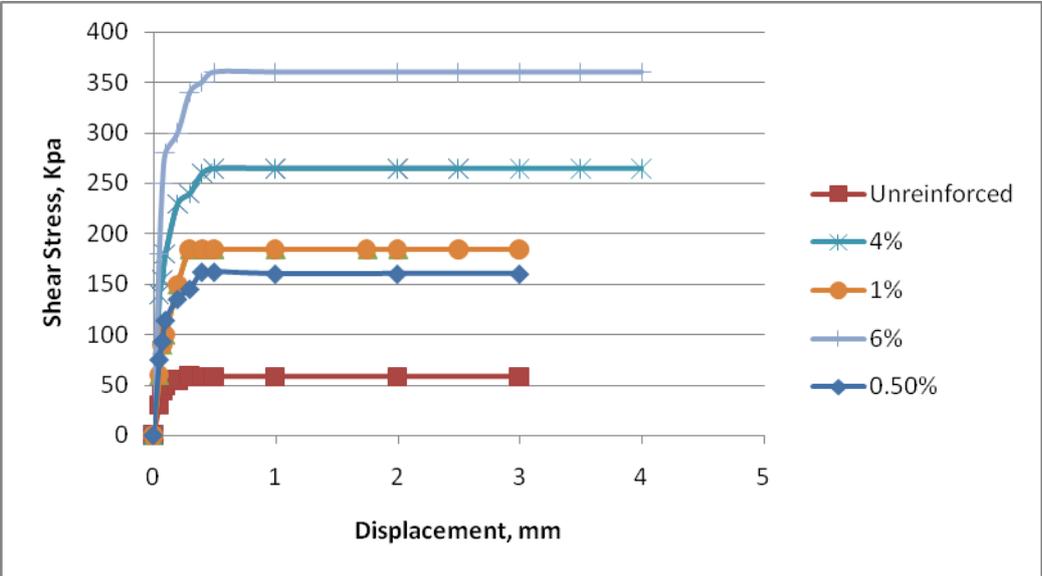


Fig. 4 Results of direct shear test in different fiber content (at 20mm, Normal stress 200 kpa)

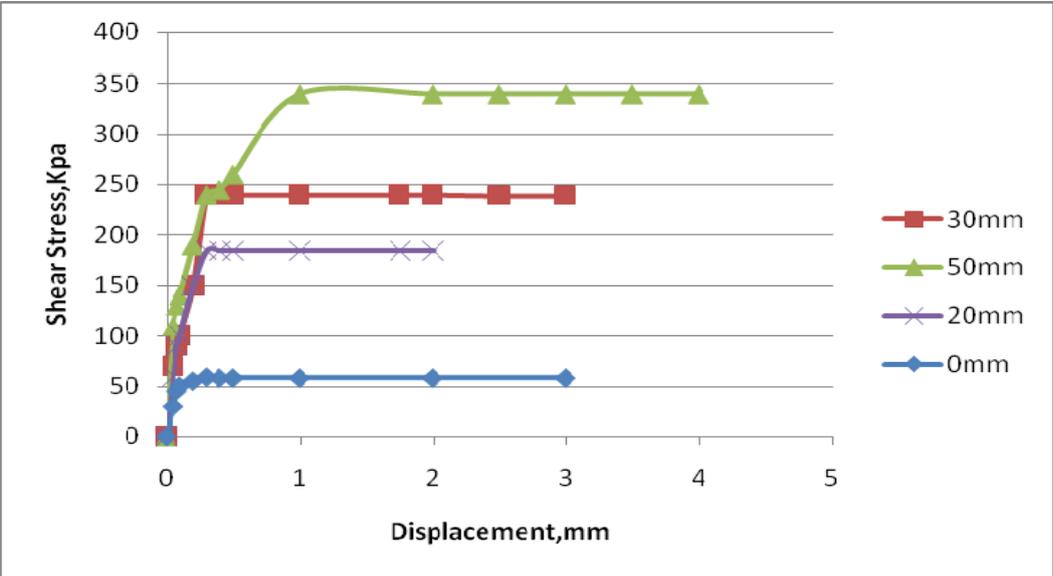


Fig. 5 Results of direct shear test in different fiber length (at 1% fiber content, Normal stress 200 kpa)

CONCLUSION

A series of direct shear test were conducted and following conclusions were derived:

- Increasing in fiber percentage increased shear strength in clayey sand samples

- During the test, it was observed that ductility behaviour of reinforced sand increased because of fiber inclusion.
- The results proved that with increasing in fiber length, the shear stress of composite clayey sand was increased.
- Short and randomly Fiber inclusion showed to be reliable in industry projects as it helps to minimize the cost of projects.

ACKNOWLEDGEMENTS

Authors would like to thank Curtin laboratory staff for their kind assistance.

REFERENCES

- [1] Akbulut, S., Arasan, S. and Kalkan, E. (2007) Modification of clayey soils using scrap tire rubber and synthetic fibres, *Journal of Applied Clay Science* 38, 23-32.
- [2] Al Refeai, T.O. (1991) Behaviour of granular soils reinforced with discrete randomly oriented inclusions, *Journal of Geotextiles and Geomembranes* 10, pp. 319–333.
- [3] Cai, Y., Shi, B., Charles, W.W. Ng. & Tang, C. (2006) Effect of polypropylene fibre and lime admixture on engineering properties of clayey soil, *Engineering Geology* 87, 230– 240.
- [4] Consoli, N.C., Vendruscolo, M.A., Fonini, A. and Dalla Rosa, F. (2009) Fibre reinforcement effects on sand considering a wide cementation range, *Geotextiles and Geomembranes* 27, pp. 196–203.
- [5] Consoli, N.C., Prietto, P.D.M. and Ulbrich, L.A. (1998) “Influence of fibre and cement addition on behavior of sandy soil”, *Journal of Geotechnical and Geoenvironmental Engineering* 124 (12), pp. 1211–1214.
- [6] Freitag, D.R. (1986) Soil randomly reinforced with fibres, *Journal of Geotechnical Engineering ASCE* 112 (8), pp. 823–826.
- [7] Fukuda ,H. and Choi, T. (1982) “A probabilistic theory of strength of short-fibre composites with variable fibre length and orientation”, *Journal of Materials Science* 17, pp. 1003–1011
- [8] Hoare, D.J. (1979) “Laboratory study of granular soils reinforced with randomly oriented discrete fibres”, *Proceedings of the International Conference on Soil Reinforcement Paris, France* 1, pp. 47–52.
- [9] Lorenzo, G. A. and Bergado, D. T. (2004). Fundamental parameters of cement-admixed clay – New approach. *Journal of Geotechnical and Geoenvironmental Engineering*, Vol. 130, No. 10, pp. 1-9.
- [10] Michalowski, R. L., Cermak, J. (2002), Strength anisotropy of fiber-reinforced sand. *Computers and Geotechnics*, Vol. 29, No. 4, pp. 279-299.
- [11] Maher, M. H., Ho, Y. C. (1994), Mechanical-properties of kaolinite fiber soil composite. *J. of Geotech. Engrg, ASCE*, Vol. 120, No. 8, pp. 1381-1393.

- [12] Nataraj, M. S., Mcmanis, K. L. (1997), Strength and deformation properties of soils reinforced with fibrillated fibers. *Geosynthetics Int.*, Vol. 4, No. 1, pp. 65-79.
- [13] Ranjan, G., Vasan, R.M. and Charan, H.D. (1996) “Probabilistic analysis of randomly distributed fibre-reinforced soil”, *Journal of Geotechnical Engineering ASCE* **122** (6), pp. 419–426.
- [14] Sivakumar Babu, G.L., Vasudevan, A.K. and Haldar, S. (2008) Numerical simulation of fibre-reinforced sand behaviour, *Geotextiles and Geomembranes* 26, pp. 181–188.
- [15] Yetimoglu, T. and Salbas, O. (2003) A study on shear strength of sands reinforced with randomly distributed discrete fibres, *Geotextiles and Geomembranes* 21 (2), pp. 103–110.
- [16] Ziegler, S., Leshchinsky, D., Ling, H. I., and Perry, E. B. (1998) Effect of short polymeric fibers on crack development in clays. *Soils and Foundations*, Vol. 38, No. 1, pp. 247-253.
- [17] Zornberg, J. G., Cabral, A. R. and Viratjandr, C. (2004) Behavior of tire shred-sand mixtures, *Canadian Geotechnical Journal* 41 (2), pp. 227–241.
- [18] Zornberg, J. G. (2002) discrete framework for limit equilibrium analysis of fibre-reinforcement, *Geotechnique Journal* 52 (8), pp. 227–241.

Shear Test on Reinforced Clay

Amin Chegenizadeh ^{1, a}, Prof. Hamid Nikraz ^{2, b}

¹PhD candidate, Department of Civil Engineering, Curtin University of Technology, Perth, Australia; Tel: +61-413165961; Fax: +61 8 9266 2681

²Prof. Hamid Nikraz, Head of the Department of Civil Engineering, Curtin University of Technology, Perth, Australia; Tel: +61 8 9266 7573; Fax: +61 8 9266 2681

a Email: amin.chegenizadeh@postgrad.curtin.edu.au,

b Email: H.Nikraz@curtin.edu.au

Abstract. Composite soils have been widely used in civil engineering applications, especially in slopes, embankment dam and landfills. This paper aims to investigate effect of fiber inclusion on shear stress of composite soil (i.e. clay composite). A series of laboratory direct shear tests carried out to evaluate fiber effect on strength behavior of composite clay. Clay was selected as soil part of the composite and plastic fiber was used as reinforcement. The fiber parameters differed from one test to another, as fiber length were changed from 20 mm to 65 mm and fiber content were varied from 0.7% and 2%. Normal stress kept constant at 150 kpa. For each test, stress_ displacement graph derived and the results were compared. The results proved that inclusion of fiber affected shear stress behaviour of clay composite so that increasing in fiber content and length caused increasing in shear stress.

Keywords: Direct shear, Reinforced, Fiber, Clay

INTRODUCTION

The direct shear test is one of the oldest strength tests for soils. In this study, a direct shear device will be used to determine the shear strength of a fiber reinforced soil. Applications of soil strengthening or stabilization range from the mitigation of complex slope hazards to enhancing the subgrade stability. Together with the many applications for improving soil, there are several widely varied methods. The mixing of randomly oriented fibers to a soil sample may be considered same as other admixtures used to stabilize soil. Material used to make fibers for reinforcement may be obtained from paper, metal, nylon, polyester and other materials having widely varied physical properties. There have been numerous past papers published on the topic of fiber strengthening of soils. Examples include Lee et al., 1973, Hoare, 1979, Andersland and Khattac, 1979, Freitag, 1986, Gray and Ohashi, 1983, Gray and Rafeai, 1986, Maher and Gray 1990, Maher and Ho, 1994, Michalowski and Zhao 2002, Ranjan et al. 1996, Kaniraj and Havanagi 2001, Consoli et al. 2009.

All of the papers listed above have generally shown that; strength of the soil was improved by fiber reinforcement. The investigation on clay is very limited. The purpose of this survey is to evaluate clay behaviour induced by fiber inclusion.

MATERIAL

Composite materials consist of two parts. The first part is soil part which can be dealt as normal soil. The second part is reinforcement part which can be made up of any material which helps soil to have better performance.

Soil Type

The soil type in this study was kaolin clay. The properties of kaolin clay are presented in table 1.

Table1. Clay properties

No.	Type	
1	Soil type	Clay
2	Liquid Limit	49
3	Plastic Limit	23
4	Pl. Index	26

Fiber Type

The plastic fiber has been used for this investigation. The fiber properties are presented in table 2. The fiber is commercially available and is called fiber Meyco FIB SP 65 macro structural synthetic polypropylene fiber which generates a very high energy absorption rate when used in the matrix. Figure 1 shows the used fiber.



Fig. 1 Plastic fiber

Table2. fiber properties

No.	Type	
1	Material	Polypropylene
2	Specific Gravity	0.92
3	Width	1.6825 mm

TEST PROGRAM

A series of direct shear tests have been conducted on reinforced clay composite.

Direct Shear Test

The test is carried out on either undisturbed samples or remoulded samples. To facilitate the remoulding purpose, a soil sample may be compacted at optimum moisture content in a compaction mould. Then specimen for the direct shear test could be obtained using the correct cutter provided. Alternatively, clay sample can be placed in a dry state at a required density, in the assembled shear box.

A normal load is applied to the specimen and the specimen is sheared across the pre-determined horizontal plane between the two halves of the shear box. Measurements of shear load, shear displacement and normal displacement are recorded. From the results, the shear strength parameters can be determined.

Equipment

- Direct Shear test specimen
- Specimen preparation equipment
- Sample extruder
- fiber
- Balance

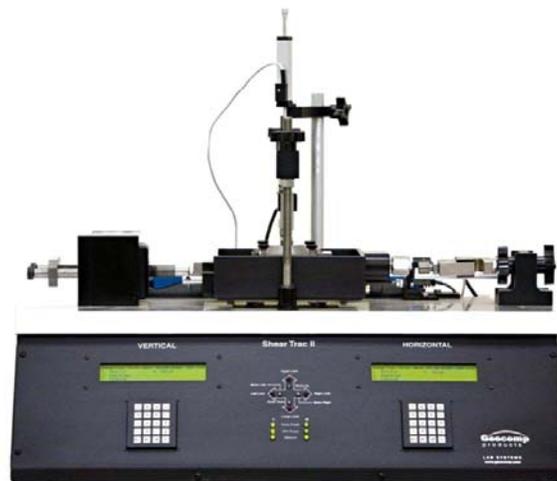


Fig. 2 Triaxial machine

Sample Preparation

The samples were prepared by mixing clay and three percentage of fiber (i.e. 0.7%, 1.4%, and 2%). The soil was first dried under laboratory air-dried conditions then ground and passed

through a 2 mm sieve. The dry powder was carefully wetted with a spray gun to the standard optimum moisture content. The moist soil was then put in sealed plastic bags in a humidity room for about two days before use. The moist residual soil was then compacted in a 300 mm x 300 mm shear box mould by machine compaction to the appropriate height and unit weight at the optimum moisture content.

Test Procedure

1. The shear box was assembled and the specimen was put into the shear box. Special care was made that the alignment screws working well.
2. The shear box was placed into the shearing device.
3. Normal load was applied to the specimen using the load transfer plate and the loading hanger.
4. Set the shearing device the advance at a rate of 0.50 mm/min.
7. The data acquisition system was run.
8. Once data acquisition has begun, the shearing device was started.
9. The Shear Stress-Displacement curve plot used for strength behavior investigation

Results and Discussion

The direct shear tests were performed in order to determine effect of fiber inclusion on shear strength of reinforced clay. Figure 4 showed the stress-displacement curve obtained from the tests at 20mm fiber length and constant normal stress of 150 kpa.

Figure 4 proved increasing in fiber content will increase the strength. Figure 5 shows the effect of fiber length on strength of composite clay at constant fiber content of 0.7% and normal stress of 150 kpa.

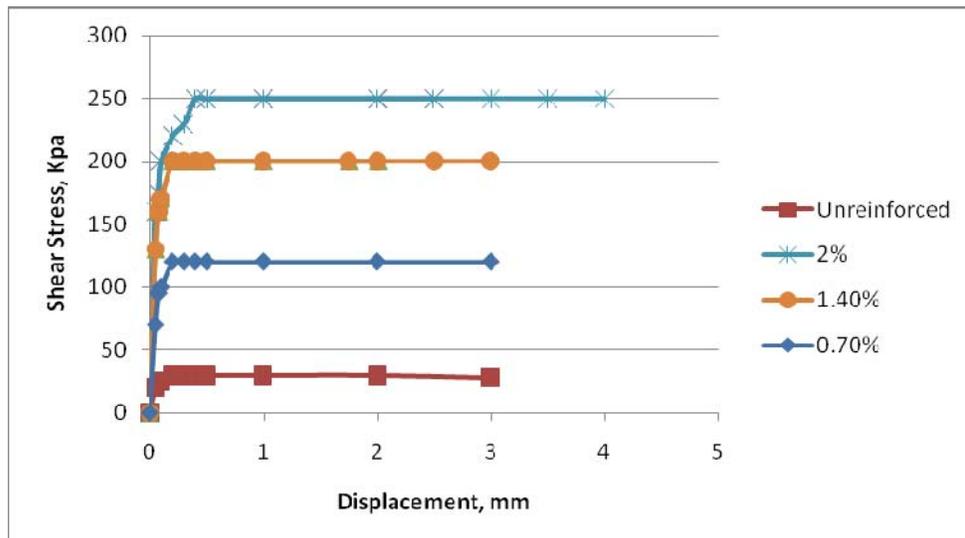


Fig. 4 Results of direct shear test in different fiber content (at 20mm, Normal stress 150 kpa)

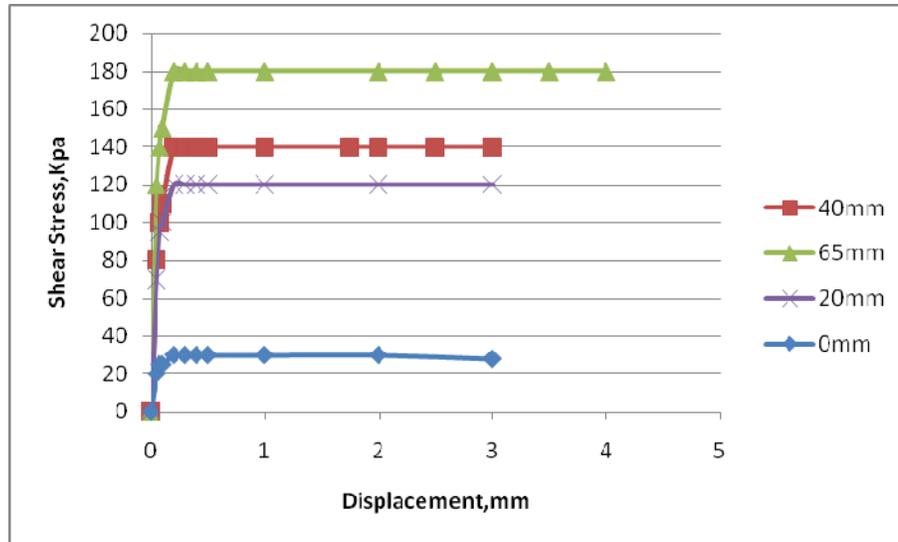


Fig. 5 Results of direct shear test in different fiber length (at 0.7% fiber content, Normal stress 150 kpa)

CONCLUSION

The direct shear tests were conducted. Following conclusions were derived:

- Increasing in fiber percentage increased shear strength in clay samples
- During the test, it was observed that ductility behaviour of reinforced clay increased because of fiber inclusion.
- The results proved that with increasing in fiber length, the shear stress of composite clay was increased.
- Short and randomly Fiber inclusion showed to be reliable in industry projects as it helps to minimize the cost of projects.

ACKNOWLEDGEMENTS

Authors would like to thank Curtin laboratory staff for their kind assistance.

REFERENCES

- [1] Akbulut, S., Arasan, S. and Kalkan, E. (2007) Modification of clayey soils using scrap tire rubber and synthetic fibers, *Journal of Applied Clay Science* 38, 23-32.
- [2] Al Refeai, T.O. (1991) Behaviour of granular soils reinforced with discrete randomly oriented inclusions, *Journal of Geotextiles and Geomembranes* 10, pp. 319-333.
- [3] Cai, Y., Shi, B., Charles, W.W. Ng. & Tang, C. (2006) Effect of polypropylene fiber and lime admixture on engineering properties of clayey soil, *Engineering Geology* 87, 230- 240.

- [4] Consoli, N.C., Vendruscolo, M.A., Fonini, A. and Dalla Rosa, F. (2009) Fiber reinforcement effects on sand considering a wide cementation range, *Geotextiles and Geomembranes* 27, pp. 196–203.
- [5] Freitag, D.R. (1986) Soil randomly reinforced with fibers, *Journal of Geotechnical Engineering ASCE* 112 (8), pp. 823–826.
- [6] Lorenzo, G. A. and Bergado, D. T. (2004). Fundamental parameters of cement-admixed clay – New approach. *Journal of Geotechnical and Geoenvironmental Engineering*, Vol. 130, No. 10, pp. 1-9.
- [7] Michalowski, R. L., Cermak, J. (2002), Strength anisotropy of fiber-reinforced sand. *Computers and Geotechnics*, Vol. 29, No. 4, pp. 279-299.
- [8] Maher, M. H., Ho, Y. C. (1994), Mechanical-properties of kaolinite fiber soil composite. *J. of Geotech. Engrg, ASCE*, Vol. 120, No. 8, pp. 1381-1393.
- [9] Nataraj, M. S., Mcmanis, K. L. (1997), Strength and deformation properties of soils reinforced with fibrillated fibers. *Geosynthetics Int.*, Vol. 4, No. 1, pp. 65-79.
- [10] Sivakumar Babu, G.L., Vasudevan, A.K. and Haldar, S. (2008) Numerical simulation of fiber-reinforced sand behaviour, *Geotextiles and Geomembranes* 26, pp. 181–188.
- [11] Yetimoglu, T. and Salbas, O. (2003) A study on shear strength of sands reinforced with randomly distributed discrete fibers, *Geotextiles and Geomembranes* 21 (2), pp. 103–110.
- [12] Ziegler, S., Leshchinsky, D., Ling, H. I., and Perry, E. B. (1998) Effect of short polymeric fibers on crack development in clays. *Soils and Foundations*, Vol. 38, No. 1, pp. 247-253.
- [13] Zornberg, J. G., Cabral, A. R. and Viratjandr, C. (2004) Behavior of tire shred-sand mixtures, *Canadian Geotechnical Journal* 41 (2), pp. 227–241.
- [14] Zornberg, J. G. (2002) discrete framework for limit equilibrium analysis of fiber-reinforcement, *Geotechnique Journal* 52 (8), pp. 227–241.

Study on Modulus of Elasticity of Reinforced Clay

Amin Chegenizadeh ^{1, a}, Prof. Hamid Nikraz ^{2, b}

¹PhD candidate, Department of Civil Engineering, Curtin University of Technology, Perth, Australia; Tel: +61-413165961; Fax: +61 8 9266 2681

²Prof. Hamid Nikraz, Head of the Department of Civil Engineering, Curtin University of Technology, Perth, Australia; Tel: +61 8 9266 7573; Fax: +61 8 9266 2681

a Email: amin.chegenizadeh@postgrad.curtin.edu.au,

b Email: H.Nikraz@curtin.edu.au

Abstract. Reinforced soil has been among the most effective soil modification materials. Its use has been expanded rapidly into civil engineering, geotechnical engineering and pavement engineering. Reinforcing subgrade in pavement systems has always been an issue. This study focuses on effect of fibre inclusion on the modulus of elasticity of subgrade material. Plastic fibre was used for this investigation. Fibre contents and aspect ratio have been changed during these tests. The fibre percentage varied from 0 % (for unreinforced samples) to 6%. Clay was used as sub grade material. Unconfined compression tests were carried out to investigate behaviour of the composite under different condition. The fibre length and fibre content found to play important rule on the modulus of elasticity of fibre. Furthermore it was observed that ductility of sample increased by fibre inclusion.

Keywords: Reinforced soil, Unconfined, Strength, Fibre.

INTRODUCTION

In conventional application of reinforcement in soil, the inclusion of tire, bars, grids etc are usually in a preferred orientation. The advances of these materials have usually been considered by an increase in their applications. The randomly discrete fibers are easily added and mixed randomly with soil part, the same way as cement, lime or other additives. Some researches have been done on cement additive (Consoli et.al. 2009; Cai et.al 2006; Lorenzo and Bergado, 2004) and can be used as a pattern of additive usage in soil. Fibre reinforced composite shows more ductility and small losses of peak strength i.e. in compared to unreinforced material. Therefore, fiber-reinforced soil composite is a practical solution in civil engineering projects. The main application of composite soil can be in embankment, subgrade, subbase, and slope stability problems. However, the data concerning the effects of fiber inclusion on the characteristics of compacted native or virgin soils are limited, (Maher and Ho, 1993). This shortage is more considerable in pavement engineering therefore research on fibre inclusion in pavement systems needs to be more performed. As in pavement engineering modulus of elasticity has considerable effect on the design procedure, this study is mainly focused on changes in this parameter due to random fibre inclusion.

MATERIAL

Composite materials consist of two parts. The first part is soil part which can be dealt as normal soil. The second part is reinforcement part which can be made up of any material which helps soil to have better performance.

Soil Type

The soil type in this study was kaolin clay. The properties of kaolin clay are presented in table 1.

No.	Type	
1	Soil type	Clay
2	Liquid Limit	49
3	Plastic Limit	23
4	Pl. Index	26

Fibre Type

The plastic fibre has been used for this investigation. The fibre properties are presented in table 2. The fibre is commercially available and is called fibre Meyco FIB SP 65 macro structural synthetic polypropylene fibre which generates a very high energy absorption rate when used in the matrix. Figure 1 shows the used fibre.



Fig. 1 Plastic fibre

No.	Type	
1	Material	Polypropylene
2	Specific Gravity	0.92
3	Width	1.6825 mm

TEST PROGRAM

A series of unconfined compression tests have been conducted to verify effect of fibre content on elasticity modulus.

Unconfined Compression Test Principle

Aim of Unconfined Compression test is to obtain unconfined compressive strength of soil. This can be applied to fine grade and cohesive soil and will represent very fast response in practical condition as the test time is very quick in respect to confined one. This test is widely used for slope stability and embankment dam applications.

Equipment

- Unconfined compression testing machine (Triaxial Machine) as shown in figure 2
- Specimen preparation equipment
- Sample extruder
- fibre
- Balance



Fig. 2 Triaxial machine

Sample Preparation

The samples were prepared by mixing clay and four percentage of fibre. Specimen preparation method was the standard compaction method, which was used in an ongoing experimental research on fiber-reinforced clay at Curtin University. The soils were first oven-dried. The dry soils were then crushed using a hammer. A mixer was used to thoroughly mix the soils with water to obtain the desired water moisture content for compaction. The mixing of soil with fibers was performed mostly by hand rather than using the mixer because the mixer caused the fibers to tangle or break. The fiber-soil mixture was placed in a closed container for 24 hours after mixing was completed. A split mold and a specific hammer were

used to compact the specimen. The specimens were prepared in different fibre content (i.e. 1%, 3%, 6%) and different fibre length (aspect ratio) which were 20mm, 30mm, 60mm.

Test Procedure

1. The specimens were prepared in the laboratory with 90% compaction effort, special care was taken during this process
2. The size of samples were checked to be suitable for the test purpose
3. The samples were put for 24 hours in geotxtile and packed
4. Special attention was applied for preventing any moisture loose
5. The samples were put in triaxial base without any confinement pressure
6. According to ASTM 1.27 mm/min were applied through the tests
7. The data was collected automatically
8. The stress-strain curve plot used for modulus elasticity investigation

Results and Discussion

The unconfined compression tests were performed in order to determine the modulus of elasticity (E-value). The E values were calculated based on the initial tangent of the stress-strain curve. The tests were conducted on cylindrical specimen of 60 mm diameter and 170 mm height.

Table 3 provides values of elastic modulus of soil with and without fiber reinforcement. The maximum E-value of clayey soil was 15010 kPa obtained at the aspect ratio of 60mm and fiber content 6% percent. It was observed that modulus of elasticity was increased with increasing in fibre length and fibre content.

Table 3 E-Values (kPa) for Reinforced and Unreinforced Soils

Fibre length(mm)	Fiber content %	E value
----	0.00	5500
20	1	9010
	3	11000
	6	12363
30	1	11000
	3	12200
	6	12650
60	1	14000
	3	14605
	6	15010

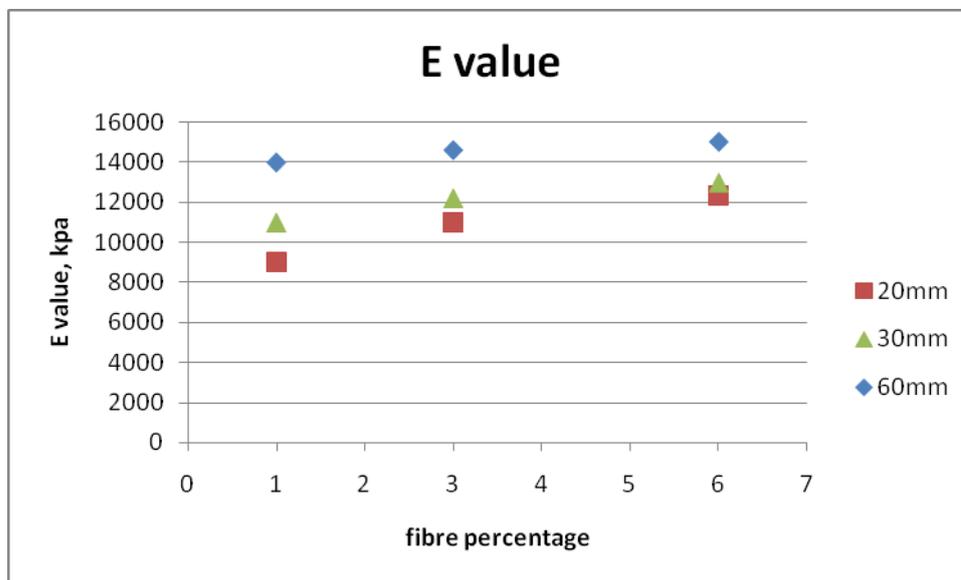


Fig. 3 Effect of fibre percentage and length on modulus of elasticity

CONCLUSION

A series of Unconfined Compression tests were performed and conclusions can be summarized as:

- Increasing in fibre percentage increased modulus of elasticity
- Increasing in fibre aspect ratio increased modulus of elasticity
- During the test, it was observed that ductility behavior of reinforced clay increased because of fibre inclusion.
- Short and randomly fibre inclusion showed to be reliable solution to enhance strength of the composites.

ACKNOWLEDGEMENTS

Authors would like to thank Curtin laboratory staff for their kind assistance.

REFERENCES

- [1] Akbulut, S., Arasan, S. and Kalkan, E. (2007) Modification of clayey soils using scrap tire rubber and synthetic fibres, *Journal of Applied Clay Science* 38, 23-32.
- [2] Al Refeai, T.O. (1991) Behaviour of granular soils reinforced with discrete randomly oriented inclusions, *Journal of Geotextiles and Geomembranes* 10, pp. 319–333.
- [3] Cai, Y., Shi, B., Charles, W.W. Ng. & Tang, C. (2006) Effect of polypropylene fibre and lime admixture on engineering properties of clayey soil, *Engineering Geology* 87, 230– 240.
- [4] Consoli, N.C., Vendruscolo, M.A., Fonini, A. and Dalla Rosa, F. (2009) Fibre reinforcement effects on sand considering a wide cementation range, *Geotextiles and Geomembranes* 27, pp. 196–203.
- [5] Freitag, D.R. (1986) Soil randomly reinforced with fibres, *Journal of Geotechnical Engineering ASCE* 112 (8), pp. 823–826.

- [6] Lorenzo, G. A. and Bergado, D. T. (2004). Fundamental parameters of cement-admixed clay – New approach. *Journal of Geotechnical and Geoenvironmental Engineering*, Vol. 130, No. 10, pp. 1-9.
- [7] Michalowski, R. L., Cermak, J. (2002), Strength anisotropy of fiber-reinforced sand. *Computers and Geotechnics*, Vol. 29, No. 4, pp. 279-299.
- [8] Maher, M. H., Ho, Y. C. (1994), Mechanical-properties of kaolinite fiber soil composite. *J. of Geotech. Engrg, ASCE*, Vol. 120, No. 8, pp. 1381-1393.
- [9] Nataraj, M. S., Mcmanis, K. L. (1997), Strength and deformation properties of soils reinforced with fibrillated fibers. *Geosynthetics Int.*, Vol. 4, No. 1, pp. 65-79.
- [10] Sivakumar Babu, G.L., Vasudevan, A.K. and Haldar, S. (2008) Numerical simulation of fibre-reinforced sand behaviour, *Geotextiles and Geomembranes* 26, pp. 181–188.
- [11] Yetimoglu, T. and Salbas, O. (2003) A study on shear strength of sands reinforced with randomly distributed discrete fibres, *Geotextiles and Geomembranes* 21 (2), pp. 103–110.
- [12] Ziegler, S., Leshchinsky, D., Ling, H. I., and Perry, E. B. (1998) Effect of short polymeric fibers on crack development in clays. *Soils and Foundations*, Vol. 38, No. 1, pp. 247-253.
- [13] Zornberg, J. G., Cabral, A. R. and Viratjandr, C. (2004) Behavior of tire shred-sand mixtures, *Canadian Geotechnical Journal* 41 (2), pp. 227–241.
- [14] Zornberg, J. G. (2002) discrete framework for limit equilibrium analysis of fibre-reinforcement, *Geotechnique Journal* 52 (8), pp. 227–241.

Composite Soil: Fiber Inclusion and Strength

Amin Chegenizadeh ^{1, a}, Prof. Hamid Nikraz ^{2, b}

¹PhD candidate, Department of Civil Engineering, Curtin University of Technology, Perth, Australia; Tel: +61-413165961; Fax: +61 8 9266 2681

²Prof. Hamid Nikraz, Head of the Department of Civil Engineering, Curtin University of Technology, Perth, Australia; Tel: +61 8 9266 7573; Fax: +61 8 9266 2681

a Email: amin.chegenizadeh@postgrad.curtin.edu.au,

b Email: H.Nikraz@curtin.edu.au

Abstract. Reinforced soil has been among the most effective soil modification materials. Its use has been expanded rapidly into civil engineering, geotechnical engineering and pavement engineering. Reinforcing subgrade in pavement systems has always been an issue. This study focuses on effect of fiber inclusion on the strength of subgrade material. Plastic fiber was used for this investigation. Fiber contents and aspect ratio have been changed during these tests. The fiber percentage varied from 0 % (for unreinforced samples) to 2%. Clay was used as sub grade material. Unconfined compression tests were carried out to investigate behaviour of the composite under different condition. The fiber length and fiber content found to play important rule on the strength of composite. Furthermore it was observed that ductility of sample increased by fiber inclusion.

Keywords: Composite, Unconfined, Strength, Fiber.

INTRODUCTION

In conventional application of reinforcement in soil, the inclusion of tire, bars, grids etc are usually in a preferred orientation. The advances of these materials have usually been considered by an increase in their applications. The randomly discrete fibers are easily added and mixed randomly with soil part, the same way as cement, lime or other additives. Some researches have been done on cement additive (Consoli et.al. 2009; Cai et.al 2006; Lorenzo and Bergado, 2004) and can be used as a pattern of additive usage in soil. Fiber reinforced composite shows more ductility and small losses of peak strength i.e. in compared to unreinforced material. Therefore, fiber-reinforced soil composite is a practical solution in civil engineering projects. The main application of composite soil can be in embankment, subgrade, subbase, and slope stability problems. However, the data concerning the effects of fiber inclusion on the characteristics of compacted native or virgin soils are limited, (Maher and Ho, 1993). This shortage is more considerable in pavement engineering therefore research on fiber inclusion in pavement systems needs to be more performed. As in pavement engineering strength of material has considerable effect on the design procedure, this study is mainly focused on changes in this parameter due to random fiber inclusion.

MATERIAL

Composite materials consist of two parts. The first part is soil part which can be dealt as normal soil. The second part is reinforcement part which can be made up of any material which helps soil to have better performance.

Soil Type

The soil type in this study was kaolin clay. The properties of kaolin clay are presented in table 1.

Table1. Clay properties

No.	Type	
1	Soil type	Clay
2	Liquid Limit	49
3	Plastic Limit	23
4	Pl. Index	26

Fiber Type

The plastic fiber has been used for this investigation. The fiber properties are presented in table 2. The fiber is commercially available and is called fiber Meyco FIB SP 65 macro structural synthetic polypropylene fiber which generates a very high energy absorption rate when used in the matrix. Figure 1 shows the used fiber.



Fig. 1 Plastic fiber

Table2. fiber properties

No.	Type	
1	Material	Polypropylene
2	Specific Gravity	0.91
3	Width	1.6825 mm

TEST PROGRAM

A series of unconfined compression tests have been conducted to verify effect of fiber content on strength of composite.

Unconfined Compression Test Principle

Aim of Unconfined Compression test is to obtain unconfined compressive strength of soil. This can be applied to fine grade and cohesive soil and will represent very fast response in practical condition as the test time is very quick in respect to confined one. This test is widely used for slope stability and embankment dam applications.

Equipment

- Unconfined compression testing machine (Triaxial Machine) as shown in figure 2
- Specimen preparation equipment
- Sample extruder
- fiber
- Balance



Fig. 2 Triaxial machine

Sample Preparation

The samples were prepared by mixing clay and three percentage of fiber. Specimen preparation method was the standard compaction method, which was used in an ongoing experimental research on fiber-reinforced clay at Curtin University. The soils were first oven-dried. The dry soils were then crushed using a hammer. A mixer was used to thoroughly mix the soils with water to obtain the desired water moisture content for compaction. The mixing of soil with fibers was performed mostly by hand rather than using the mixer because the mixer caused the fibers to tangle or break. The fiber-soil mixture was placed in a closed container for 24 hours after mixing was completed. A split mold and a specific hammer were

used to compact the specimen. The specimens were prepared in different fiber content (i.e. 0.5%, 1%, 2%) and different fiber length (aspect ratio) which were 10mm, 20mm and 30mm.

Test Procedure

1. The specimens were prepared in the laboratory with 90% compaction effort, special care was taken during this process
2. The size of samples were checked to be suitable for the test purpose
3. The samples were put for 24 hours in geotextile and packed
4. Special attention was applied for preventing any moisture loose
5. The samples were put in triaxial base without any confinement pressure
6. According to ASTM 1.27 mm/min were applied through the tests
7. The data was collected automatically
8. The stress-strain curve were plotted for each test

Results and Discussion

The unconfined compression tests were performed in order to determine the effect of fiber inclusion on strength of reinforced clay. The tests were conducted on cylindrical specimen of 60 mm diameter and 170 mm height.

The effect of fiber content was well investigated as the UCS tests were run for different fiber content and constant length and type. The fiber length kept as 10mm and plastic fiber used for these tests. The figure 3 shows the effect of fiber content on strength of the samples.

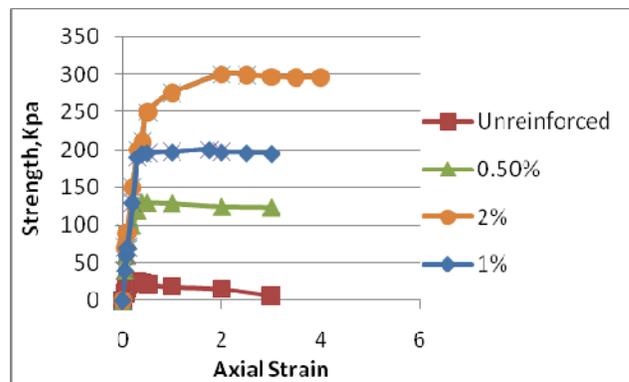


Fig. 3 Effect of fiber content on Strength of clay composite(at 10mm)

The effect of fiber length was well investigated as the UCS tests were run for different fiber length and constant content and type. The fiber type kept as plastic fiber and the fiber content as 0.5%. The figure 4 shows the effect of fiber content on strength of the samples.

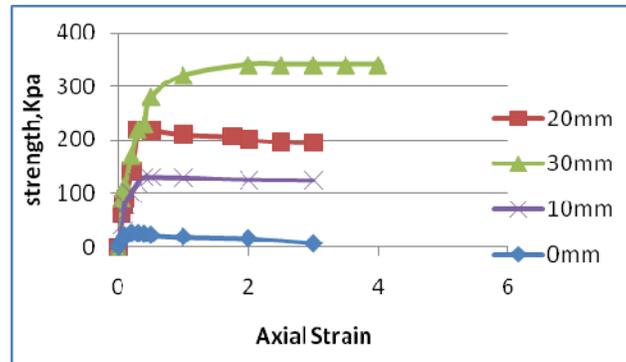


Fig. 4 Effect of fiber length on Strength of clay composite(at 0.5%)

CONCLUSION

A series of Unconfined Compression tests were performed and conclusions can be summarized as:

- Increasing in fiber percentage increased strength of composite clay
- Increasing in fiber aspect ratio increased strength of composite clay
- Short and randomly fiber inclusion showed to be reliable solution to enhance strength of the composites.

ACKNOWLEDGEMENTS

Authors would like to thank Curtin laboratory staff for their kind assistance.

REFERENCES

- [1] Akbulut, S., Arasan, S. and Kalkan, E. (2007) Modification of clayey soils using scrap tire rubber and synthetic fibers, *Journal of Applied Clay Science* 38, 23-32.
- [2] Al Refeai, T.O. (1991) Behaviour of granular soils reinforced with discrete randomly oriented inclusions, *Journal of Geotextiles and Geomembranes* 10, pp. 319–333.
- [3] Cai, Y., Shi, B., Charles, W.W. Ng. & Tang, C. (2006) Effect of polypropylene fiber and lime admixture on engineering properties of clayey soil, *Engineering Geology* 87, 230– 240.
- [4] Consoli, N.C., Vendruscolo, M.A., Fonini, A. and Dalla Rosa, F. (2009) Fiber reinforcement effects on sand considering a wide cementation range, *Geotextiles and Geomembranes* 27, pp. 196–203.
- [5] Freitag, D.R. (1986) Soil randomly reinforced with fibers, *Journal of Geotechnical Engineering ASCE* 112 (8), pp. 823–826.
- [6] Lorenzo, G. A. and Bergado, D. T. (2004). Fundamental parameters of cement-admixed clay – New approach. *Journal of Geotechnical and Geoenvironmental Engineering*, Vol. 130, No. 10, pp. 1-9.

- [7] Michalowski, R. L., Cermak, J. (2002), Strength anisotropy of fiber-reinforced sand. *Computers and Geotechnics*, Vol. 29, No. 4, pp. 279-299.
- [8] Maher, M. H., Ho, Y. C. (1994), Mechanical-properties of kaolinite fiber soil composite. *J. of Geotech. Engrg, ASCE*, Vol. 120, No. 8, pp. 1381-1393.
- [9] Nataraj, M. S., Mcmanis, K. L. (1997), Strength and deformation properties of soils reinforced with fibrillated fibers. *Geosynthetics Int.*, Vol. 4, No. 1, pp. 65-79.
- [10] Sivakumar Babu, G.L., Vasudevan, A.K. and Haldar, S. (2008) Numerical simulation of fiber-reinforced sand behaviour, *Geotextiles and Geomembranes* 26, pp. 181–188.
- [11] Yetimoglu, T. and Salbas, O. (2003) A study on shear strength of sands reinforced with randomly distributed discrete fibers, *Geotextiles and Geomembranes* 21 (2), pp. 103–110.
- [12] Ziegler, S., Leshchinsky, D., Ling, H. I., and Perry, E. B. (1998) Effect of short polymeric fibers on crack development in clays. *Soils and Foundations*, Vol. 38, No. 1, pp. 247-253.
- [13] Zornberg, J. G., Cabral, A. R. and Viratjandr, C. (2004) Behavior of tire shred-sand mixtures, *Canadian Geotechnical Journal* 41 (2), pp. 227–241.
- [14] Zornberg, J. G. (2002) discrete framework for limit equilibrium analysis of fiber-reinforcement, *Geotechnique Journal* 52 (8), pp. 227–241.

Geotechnical Parameters of Composite soil

Amin Chegenizadeh^{1, a}, Prof. Hamid Nikraz^{2, b}

¹PhD candidate, Department of Civil Engineering, Curtin University of Technology, Perth, Australia; Tel: +61-413165961; Fax: +61 8 9266 2681

²Prof. Hamid Nikraz, Head of the Department of Civil Engineering, Curtin University of Technology, Perth, Australia; Tel: +61 8 9266 7573; Fax: +61 8 9266 2681

a Email: amin.chegenizadeh@postgrad.curtin.edu.au,

b Email: H.Nikraz@curtin.edu.au

Keywords: Composite, soil, Compaction, Fiber.

Abstract. Composite soils have been widely used in civil engineering applications, especially in slopes, embankment dam and landfills. This paper aims to investigate effect of fiber inclusion on compaction characteristic of composite soil (i.e. clay composite). A series of laboratory tests carried out to evaluate fiber effect on optimum water content and maximum dry unit weight of composite soils. Clay was selected as soil part of the composite and natural fiber was used as reinforcement. The fiber parameters differed from one test to another, as fiber length varied from 10 mm to 25mm and fiber content were selected as 0.1% and 0.3%. For each test, compaction curved derived and the results were compared. The results proved that inclusion of fiber affected compaction behaviour of samples so that increasing in fiber content and length caused increasing in Optimum Moisture Content (OMC) and slightly decreased maximum dry unit weight.

Introduction

Fletcher and Humphries (1991) investigated influence of fiber inclusion on compaction of silty clay soil. Unlike the case of sandy gravel reported by Hoare (1977), the test results indicated that increasing the fiber content causes a modest increase in the maximum dry unit weight. The optimum water content was found to decrease by increasing fiber content. Other researchers (Nataraj and McManis, 1997; Al Wahab and El-Kedrah, 1995; Puppala et al., 2006; Miller and Rifai, 2004; Ozkul et al., 2007; Kumar Tabor, 2003) also reported similar results. In contrast, other researcher such as Ozkul et al, 2007 reported not significant changes on compaction parameter by fiber inclusion. Therefore, the problem of effect of fiber inclusion needs to be investigated precisely. Authors believe that different results are due to different material each researcher has used. This paper aims to investigate influences that are induced by fiber inclusion.

Material

Composite materials consist of two parts. The first part is soil part which can be dealt as normal soil. The second part is reinforcement part which can be made up of any material which helps soil to have better performance. Reinforcement expects to work in tensile.

Soil Type

The soil type in this study was kaolin clay. The properties of kaolin clay are presented in table 1.

Table1. Clay properties

No.	Type	
1	Soil type	Clay
2	Liquid Limit	49
3	Plastic Limit	23
4	Pl. Index	26

Fiber Type

The natural fiber has been used for this investigation. Figure1 shows the used fiber. Good adhesion with soil part can be named as major advantage of this natural fiber. This fibre is available easily in Western Australia.



Fig. 1 Natural fiber

Test program

A series of compaction tests have been conducted. The results of the tests have been presented and well discussed.

Compaction Test Principle

Soil compaction is a mean to increase the density of soil. In geotechnical projects, soil density is an important parameter. Any difficulty related to compaction may cause settlement of the soil and as a consequence unnecessary maintenance costs or structure failure will be needed. Therefore, all types of construction sites and construction projects use mechanical compaction method Figure 2 shows the difference between compacted and loose soil.

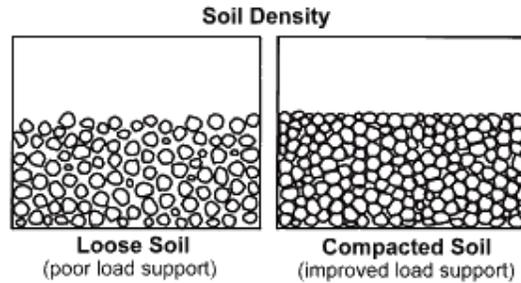


Fig. 2 Structure of loose and compacted soil (Online compaction handbook, 2010)

Effect of Moisture on Compaction Procedure

To compact properly moisture content is vital. Moisture plays as a lubricant within soil, sliding the particles together. If moisture content is very low amount that means inadequate compaction - the particles cannot slip well to achieve density. In contrast, if moisture is too high then weakens the load-bearing ability. The maximum density for most soils is at a specific water content for a given compaction effort. Therefore, the drier the soil is more unsuitable for compaction.

Compaction Methods

The standard compaction Test determines the maximum density of a soil needed for a specific project. Standard compaction method is widely used in geotechnical engineering. Figure 3 shows the technical specification for standard compaction method.

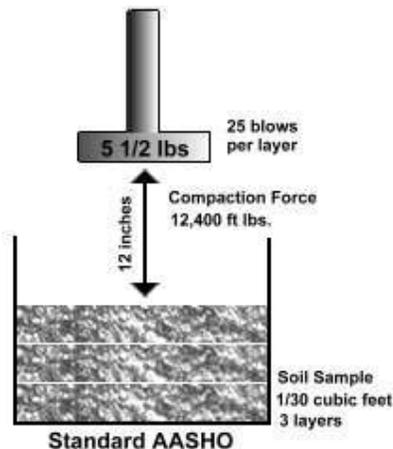


Fig. 3 Standard compaction sketch (Online compaction handbook,2010)

Main Equipments

1. Proctor mould with a detachable collar assembly and base plate.
2. Manual rammer weighing 2.5 kg and equipped with height of drop to a free fall of 30 cm.
3. Sample Extruder.
4. A sensitive balance.

5. Straight edge.
8. Moisture cans.
9. Drying Oven

Test Methodology and Procedure

- About 4.5 kg of air-dried soil was put in the mixing pan so that it could pass No. 4 sieve.
- The moisture content was increased by about 5%.
- The weight of empty mould without the base plate and the collar was recorded as W1(gr).
- The collar and base plate was fixed and the first soil part was compacted with 25 blows in proctor mould
- Some scratches were put with a spatula forming a grid to ensure uniformity in distribution of compaction energy to the subsequent layer. The second and third layer was placed and 25 blows were applied.
- The final layer was placed so that the compacted soil is just above the rim of the compaction mould when the collar is still attached.
- The collar carefully was detached without disturbing the compacted soil inside the mould and edge was used to trim the excess soil leveling to the mould.
- The weight of the mould with the moist soil W2, (gr) was determined.
- Sample was extruded the sample and evaluated for water content in some cans
- The rest of the compacted soil was broken with hand to pass US Sieve No.4. and moisture content was increased by 2%.
- Repeat previous steps for different moisture contents.
- The dry density plotted versus moisture contents.

Results and discussions

The results of laboratory investigation are presented in this section. As the tests were designed systematically the effect of each fiber parameter can be observed in this study. The first engineering graph is related to effect of fiber dosage on compaction curve of composite soil. Respectively, second part is focused on effect of fiber length (aspect ratio) on soil composite compaction characteristics.

The results from laboratory compaction test were interpreted and figure 4 shows the effect of fiber content on maximum dry density and optimum moisture content while the fiber length kept constant at 10mm. Respectively, figure 5 indicates effect of fiber length on maximum dry density and optimum moisture content while the fiber content is constant at 0.3%.

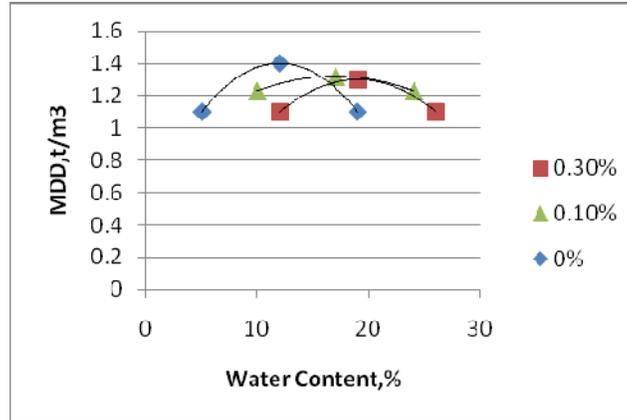


Fig. 4 Effect of fiber content on compaction curve (fiber length 10mm)

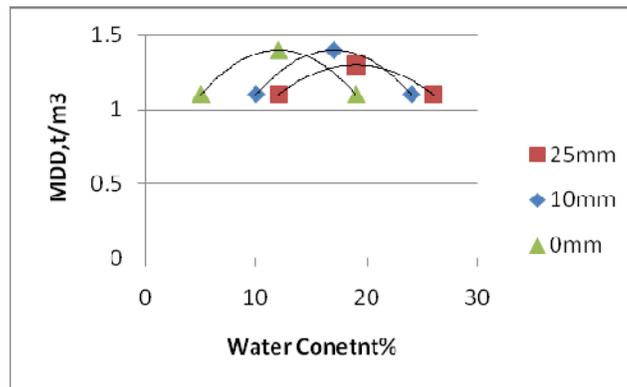


Fig. 5 Effect of fiber length on compaction curve (fiber content 0.3%)

Conclusion

Compaction tests were performed on composite clay. This investigation proved that:

- 1- Induction of fiber caused decrease in maximum dry density
- 2- Optimum Moisture Content (OMC) increased with increasing in fiber content
- 3- Increasing in compaction effort causes increasing maximum dry density; this fact was observed for composite soil as well.
- 4- Natural fiber showed to be good material to be used in practical projects

Acknowledgement

The technical support from the Curtin University Laboratory is gratefully acknowledged.

Reference

- [1] AlWahab, R.M. and Al Quirma, H.H. (1995) Fiber Reinforced Cohesive Soils for Application in Compacted Earth Structures, Proceedings of Geosynthetics '95, IFAI, Vol. 2, Nashville, Tennessee, USA, March 1995, pp. 433-476.
- [2] Al Wahab, R. M., and El-Kedrah, M. A. (1995) Using fibers to reduce tension cracks and shrink/swell in compacted clay, Proc. Geoenvironment 2000, ASCE, New Orleans, 791–805.
- [3] Fletcher, C.S. and Humphries, W.K. (1991) California Bearing Ratio Improvement of Remoulded Soils by the Addition of Polypropylene Fiber Reinforcement, Transportation Research Record 1295, Washington, DC, USA, pp. 80-86.
- [4] Gray, D.H. and Ohashi, H. (1983) Mechanics of Fiber Reinforcement in Sand, Journal of Geotechnical Engineering, Vol. 109, No. 3, pp. 335-353.
- [5] Kumar, Kanaujia and Chandrad (1983) Fiber-Reinforced Pond Ash and Silty Sand , Geosynthetic international S 1999, VOL. 6, NO. 6
- [6] Maher, M.H. and Gray, D.H. (1990) Static Response of Sands Reinforced with Randomly Distributed Fibers, Journal of Geotechnical Engineering, Vol. 116, No. 11 pp. 1661-1667.
- [7] Maher, M.H. and Ho, Y.C. (1964) Mechanical Properties of Kaolinite/Fiber Soil Composite, Journal of Geotechnical Engineering, Vol. 120, No. 8, pp. 1981-1993.
- [8] Nataraj, M.S. and McManis, K.L. (1997) Strength and Deformation Properties of Soils Reinforced with Fibrillated Fibers, Geosynthetics International, Vol. 4, No. 1, pp. 65-79.
- [9] Ozkul, Z. H., and Baykal, G. (2007) Shear behavior of compacted rubber fiber–clay composite in drained and undrained loading, Journal of Geotechnical and Geoenvironmental Engineering ASCE 7, pp. 767–781.
- [10] Online Compaction handbook, http://www.concrete-catalog.com/soil_compaction.html, 2010
- [11] Sivakumar Babu, G.L., Vasudevan, A.K. and Haldar, S. (2008) Numerical simulation of fiber-reinforced sand behaviour, Geotextiles and Geomembranes 26, pp. 181–188.
- [12] Yetimoglu, T. and Salbas, O. (2003) A study on shear strength of sands reinforced with randomly distributed discrete fibers, Geotextiles and Geomembranes 21 (2), pp. 103–110.
- [13] Ziegler, S., Leshchinsky, D., Ling, H. I., and Perry, E. B. (1998) Effect of short polymeric fibers on crack development in clays. Soils and Foundations, Vol. 38, No. 1, pp. 247-253.
- [14] Zornberg, J. G., Cabral, A. R. and Viratjandr, C. (2004) Behavior of tire shred-sand mixtures, Canadian Geotechnical Journal 41 (2), pp. 227–241.

- [15] Zornberg, J. G. (2002) discrete framework for limit equilibrium analysis of fiber-reinforcement, *Geotechnique Journal* 52 (8), pp. 227–241

Permeability Test on Reinforced Clayey Sand

Amin Chegenizadeh¹, Prof. Hamid Nikraz²

Abstract—Composite soils have been widely used in civil engineering applications, especially in slopes, embankment dam and landfills. This paper aims to investigate effect of fiber inclusion on permeability of composite soil (i.e. sand composite). A series of laboratory permeability tests carried out to evaluate fiber effect on hydraulic conductivity behavior of composite sand. Clayey sand was selected as soil part of the composite and natural fiber was used as reinforcement. The fiber parameters differed from one test to another, as fiber length were changed from 10 mm to 25 mm and fiber content were varied from 0.1% and 0.3%. For each test, permeability coefficients derived and the results were compared. The results proved that inclusion of fiber affected hydraulic conductivity of sand composite so that increasing in fiber content and length caused increasing in permeability coefficients.

Keywords—Permeability, Reinforced, Fiber, Sand

I. INTRODUCTION

THE permeability test is one of the oldest tests for soils. In this study, permeability device will be used to determine the hydraulic conductivity of a fibre reinforced soil. Different aspect of reinforced soil has been investigated in literature. Fletcher and Humphries (1991) investigated influence of fibre inclusion on compaction of silty clay soil. Unlike the case of sandy gravel reported by Hoare (1977), the test results indicated that increasing the fibre content causes a modest decrease in the maximum dry unit weight. The optimum water content was found to increase by increasing fibre content. Other researchers (Nataraj and McManis, 1997; Al Wahab and El-Kedrah, 1995; Puppala et al., 2006; Miller and Rifai, 2004; Ozkul et al., 2007; Kumar Tabor, 2003) also reported similar results. In contrast, some researchers such as Ozkul et al, 2007 reported not significant changes on compaction parameter by fibre inclusion. Applications of soil strengthening or stabilization range from the mitigation of complex slope hazards to enhancing the subgrade stability. The mixing of short randomly distributed fibres to a soil specimen may be considered same as other admixtures used to stabilize soil. Material used to make fibres for reinforcement may be obtained from paper, metal, nylon, polyester and other materials having widely varied physical properties. There have been numerous past papers published on the topic of fibre strengthening of soils. Examples include Lee et al., 1973, Hoare, 1979, Andersland and Khattac, 1979, Freitag, 1986, Gray and Ohashi, 1983, Gray and Rafeai, 1986, Maher and

Gray 1990, [12] and Ho, 1994, [13], Ranjan et al. 1996, [1], Consoli et al. 2009. All of the papers listed above have generally shown that; strength of the soil was improved by fibre reinforcement. The investigation on permeability characteristic of clayey sand composite is very limited. The purpose of this survey is to evaluate clayey sand behaviour induced by fibre inclusion.

II. MATERIAL

Composite soils consist of two parts. The first part is soil part which can be dealt as normal soil. The second part is reinforcement part which can be made up of any material which helps soil to have better performance.

A. Soil Type

The soil type in this study was Western Australian sand. The properties of clay are presented in table 1. The sand distribution curve is presented in Fig 1. The soil part was reconstituted in lab by using sand with 20% of kaolin clay.

TABLE I
CLAY PROPERTIES

No.	Type	
1	Soil type	Clay
2	Liquid Limit	49
3	Plastic Limit	23
4	Pl. Index	26

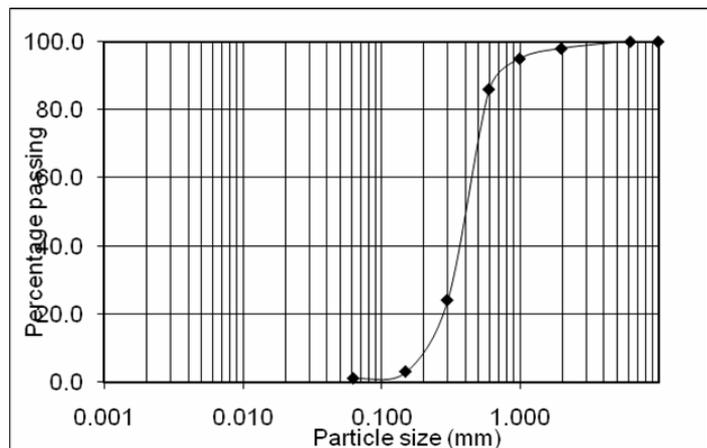


Fig. 1 Sand Particle Distribution

B. Fiber Type

The natural fiber has been used for this investigation. Figure 2 shows the used fiber. The used fiber has good potential to absorb energy and good adhesion with soil particle.

¹F. A. Author is with the Curtin University of Technology, Perth, Australia Tel: +61-413165961; Email: amin.chegenizadeh@postgrad.curtin.edu.au

²S. B. Author, Head of the Department of Civil Engineering, Curtin University of Technology, Perth, Australia; Tel: +61 8 9266 7573; Fax: +61 8 9266 2681; Email: H.Nikraz@curtin.edu.au



Fig. 2 Natural fiber

III. TEST PROGRAM

A series of constant head permeability tests have been conducted on reinforced sand composite.

C. Permeability Test

Permeability is a measure of the ease in which water can flow through a soil volume. It is one of the most important geotechnical parameters. However, it is probably the most difficult parameter to determine. In large part, it controls the strength and deformation behavior of soils. It directly affects the following:

- Quantity of water that will flow toward an excavation
- Design of cutoffs beneath dams on permeable foundations
- Design of the clay layer for a landfill liner.

For fine grained soil Falling head permeability test is done, whereas constant head permeability test is done for the coarse grained soil. As this study is focused on clayey sand, the constant head permeability test was applied.

D. Main Equipments

- Constant head apparatus
- Specimen preparation equipment
- fiber
- Balance

Figure 3 shows the chamber which was used to run permeability test. Figure 4 shows the apparatus of running the constant head permeability test.



Fig. 3 Sample chamber

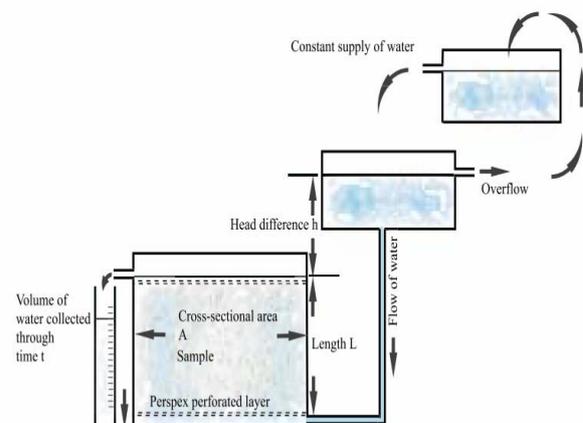


Fig. 4 constant head apparatus

IV. TEST METHODOLOGY AND PROCEDURE

- Sufficient water mixed into the sample to prevent segregation of particle sizes during placement into the permeameter. Enough water should be added to allow the mixture to flow freely, forming layers.
- One porous stone on the inner support ring in the base of the chamber positioned.
- A scoop used, the prepared specimen poured into the lower chamber, using a circular motion to fill the lower chamber to a depth of 1.5 cm. Special care was taken until a uniform layer formed.

- An appropriate tamping device used to compact the layer of soil to the desired density. The compacting repeated procedure until the sample is within 2 cm of the top of the lower chamber section.
- The sample length recorded
- The constant head funnel, rod and meter stick assembled.
- The level of the funnel was adjusted to allow the constant water level in it to remain a few inches above the top of the specimen.
- The vertical distance between the funnel overflow level and the chamber outflow level measured accurately.
- Adequate time allowed for the flow pattern and/or specimen to stabilize.
- After equilibrium flow was established, the time taken to have specified volume of water flowing out recorded. Use a measuring cylinder and a stop watch.
- Test repeated for three or more times, the average time were calculated.

a. Equation to be used

$$K = VL/Aht \quad (1)$$

Where,

K = Coefficient of permeability

V = Collected volume of water

L = Length of soil column

A = Area of the soil column

h = Head difference

t = Time required to get V volume

V. RESULTS AND DISCUSSIONS

The permeability tests were performed in order to determine effect of fibre inclusion on hydraulic conductivity of reinforced clayey sand composite. Table II shows the effect of fibre on hydraulic conductivity of the samples.

TABLE II
HYDRAULIC CONDUCTIVITY OF THE SAMPLES

Sample type	Coefficient of permeability (Cm/S)
Unreinforced sample	1.2 E- 5
Reinforced with 0.1 % of fibre at 15mm	2.5 E -5
Reinforced with 0.2% of fibre at 15mm	2.7 E -5
Reinforced with 0.3 % of fibre at 15mm	3.45 E -5
Reinforced with 10mm of fibre at 0.1% content	2.07E -5
Reinforced with 25mm of fibre at 0.1% content	2.76 E -5

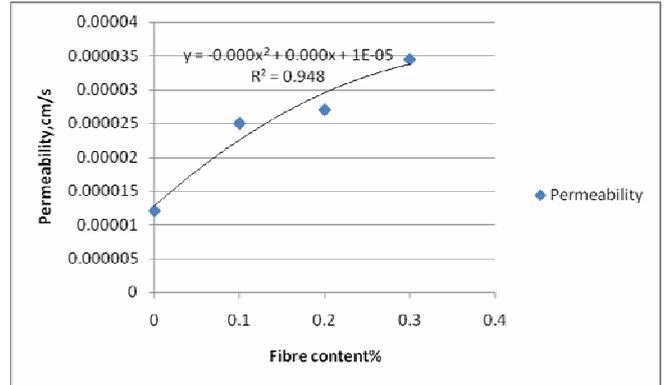


Fig. 5 Results of permeability test in different fiber content (at 15mm)

Figure 5 and figure 6 visualize the results of the tests. The results proved with increasing in fibre content and length the hydraulic conductivity increased. The best line which could represent the laboratory data was derived and regression of that was determined.

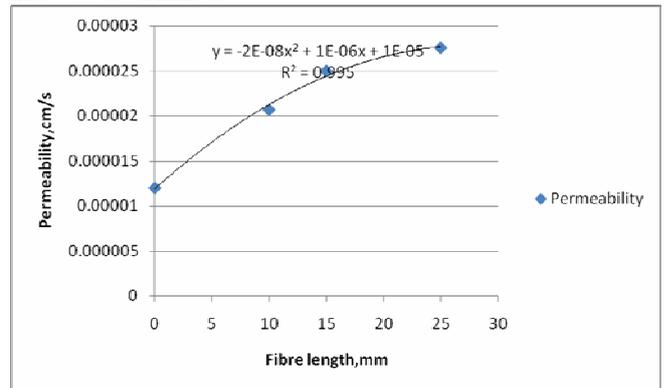


Fig. 6 Results of permeability test in different fiber length (at 0.1% fiber content)

VI. CONCLUSION

A series of permeability test performed. The methodology which applied to the test was constant head method. The clayey sand was reinforced by short plastic fibre .The results from the tests presented in this paper which showed effect of each fibre parameters on permeability characteristics of composite samples. It was proved that increase in fibre content and length caused increase in hydraulic conductivity. The value of coefficient of permeability jumped from 1.2 E- 5 (cm/s) to 3.45E -5 (cm/s) with increasing in fibre content from zero to 0.3% and also with increasing in fibre length from 10mm to 15 mm the value of coefficient of permeability increased from 2.07 E -5 (cm/s) to 2.5 E -5 (cm/s). The behaviour of composite soil in terms of hydraulic conductivity was not linear due to change in fibre content and fibre length. Interaction of fibre and soil could be reason of increasing hydraulic conductivity as may cause creating some paths for water to escape in soil matrix.

REFERENCES

- [1] Akbulut, S., Arasan, S. and Kalkan, E. (2007) "Modification of clayey soils using scrap tire rubber and synthetic fibres", *Journal of Applied Clay Science* 38, 23-32.
- [2] Al Refeai, T.O. (1991) "Behaviour of granular soils reinforced with discrete randomly oriented inclusions", *Journal of Geotextiles and Geomembranes*, 10, pp. 319-333.
- [3] Al Wahab, R. M., and El-Kedrah, M. A. (1995) "Using fibres to reduce tension cracks and shrink/swell in compacted clay", *Proc. Geoenvironment 2000, ASCE, New Orleans*, 791-805.
- [4] Cai, Y., Shi, B., Charles, W.W. Ng. & Tang, C. (2006) "Effect of polypropylene fibre and lime admixture on engineering properties of clayey soil", *Engineering Geology* 87, 230- 240.
- [5] Consoli, N.C., Vendruscolo, M.A., Fonini, A. and Dalla Rosa, F. (2009) "Fibre reinforcement effects on sand considering a wide cementation range", *Geotextiles and Geomembranes* 27, pp. 196-203.
- [6] Freitag, D.R. (1986) "Soil randomly reinforced with fibres", *Journal of Geotechnical Engineering ASCE* 112 (8), pp. 823-826.
- [7] Gray, D. and Al-Rafeai, T. O. (1986). "Behavior of fabric versus fibre reinforced sand". *Journal of Geo-technical Engineering*, vol. 112, no. 8, pp. 804-820.
- [8] Gray, D. H. and Ohashi, H. (1983). "Mechanics of fibre reinforcement in sand". *Journal of Geotechnical and Geo-environmental Engineering*, ASCE, vol. 109, no. 3, pp. 335-353.
- [9] Lorenzo, G. A. and Bergado, D. T. (2004). "Fundamental parameters of cement-admixed clay – New approach". *Journal of Geotechnical and Geoenvironmental Engineering*, Vol. 130, No. 10, pp. 1-9.
- [10] Michalowski, R. L., Cermak, J. (2002), "Strength anisotropy of fibre-reinforced sand". *Computers and Geotechnics*, Vol. 29, No. 4, pp. 279-299.
- [11] Kaniraj, S. R. and Havanagi, V. G.(2001). "Behavior of cement-stabilization fibre-reinforced fly ash-soil mixtures. *Journal of Geotechnical and Geo-environmental Engineering*, vol. 127, no. 7, pp. 574-584.
- [12] Maher, M. H., Ho, Y. C. (1994), "Mechanical-properties of kaolinite fibre soil composite". *J. of Geotech. Engrg, ASCE*, Vol. 120, No. 8, pp. 1381-1393.
- [13] Michalowski, R.L. and Zhao. (1996) "A. Failure of unidirectionally reinforced composites with frictional matrix", *Journal of Engineering Mechanics ASCE* 122 (11), pp. 1086-1092.
- [14] Michalowski, R.L. and Cermák, J. (2003) "Triaxial compression of sand reinforced with fibres", *Journal of Geotechnical and Geoenvironmental Engineering* 129 (2), pp. 125-136.
- [15] Nataraj, M. S., Mcmanis, K. L. (1997)," Strength and deformation properties of soils reinforced with fibrillated fibres.", *Geosynthetics Int.*, Vol. 4, No. 1, pp. 65-79.
- [16] Ozkul, Z. H., and Baykal, G. (2007) "Shear behavior of compacted rubber fibre-clay composite in drained and undrained loading.", *Journal of Geotechnical and Geoenvironmental Engineering ASCE* 7, pp. 767-781.
- [17] Puppala, A. J. and Musenda, C. (2000) "Effects of fibre reinforcement on strength and volume change in expansive soils", *Transportation Res. Rec.*(1736), pp.134- 140.
- [18] Sivakumar Babu, G.L., Vasudevan, A.K. and Haldar, S. (2008) Numerical simulation of fibre-reinforced sand behaviour, *Geotextiles and Geomembranes* 26, pp. 181-188.
- [19] Yetimoglu, T. and Salbas, O. (2003) "A study on shear strength of sands reinforced with randomly distributed discrete fibres", *Geotextiles and Geomembranes* 21 (2), pp. 103-110.
- [20] Ziegler, S., Leshchinsky, D., Ling, H. I., and Perry, E. B. (1998)" Effect of short polymeric fibres on crack development in clays. *Soils and Foundations*", *J of Applied clay science*, Vol. 38, No. 1, pp. 247-253.
- [21] Zornberg, J. G., Cabral, A. R. and Viratjandr, C. (2004) "Behavior of tire shred-sand mixtures", *Canadian Geotechnical Journal* 41 (2), pp. 227-241.
- [22] Zornberg, J. G. (2002) "discrete framework for limit equilibrium analysis of fibre-reinforcement", *Geotechnique Journal* 52 (8), pp. 227-241.

CBR TEST ON REINFORCED CLAY

Amin Chegenizadeh, Prof. Hamid Nikraz
Curtin University of Technology, Perth, Australia Tel: +61-413165961; Email:
amin.chegenizadeh@postgrad.curtin.edu.au
Head of the Department of Civil Engineering, Curtin University of
Technology, Perth, Australia; Tel: +61 8 9266 7573; Fax: +61 8 9266 2681;
Email: H.Nikraz@curtin.edu.au



ABSTRACT

Geosynthetic fibers are an established family of geomaterials used in a wide variety of civil engineering applications such as pavement systems. In pavement design, CBR ratio count as an important parameter. This study aims to investigate effect of fiber inclusion on CBR ratio. A series of laboratory investigation were carried out to evaluate effects of reinforcing the sub grade soil in pavement system with randomly distributed plastic fibers. In this study, two types of clay and one type of fiber were used. CBR test were conducted on unreinforced samples as well as reinforced ones at different fiber contents (i.e. 0.1%, 0.3%) and different fiber length (i.e. 10mm , 25 mm and 50mm). The results of CBR test showed that the CBR ratio for reinforced clay increased even more than two times in some cases as fiber content and fiber length increased. The results proved that application of short randomly distributed fiber is a good method to apply in practical projects.

RÉSUMÉ

Les fibres de Geosynthetic sont une famille établie de geomaterials utilisé dans une large variété d'applications de travaux publics comme les systèmes de pavé. Dans le design de pavé, le compte de rapport de CBR comme un paramètre important. Cette étude a l'intention d'enquêter sur l'effet d'inclusion de fiber sur le rapport CBR. Une série d'enquête de laboratoire a fait pour évaluer des effets de renforcer le sol de qualité sub dans le système de pavé avec les fibres au hasard distribuées de plastique. Dans cette étude, deux types de glaise et d'un type de fiber ont été utilisés. L'épreuve de CBR a été accomplie sur les échantillons non renforcés aussi bien que les renforcés à de différents contenus de fiber (c'est-à-dire 0.1 %, 0.3 %) et différente longueur de fiber (c'est-à-dire 10 millimètres et 25 millimètres). Les résultats d'épreuve de CBR ont montré que le rapport CBR pour la glaise renforcée a augmenté même plus de deux fois dans certains cas comme le contenu de fiber et la longueur de fiber a augmenté. Les résultats ont prouvé que l'application de fiber courte au hasard distribuée est une bonne méthode de faire une demande dans les projets pratiques.

1 INTRODUCTION

CBR test is the ratio of force per unit area required to penetrate a soil mass with standard circular piston at the rate of 1.25 mm/min. to that required for the corresponding penetration of a standard material. The California Bearing Ratio Test (CBR Test) is a penetration test developed by California State Highway Department (U.S.A.) for evaluating the bearing capacity of subgrade soil for design of flexible pavement. Tests are carried out on natural or compacted soils in water soaked or unsoaked conditions and the results so obtained are compared with the curves of standard test to have an idea of the soil strength of the subgrade soil. Applications of soil strengthening or stabilization range from the mitigation of complex slope hazards to enhancing the subgrade stability. Together with the many applications for improving soil, there are several widely varied methods. The mixing of randomly oriented fibers to a soil sample may be considered same as other admixtures used to stabilize soil. Material used to make fibers for reinforcement may be obtained from paper, metal, nylon, polyester and other materials having widely varied physical properties. There have been numerous past

papers published on the topic of fiber strengthening of soils. Examples include Lee et al., 1973, Hoare, 1979, Andersland and Khattac, 1979, Freitag, 1986, Gray and Ohashi, 1983, Gray and Rafeai, 1986, Maher and Gray 1990, Maher and Ho, 1994, Michalowski and Zhao 2002, Ranjan et al. 1996, Kaniraj and Havanagi 2001, Consoli et al. 2009.

All of the papers listed above have generally shown that; strength of the soil was improved by fiber reinforcement. The investigation on clayey soil is very limited. The purpose of this survey is to evaluate of CBR values of clayey soil induced by fiber inclusion. The CBR tests were conducted as per ASTM D1883 on the selected soils with and without reinforcement to investigate the influence of length and fiber content on CBR values. Moreover, the obtained CBR values were taken as indication of improvement in the soil strength due to fiber reinforcement. For different length and fiber contents, the dry weight required to fill the CBR mould was calculated based upon maximum dry densities of the soil and the volume of the mould. The water corresponding to Optimum Moisture Content (OMC) was put and mixed

thoroughly. The water was added prior to fiber to prevent floating problems.

2 MATERIAL

Composite soils consist of two parts. The first part is soil part which can be dealt as normal soil. The second part is reinforcement part which can be made up of any material which helps soil to have better performance.

2.1 Soil Type

The soil type in this study was Western Australian clay. The properties of clay are presented in table 1.

Table1. Clay properties

No.	Type	
1	Soil type	Clay
2	Liquid Limit	49
3	Plastic Limit	23
4	Pl. Index	26

2.2 Fiber Type

The natural fiber and plastic fiber has been used for this investigation. Figure2 and figure 3 shows the used fiber. The used fiber has good potential to absorb energy and good adhesion with soil particle.



Figure. 2 Plastic fiber



Figure. 3 Natural fiber

3 TEST PROGRAM

A series of CBR tests have been conducted on reinforced clay composite. Reinforced samples prepared by putting plastic and natural fiber inside clay.

3.1 CBR Test

The California Bearing Ratio (CBR) test was developed by the California Division of Highways as a method of classifying and evaluating soil- subgrade and base course materials for flexible pavements. CBR is a measure of resistance of a material to penetration of standard plunger under controlled density and moisture conditions. CBR test may be conducted in remoulded or undisturbed sample. Test consists of causing a cylindrical plunger of 50mm diameter to penetrate a pavement component material at 1.25mm/minute. The loads for 2.5mm and 5mm are recorded. This load is expressed as a percentage of standard load value at a respective deformation level to obtain CBR value.

3.2 Main Equipments

- Mould
- Steel Cutting collar
- Spacer Disc
- Surcharge weight
- Dial gauges
- IS Sieves
- Penetration Plunger
- Loading Machine
- Miscellaneous Apparatus

Figure 3 shows the mechanism of CBR test machine.

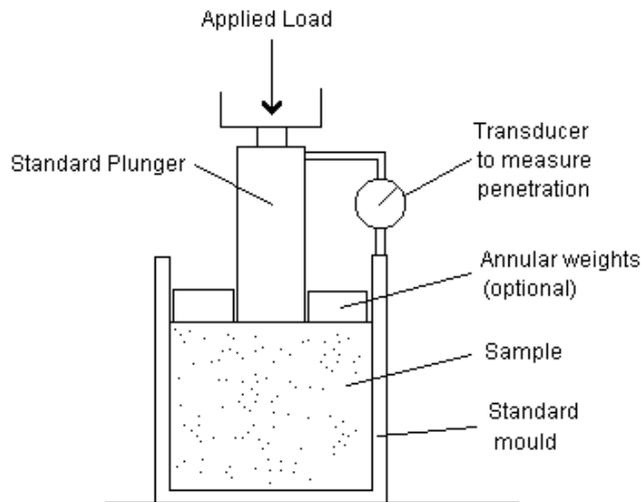


Figure. 3 Mechanism of CBR Test Machine(Gray,1983)

4 TEST METHODOLOGY AND PROCEDURE

The sample was sieved through 20mm sieve. 5kg of the sample of soil specimen was taken. Water was added to the soil in the quantity such that optimum moisture content or field moisture content was reached. Then soil and water were mixed thoroughly. Spacer disc was placed over the base plate at the bottom of mould and a coarse filter paper was placed over the spacer disc. The prepared soil water mix was divided into five. The mould was cleaned and oil was applied. Then was filled one fifth of the mould with the prepared soil. That layer was compacted by giving 56 evenly distributed blows using a hammer of weight 4.89kg. The top layer of the compacted soil was scratched. Again second layer was filled and process was repeated. After 3rd layer, collar was also attached to the mould and process was continued. After fifth layer collar was removed and excess soil was struck off. The base plate was removed and the mould was inverted. Then it was clamped to base plate. Then the normal load was applied and CBR values recorded. The fiber content and length were varied during the tests. Fiber contents were selected as 0.1%,0. 2% and 0.3%. On other hand, fiber lengths were varied from 10mm up to 50mm. For both fiber type (i.e. plastic and natural) same procedure applied.

5 RESULTS AND DISCUSSIONS

The CBR tests were performed in order to determine effect of fiber inclusion on CBR values of reinforced clayey soil. Figure 4 showed the CBR values obtained from the tests at different plastic fiber length and content. The

maximum CBR value obtained for a length of 50mm and 0.3 percent fiber content.

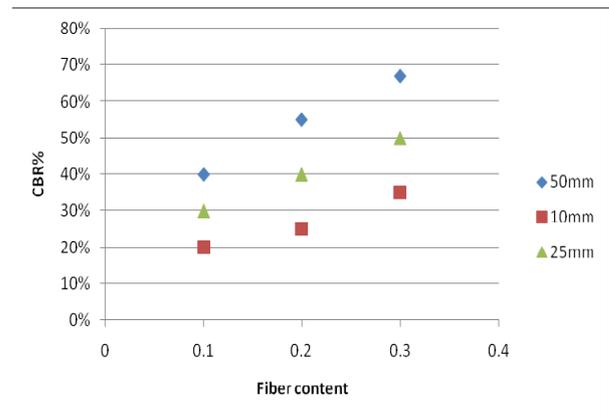


Figure. 4 results of CBR test for plastic fiber

Same procedure applied for natural fiber. Figure 5 shows the effect of fibre length and content on CBR values.

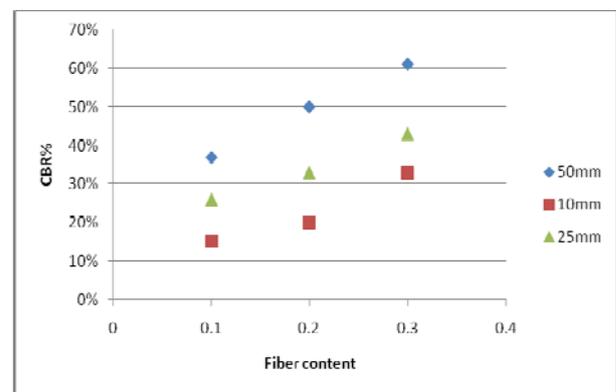


Figure. 5 results of CBR test for natural fiber

The maximum cbr value for natural fiber obtained in fiber content of 0.3% and length of 50mm. The CBR values in natural fiber were less than plastic fiber. However, the results for both types of fiber proved that fiber inclusion will be recommended for practical projects.

Two important parameters have been well investigated in this paper. The first parameter is fiber content and the second one is aspect ratio. The effect of these two parameters studied on CBR values. Two types of fiber used in this study (i.e. plastic and natural). Following results were derived:

- Increasing in fiber percentage increased CBR values in clayey samples for both natural and plastic fiber
- The results proved that with increasing in fiber length, the CBR values of composite clayey were increased for both kinds of fiber
- CBR values for case of natural fiber was less than those plastic fiber. That shows plastic would be better solution for subgrade material.
- Short and randomly Fiber inclusion showed to be reliable in industry projects as it helps to minimize the cost of projects.

ACKNOWLEDGEMENTS

The technical support from the Curtin University Laboratory is gratefully acknowledged.

REFERENCES

- [1] Akbulut, S., Arasan, S. and Kalkan, E. 2007 "Modification of clayey soils using scrap tire rubber and synthetic fibers", *Journal of Applied Clay Science* 38, 23-32.
- [2] Allan, M. L., Kukacka, L. E. 1995 "Permeability of microcracked fiber-reinforced containment barriers." *Waste Management* 15 (2), pp. 171-177.
- [3] Al Refeai, T.O. 1991 "Behaviour of granular soils reinforced with discrete randomly oriented inclusions", *Journal of Geotextiles and Geomembranes*, 10, pp. 319–333.
- [4] Cai, Y., Shi, B., Charles, W.W. Ng. & Tang, C. (2006) "Effect of polypropylene fiber and lime admixture on engineering properties of clayey soil", *Engineering Geology* 87, 230–240.
- [5] Consoli, N.C., Vendruscolo, M.A., Fonini, A. and Dalla Rosa, F. 2009 "Fiber reinforcement effects on soil considering a wide cementation range", *Geotextiles and Geomembranes* 27, pp. 196–203.
- [6] Freitag, D.R. 1986 "Soil randomly reinforced with fibers", *Journal of Geotechnical Engineering ASCE* 112 (8), pp. 823–826.
- [7] Gray, D. and Al-Rafeai, T. O. 1986. "Behavior of fabric versus fiber reinforced soil". *Journal of Geo-technical Engineering*, vol. 112, no. 8, pp. 804-820.
- [8] Gray, D. H. and Ohashi, H. 1983. "Mechanics of fiber reinforcement in soil". *Journal of Geotechnical and Geo-environmental Engineering*, ASCE, vol. 109, no. 3, pp. 335-353.
- [9] Kaniraj, S. R., Havanagi, V. G. 2001. "Behaviour of cement-stabilized fiber reinforced fly ash-soil Mixtures", *Journal of Geotech. and Geoenvironmental. Engineering* 127 (7), pp. 574-584.
- [10] Lorenzo, G. A. and Bergado, D. T. 2004. "Fundamental parameters of cement-admixed clay – New approach". *Journal of Geotechnical and Geoenvironmental Engineering*, Vol. 130, No. 10, pp. 1-9.
- [11] Michalowski, R. L., Cermak, J. 2002, "Strength anisotropy of fiber-reinforced soil". *Computers and Geotechnics*, Vol. 29, No. 4, pp. 279-299.
- [12] Kaniraj, S. R. and Havanagi, V. G. 2001. "Behavior of cement-stabilization fiber-reinforced fly ash-soil mixtures. *Journal of Geo-technical and Geo-environmental Engineering*, vol. 127, no. 7, pp. 574-584.
- [13] Maher, M. H., Ho, Y. C. 1994, "Mechanical-properties of kaolinite fiber soil composite". *J. of Geotech. Engrg, ASCE*, Vol. 120, No. 8, pp. 1381-1393.
- [14] Nataraj, M. S., Mcmanis, K. L. 1997, "Strength and deformation properties of soils reinforced with fibrillated fibers.", *Geosynthetics Int.*, Vol. 4, No. 1, pp. 65-79.
- [15] Sivakumar Babu, G.L., Vasudevan, A.K. and Haldar, S. 2008 Numerical simulation of fiber-reinforced soil behaviour, *Geotextiles and Geomembranes* 26, pp. 181–188.
- [16] Yetimoglu, T. and Salbas, O. 2003 "A study on shear strength of soils reinforced with randomly distributed discrete fibers", *Geotextiles and Geomembranes* 21 (2), pp. 103–110.
- [17] Ziegler, S., Leshchinsky, D., Ling, H. I., and Perry, E. B. 1998 "Effect of short polymeric fibers on crack development in clays. *Soils and Foundations*", *J of Applied clay science*, Vol. 38, No. 1, pp. 247-253.
- [18] Zornberg, J. G., Cabral, A. R. and Viratjandr, C. 2004 "Behavior of tire shred-soil mixtures", *Canadian Geotechnical Journal* 41 (2), pp. 227–241.
- [19] Zornberg, J. G. 2002 "discrete framework for limit equilibrium analysis of fiber-reinforcement", *Geotechnique Journal* 52 (8), pp. 227–241.

Influence of fibre inclusion on crack propagation

L'influence d'inclusion de fibre sur la propagation de première

Amin Chegenizadeh, PhD Candidate, Curtin University of Technology, Perth, Australia
achegenizadeh@yahoo.com

Prof. Hamid Nikraz, Head of the Department of Civil Engineering, Curtin University of Technology, Perth, Australia
H.Nikraz@curtin.edu.au

ABSTRACT

Desiccation cracking has been a major concern for the proper functioning of clay soils. Reinforcement of sand with discrete fibres has been well investigated in the literature. In contrast, clayey soil reinforced with discrete fibres has been less studied. Fibre-reinforcement has been considered in projects involving slope stabilization, embankment construction, subgrade stabilization, and stabilization of thin veneers such as landfill covers. Some recent researches have indicated that benefits may be gained by inclusion of discrete fibres in clay.

Influence of fibre inclusion on soil compaction parameters and crack propagation pattern have been investigated in this paper. Different type of clay and fibre were used for this investigation. The main parameters such as fibre length and percentage were changed. (i.e. Fibre length varied from 5mm to 25mm and fibre percentage varied from 0.1 to 1% as dry weight of soil). Sample size also was changed throughout this study and crack propagation pattern has been well investigated.

Image analysis was used to evaluate crack percentage. The results showed that crack propagation percentage will be reduced with adding fibre. Furthermore, compaction curve for used samples showed that inclusion of fibre caused a slight decrease in maximum dry density and increased in optimum moisture content (OMC).

Résumé

La dessiccation se fendant a été une inquiétude importante pour le fonctionnement nécessaire de sols de glaise. Le renforcement de sable avec les fibres séparées a été bien enquêté dans la littérature. Au contraire, le sol glaiseux renforcé avec les fibres séparées a été moins étudié. Le renforcement de fibre a été considéré dans les projets impliquant la stabilisation inclinée, la construction de digue, la stabilisation de sous-qualité et la stabilisation de placages fins comme les couvertures d'enfouissement des déchets. Quelques recherches récentes ont indiqué que les avantages peuvent être gagnés par l'inclusion de fibres séparées dans la glaise.

L'influence d'inclusion de fibre sur le sol compaction les paramètres et le dessin de propagation de première a été enquêtée dans ce papier. Le différent type de glaise et de fibre a été utilisé pour cette enquête. Les paramètres principaux comme la longueur de fibre et le pourcentage ont été changés. (c'est-à-dire. La longueur de fibre variait de 5 millimètres à 25 millimètres et à pourcentage de fibre varié de 0.1 à 1 % comme le poids sec de sol). La grandeur de promotion a aussi été changée au cours de cette étude et le dessin de propagation de première a été bien enquêté.

L'analyse d'image a été utilisée pour évaluer le pourcentage de première. Les résultats ont montré que le pourcentage de propagation de première sera réduit avec l'ajoutant de la fibre. En outre, compaction la courbe pour les échantillons utilisés a montré que l'inclusion de fibre a provoqué une augmentation faible dans la densité sèche maximum et la diminution dans la teneur en humidité optimale (OMC).

Keywords: Crack, Fibre, Compaction

1 INTRODUCTION

In conventional application of reinforcement in soil, the inclusion of tire, bars, grids etc are usually in a preferred orientation. The advances of these materials have usually been considered by an increase in their applications. The randomly discrete fibers are easily added and mixed randomly with soil part, the same way as cement, lime or other additives. Some researches have been done on cement additive (Consoli et.al. 2009; Cai et.al 2006; Lorenzo and Bergado, 2004) and can be used as a pattern of additive usage in soil. Fibre reinforced composite shows more ductility and small losses of peak strength i.e. in compared to unreinforced material. Therefore, fiber-reinforced soil composite is a practical solution in civil engineering projects. The main application of composite soil can be in embankment, subgrade, subbase, and slope stability problems. However, the data concerning the effects of fiber inclusion on the characteristics of compacted native or virgin soils are limited, (Maher and Ho, 1993). This shortage is more considerable in pavement engineering and land-fill systems in terms of crack control. Limited attempts have been made to control clay cracking by fibre reinforcement (Allan and Kukacka, 1995; Al Wahab and El-Kedrah, 1995; Ziegler et al., 1998). Miller and Rifai (2004) studied the effects of fibre reinforcement on the development of desiccation cracking in compacted clay samples. Therefore, the significance this study is to evaluate the effect of fibre inclusion on crack propagation in clayey soil. The application of controlling crack cause significant improvement in land fill systems and pavement engineering as cracking which lead these systems to be failed in the real civil projects.

2 MATERIAL

Composite soils consist of two parts. The first part is soil part which can be dealt as normal soil. The second part is reinforcement part which can

be made up of any material which helps soil to have better performance.

2.1 Soil Type

The soil type in this study was kaolin clay. The properties of clay are presented in table 1. This type of kaolin clay is widely used in industrial project and research activities in Western Australia.

Table 1. Clay properties

No.	Size (cm)	
1	Soil type	Clay
2	Liquid Limit	49
3	Plastic Limit	23
4	Pl. Index	26

2.2 Fiber Type

The plastic fiber has been used for this investigation. Figure1 shows the used fiber. The used fiber has good potential to absorb energy and good adhesion with soil particle.



Figure. 1 Plastic fiber

3 TEST PROGRAM

Test program in this study includes two parts. First part is series of cracking test were conducted to investigate the effect of fibre inclusion

on cracking phenomenon. The second part is compaction test to find out the effect of fibre content on compaction characteristics of clayey soil.

3.1 Main Equipments

- Metal container for cracking test
- Electrical light for cracking test
- Balance for cracking test
- Rammer for Compaction test
- Mould for Compaction test

Figure 2 shows the metal container which was used to run the crack test.



Figure 2. Metal Container used for cracking test

4 SAMPLE PREPARATION FOR CRACK TEST

The soil was passed through a 4mm sieve in order to obtain a consistent mixture once water had been added. The cured soil would be sealed in a couple of plastic bags to prevent moisture loss. When placing soil at 45% moisture content into containers, they were continuously tapped to surface any trapped air bubbles in the soil. Cling wrap was used to smoothen the surface of each sample as well as provide a cover to prevent moisture loss when allowing the soil to settle

over night. The surface of the sample was a circle with 50mm and thickness was 10mm.

5 TEST METHODOLOGY AND PROCEDURE

Experimental program was included two parts: first cracking tests and secondly compaction test.

5.1 Cracking test

To run the cracking test following steps were taken:

- Putting soil into container
- Making sure that moisture content is as what required (i.e. 45%)
- Setting up the height of light faced to sample precisely on 1m
- Using digital camera to record image of soil specimen every hour
- Extracting of images to analysis of crack pattern
- Crack Intensity Factor is considered as ratio of crack area to total surface of sample.

The figure 3 shows the sketch of experimental set-up which used to run the cracking tests. As previously mentioned the flood light used to run cracking test. The soil in metal container is directly faced to flood light.

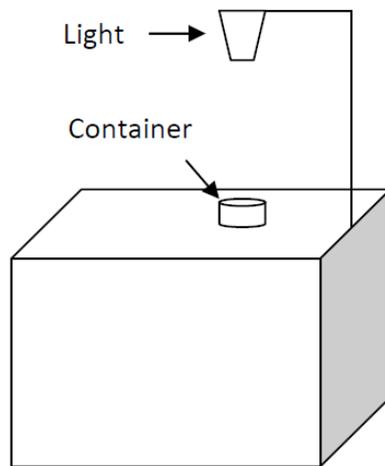


Figure 3. Cracking test procedure sketch

5.2 Compaction test

Compaction test also conducted to observe the effect of fibre inclusion on compaction parameters clayey composite.

The test procedure can be listed as:

- About 4.5 kg of air-dried soil was put in the mixing pan so that it could pass No. 4 sieve.
- The moisture content was increased by about 5%.
- The weight of empty mould without the base plate and the collar was recorded as W_1 (gr).
- The collar and base plate was fixed and the first soil part was compacted with 25 blows in proctor mould
- Some scratches were put with a spatula forming a grid to ensure uniformity in distribution of compaction energy to the subsequent layer. The second and third layer was placed and 25 blows were applied.

- The final layer was placed so that the compacted soil is just above the rim of the compaction mould when the collar is still attached.
- The collar carefully was detached without disturbing the compacted soil inside the mould and edge was used to trim the excess soil levelling to the mould.
- The weight of the mould with the moist soil W_2 , (gr) was determined.
- Sample was extruded the sample and evaluated for water content in some cans
- The rest of the compacted soil was broken with hand to pass US Sieve No.4. and moisture content was increased by 2%.
- Steps repeated again for different moisture contents.
- Different fibre contents (i.e. 0.1% and 1%) were used.
- The dry density plotted versus moisture contents for unreinforced clay and reinforced clay

6 RESULTS AND DISCUSSIONS

In this section the results of cracking tests and compaction tests are presented.

6.1 Result of cracking test

A series of cracking tests were conducted and following results obtained. Table 2 shows the crack density with different fibre content and length. Crack density factor was computed based on image processing and obtaining the ratio of crack to total surface area.

Table 2. Crack density versus fibre content

Fibre Percentage	Fibre length	Crack Intensity Factor
No fibre		5.28
0.1%	5mm	3.4
0.1%	25mm	2.85
1%	5mm	0.37
1%	25mm	0.24

Figure 4,5,6,7 and 8 show the images from different fibre contents. The results proved that with increasing in fibre content and length crack density decreased rapidly.

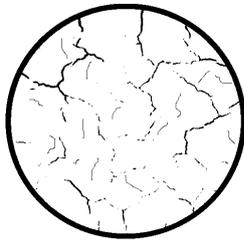


Figure 4. The crack propagation without fibre

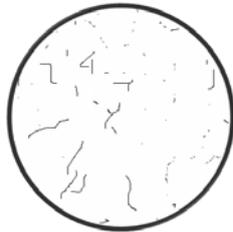


Figure 5. The crack propagation 0.1% fibre with 5mm length

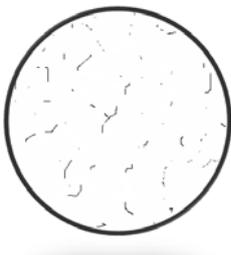


Figure 6. The crack propagation 0.1% fibre with 25mm length

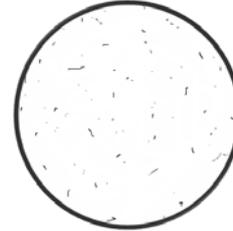


Figure 7. The crack propagation 1% fibre with 5mm length

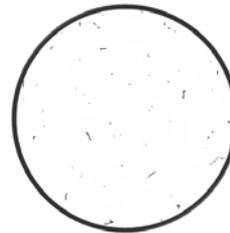


Figure 8. The crack propagation 1% fibre with 25mm length

The results from cracking test proved that increasing in fibre content and fibre length decreased the Crack Intensity Factor (CIF). Therefore, fibre inclusion is good solution to solve the cracking problem of clayey soil.

6.2 Result of compaction test

Compaction tests were conducted in order to determine effect of fiber inclusion on compaction characteristics of reinforced clay. Figure 9 showed the compaction curve obtained from the tests. The presented results in figure 9 are at fiber length of 25mm.

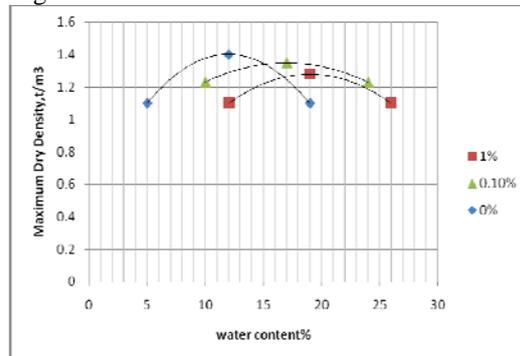


Figure 9 Results of compaction test in different fiber content (at 25mm)

Figure 9 proved increasing in fiber content will decrease the maximum dry density and increased OMC.

7 CONCLUSION

A series of cracking on cylindrical clayey soil with 50 mm diameter and 10 mm thickness, were conducted and following results obtained:

- 1- Using fibre caused huge decrease in crack intensity factor
- 2- Increasing in fibre length and content directly decreased the crack
- 3- Image processing proved that can be used as useful tool in further crack analysis

Compaction tests were also conducted on composite clayey soil. This investigation proved that:

- 4- Maximum dry density showed slight decrease due to induction of fiber and with increasing in fibre content maximum dry density decreased
- 5- Optimum Moisture Content (OMC) increased with increasing in fiber content.

ACKNOWLEDGEMENT

The technical support from the Curtin University Laboratory is gratefully acknowledged.

REFERENCES

- [1] Akbulut, S., Arasan, S. and Kalkan, E., Modification of clayey soils using scrap tire rubber and synthetic fibers, *Journal of Applied Clay Science* 38(2007), 23-32.
- [2] Allan, M. L., Kukacka, L. E. (1995) "Permeability of microcracked fibre-reinforced containment barriers." *Waste Management*, Vol. 15, No. 2, pp. 171-177.
- [3] Al Rafeai, T.O. Behaviour of granular soils reinforced with discrete randomly oriented inclusions, *Journal of Geotextiles and Geomembranes*, 10, (1991) pp. 319-333.
- [4] Cai, Y., Shi, B., Charles, W.W. Ng. & Tang, C. ,Effect of polypropylene fiber and lime admixture on engineering properties of clayey soil, *Engineering Geology* 87, (2006),230– 240.
- [5] Consoli, N.C., Vendruscolo, M.A., Fonini, A. and Dalla Rosa, F. ,Fiber reinforcement effects on sand considering a wide cementation range, *Geotextiles and Geomembranes* 27, (2009) , pp. 196–203.
- [6] Dvorak, G.K. and Bahei-El-Din, Y.A. ,Plasticity analysis of fibrous composites, *Journal of Applied Mechanics* 49, (1982) , pp. 327–335.
- [7] Freitag, D.R. ,Soil randomly reinforced with fibers, *Journal of Geotechnical Engineering ASCE* 112 (8), (1986) ,pp. 823–826.
- [8] Gray, D. and Al-Rafeai, T. O. .Behavior of fabric versus fiber reinforced sand,. *Journal of Geo-technical Engineering*, vol. 112, no. 8, (1986),pp. 804-820.
- [9] Gray, D. H. and Ohashi, H. ,Mechanics of fiber reinforcement in sand,. *Journal of Geotechnical and Geoenvironmental Engineering*, ASCE, vol. 109, no. 3, (1983) pp. 335-353.
- [10] Lorenzo, G. A. and Bergado, D. T. ,Fundamental parameters of cement-admixed clay – New approach,. *Journal of Geotechnical and Geoenvironmental Engineering*, Vol. 130, No. 10, (2004). , pp. 1-9.
- [11] Kaniraj, S. R. and Havanagi, V. G ,Behavior of cement-stabilization fiber-reinforced fly ash-soil mixtures. *Journal of Geo-technical and Geo-environmental Engineering*, vol. 127, no. 7, (2001) .,pp. 574-584.
- [12] Maher, M. H., Ho, Y. C. ,Mechanical-properties of kaolinite fiber soil composite,. *J. of Geotech. Engrg*, ASCE, Vol. 120, No. 8, (1994),pp. 1381-1393.
- [13] Nataraj, M. S., Mcmanis, K. L., Strength and deformation properties of soils reinforced with fibrillated fibers., *Geosynthetics Int.*, Vol. 4, No. 1, (1997), pp. 65-79.
- [14] Sivakumar Babu, G.L., Vasudevan, A.K. and Haldar, S. (2008) Numerical simulation of fiber-reinforced sand behaviour, *Geotextiles and Geomembranes* 26, pp. 181–188.
- [15] Waldron, L. J.,Shear resistance of root-permeated homogeneous and stratified soil., *Soil Society. Of American Journal*41,(1977). (5), pp. 843–849.
- [16] Yetimoglu, T. and Salbas, O.,A study on shear strength of sands reinforced with randomly distributed discrete fibers, *Geotextiles and Geomembranes* 21, (2003) (2), pp. 103–110.
- [17] Ziegler, S., Leshchinsky, D., Ling, H. I., and Perry, E. B., Effect of short polymeric fibers on crack development in clays. *Soils and Foundations*, *J of Applied clay science*, Vol. 38, No. 1, (1998),pp. 247-253.
- [18] Zornberg, J. G., Cabral, A. R. and Viratjandr, C. ,Behavior of tire shred-sand mixtures, *Canadian Geotechnical Journal* 41 (2), (2004), pp. 227–241.
- [19] Zornberg, J. G. ,discrete framework for limit equilibrium analysis of fiber-reinforcement, *Geotechnique Journal* 52 (8), (2002) , pp. 227–241.
- [20] H. Nahlawi and J.K. Kodikara, Laboratory experiments on desiccation cracking of thin soil layers *Geotechnical and Geological Engineering* (2006) 24: 1641–1664

Laboratory Investigation on Strength of Clay Composite

Amin Chegenizadeh

PhD candidate, Department of Civil Engineering, Curtin University of Technology, Perth, Australia; Tel: +61-413165961; Fax: +61 8 9266 2681; Email: amin.chegenizadeh@postgrad.curtin.edu.au

Professor Hamid Nikraz

Head of the Department of Civil Engineering, Curtin University of Technology, Perth, Australia; Tel: +61 8 9266 7573; Fax: +61 8 9266 2681; Email: H.Nikraz@curtin.edu.au

ABSTRACT: Reinforced soil has been among the most effective soil modification materials. Its use has been expanded rapidly into civil engineering, geotechnical engineering and pavement engineering. This study focuses on effect of fiber inclusion on the unconfined compressive strength of composite soil. Plastic fiber was used for this investigation. Fibers were put in composite in random orientation. Fiber contents and aspect ratio have been changed during these tests. The fiber percentage varied from 0 % (for unreinforced samples) to 0.6%. Kaolin Clay was selected as soil. Moreover, effect of fiber inclusion well investigated on cemented clay as well. Unconfined compression tests were carried out to evaluate the behaviour of the composite under different loading condition. The results showed that the unconfined compressive strength of fiber reinforced composite soil was increased by increasing in fiber content and fiber aspect ratio. The fiber aspect ratio and fiber content found to play important rule on the strength of fiber composite clay.

1 INTRODUCTION

The paper presents the effect of fiber inclusion on unconfined compressive strength of clay composite. Applications of soil strengthening or stabilization range from the mitigation of complex slope hazards to enhancing the subgrade stability. Together with the many applications for improving soil, there are several widely varied methods. Chemical stabilization by cement or lime is a proven technique for improving the performance (strength and stabilization) of soil (Ismail et al., 2002; Aiban, 1994; Huang and Airey, 1998; Basha et al., 2005; Koliass et al., 2005; Sherwood, 1993; Al-Rawas, 2002; Tremblay et al., 2002; Lima et al., 1996; Thome, 1999). However, these chemical additives usually result in a high stiffness and brittle behavior (Wang et al., 2003; Basha et al., 2005). The mixing of randomly oriented fibers to a soil sample may be considered same as other admixtures used to stabilize soil. Materials which are

used to make fibers for reinforcement may be obtained from paper, metal, nylon, polyester and other materials having widely varied physical properties. There have been numerous past papers published on the topic of fiber strengthening of soils. Examples include Lee et al., 1973, Hoare, 1979, Andersland and Khattac, 1979, Freitag, 1986, Gray and Ohashi, 1983, Gray and Rafeai, 1986, Maher and Gray 1990, Maher and Ho, 1994, Michalowski and Zhao 2002, Ranjan et al. 1996, Kaniraj and Havanagi 2001, Consoli et al. 2009. All of the papers listed above indicated that; strength of the soil was improved by fiber reinforcement. The investigation on clay composite is very limited. The purpose of this survey is to evaluate clay behaviour induced by fiber inclusion. Furthermore, effect of cement on clay composite also investigated in this study.

2 MATERIAL

Composite soils consist of two parts. The first part is soil part which can be dealt as normal soil. The second part is reinforcement part which can be made up of any material which helps soil to have better performance.

2.1 Soil Type

The soil type in this study was kaolin clay. The properties of clay are presented in table 1. This type of kaolin clay is widely used in industrial project and research activities in Western Australia.

Table 1. Clay properties

No.	Size (cm)	
1	Soil type	Clay
2	Liquid Limit	49
3	Plastic Limit	23
4	Pl. Index	26

2.2 Fiber Type

The plastic fiber has been used for this investigation. Fig1 shows the used fiber. The used fiber has good potential to absorb energy and good adhesion with soil particle.



Fig. 1 Plastic fiber

2.3 Cement Type

Portland cement type IV was used in this study. Type IV Portland cement is generally known for its low heat of hydration. Its normal compound composition is:

28% (C3S), 49% (C2S), 4% (C3A), 12% (C4AF), 1.8% MgO, 1.9% (SO₃), 0.9% Ignition loss, and 0.8% free CaO.

The percentages of (C2S) and (C4AF) are relatively high and (C3S) and (C3A) are relatively low. A limitation on this type is that the maximum percentage of (C3A) is seven, and the maximum percentage of (C3S) is thirty-five. This causes the heat given off by the hydration reaction to expand at a slower rate. However, as a result the strength of the concrete develops slowly. After one or two years the strength is more than the other types after full curing. This cement is used for very large concrete structures, such as dams, which have a low surface to volume ratio. This kind of cement is generally not stocked by manufacturers but some might consider a large special order. This type of cement has not been made for many years, because Portland-pozzolan cements and ground granulated blast furnace slag addition offer a cheaper and more reliable option.

3 TEST PROGRAM

A series of unconfined compression have been performed on reinforced clay composite.

3.1 Unconfined Compression Test

The unconfined compression test applies uniaxial stress conditions on a sample of soil, and is therefore a special case of the triaxial test with no confining stress. The unconfined compression test has a considerable cost advantage over triaxial test due to the simpler testing requirement. The limitation of this test can be named as: preparing stable sample for cohesionless material and undrained estimation due to quick test.

3.2 Main Equipments

To run the test, tools are needed as:

- Unconfined compression testing machine (Triaxial Machine)
- Specimen preparation equipment
- Sample extruder
- Fiber

- Balance

Fig 2 shows the triaxial base which was used to run the UCS test. The device is fully automated so the results easily transferred without any user interference.



Fig. 2 Triaxial Base

4 SAMPLE PREPARATION

The samples were provided by mixing clay and three percentage of fiber. Specimen preparation procedure was the standard compaction method, which was used in an ongoing experimental research on fiber-reinforced clay at Curtin University. The soils were first oven-dried. The dry soils were then crushed using a hammer. A mixer was used to thoroughly mix the soils with water to obtain the desired water moisture content for compaction. The mixing of soil with fibers was performed mostly by hand rather than using the mixer because the mixer caused the fibers to tangle or break. The fiber-soil mixture was placed in a closed container for 24 hours after mixing was completed. A split mould and a specific hammer were used to compact the specimen. The specimens were prepared in different fiber content (i.e. 0.2%, 0.4%, and 0.6 %) and different fiber length (aspect ratio) which were 10mm, 20mm, 30mm. For the cemented samples 0.5% of type IV Portland cement mixed with soil.

5 TEST METHODOLOGY AND PROCEDURE

The test procedure can be listed as:

- The specimens were prepared in the laboratory with 90% compaction effort, special care was taken during this process
- The size of samples were checked to be suitable for the test purpose
- The samples were put for 24 hours in geotextile and packed
- Special attention was applied for preventing any moisture loose
- The samples were placed in triaxial base without any confinement pressure
- According to ASTM 1.27 mm/min were applied through the tests
- The data was collected automatically

The stress-strain curve plot used for strength behavior investigation

6 RESULTS AND DISCUSSIONS

The unconfined compression tests were conducted in order to determine effect of fiber inclusion on Unconfined Compressive Strength (UCS). The tests were included two parts. First part was to consider the effect of fiber inclusion on normal kaolin clay. The second part was related to effect of fiber inclusion on cemented clay. The cemented clay was constructed with 0.5% of cement content.

6.1 *Effect of fiber on normal clay*

The tests were conducted on cylindrical specimen of 60 mm diameter and 170 mm height. Fig 3 showed the stress-strain curve obtained from the tests. The results in Fig 3 proved that strength of the composite increased with increasing in fiber content. It should be noted that the results in Fig 3 is at fiber length 10mm.

6.2 Effect of fiber on cemented clay

In this section, effect of fiber inclusion investigated on cemented clay. As previously mentioned, the cemented samples were provided by 0.5% of cemented material. Similar to previous section, UCS tests were performed and following results obtained. Fig 5 indicates the effect of fiber content on UCS of composite cemented clay.

As it can be seen inclusion of fiber in cemented specimen increased the strength of the composites. More importantly, usage of cement in soil will increase the brittle behaviour of the composite. The results proved that usage of fiber will help to increase ductility of the cemented clay.

Therefore, fiber inclusion would be an option to solve the brittle behaviour of cemented composite. It should be noted that results in Fig 5 is at constant fiber length of 10mm.

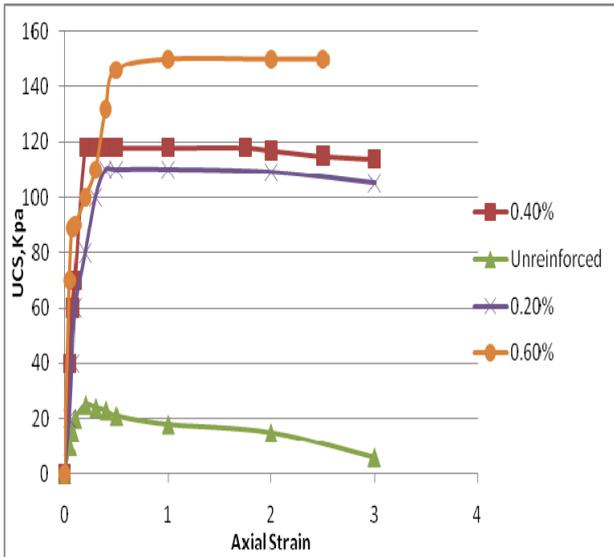


Fig. 3 UCS results with different fiber content (at 10mm fiber length)

The presented results in Fig 4 are at fiber content of 0.2%. Fig 4 shows effect of fiber length on composite samples. As can be found from the results, with increasing in fiber length, strength of composite was increased.

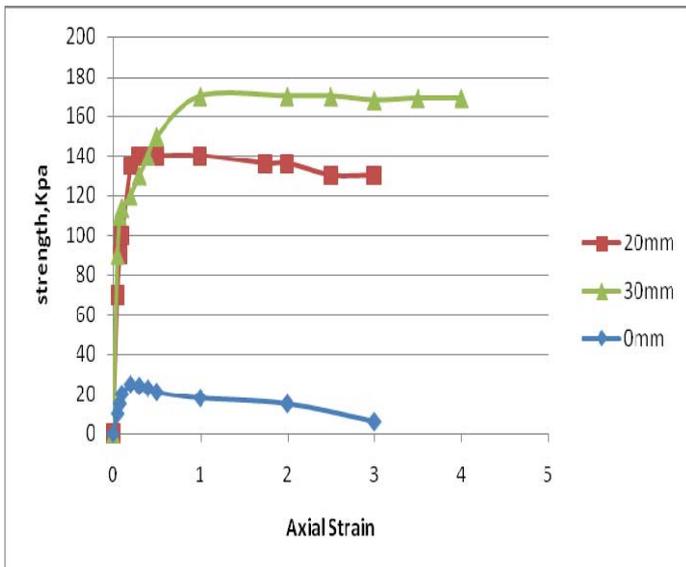


Fig. 4 UCS results with different fiber length(at fiber content of 0.2%)

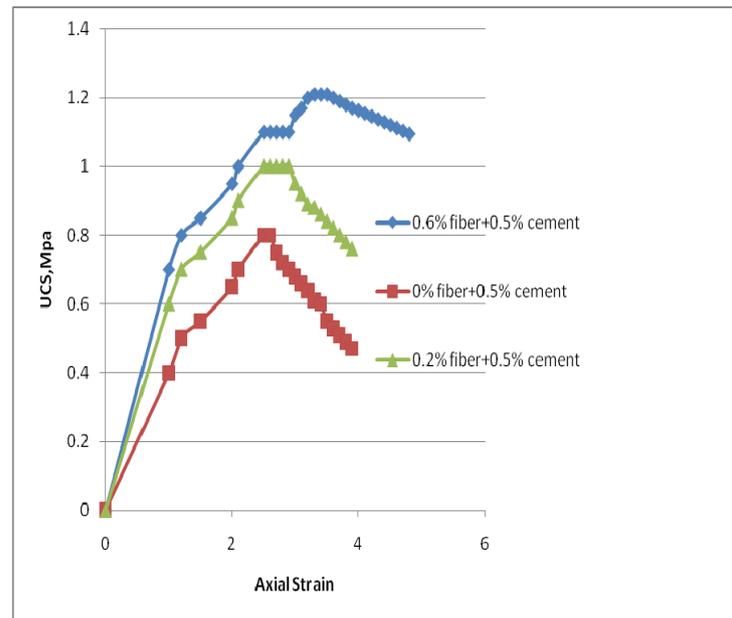


Fig. 5 UCS results with different fiber content (at 10mm fiber length)

Fig 6 shows the effect of fiber length on clayey cemented composite. As, it can be observed the strength of the composite increased with increasing in fiber length.

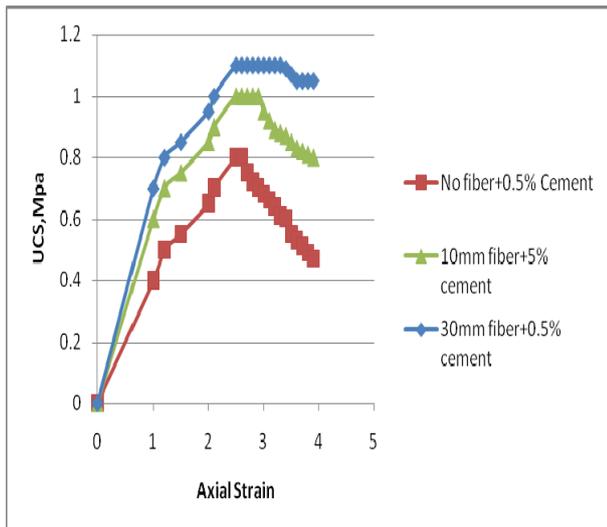


Fig. 6 UCS results with different fiber content(at 2% fiber content)

7 CONCLUSION

A series of Unconfined Compression Test were performed to evaluate the effect of fiber inclusion on strength behaviour of composite material. The following results were derived:

- Increasing in fiber percentage increased strength in clay samples
- During the test, it was observed that ductility behaviour of reinforced clay increased because of fiber inclusion.
- The results proved that with increasing in fiber length, the UCS of composite clay was increased.
- The effect of fiber on cemented clayey composite observed in this study. The results proved that with increasing in fiber content the strength of composite increased.
- Fiber inclusion can be a good solution for cemented soil as it helps composite to have more ductile behaviour.
- Short and randomly Fiber inclusion showed to be reliable in industry projects as it helps to minimize the cost of projects.

ACKNOWLEDGEMENTS

The technical support from the Curtin University Laboratory is gratefully acknowledged

References

- Aiban, S.A., 1994. A study of sand stabilization in Eastern Saudi Arabia. *Engineering Geology* 38, 65 – 97.
- Akbulut, S., Arasan, S. and Kalkan, E. (2007) "Modification of clayey soils using scrap tire rubber and synthetic fibers", *Journal of Applied Clay Science* 38, 23-32.
- Al Refeai, T.O. (1991) "Behaviour of granular soils reinforced with discrete randomly oriented inclusions", *Journal of Geotextiles and Geomembranes*, 10, pp. 319–333.
- Basha, E.A., Hashim, R., Mahmud, H.B., Muntobar, A.S., 2005. Stabilization of residual soil with rice husk ash and cement. *Construction and Building Materials* 19 (6), 448 – 453.
- Cai, Y., Shi, B., Charles, W.W. Ng. & Tang, C. (2006) "Effect of polypropylene fiber and lime admixture on engineering properties of clayey soil", *Engineering Geology* 87, 230–240.
- Consoli, N.C., Vendruscolo, M.A., Fonini, A. and Dalla Rosa, F. (2009) "Fiber reinforcement effects on sand considering a wide cementation range", *Geotextiles and Geomembranes* 27, pp. 196–203.
- Freitag, D.R. (1986) "Soil randomly reinforced with fibers", *Journal of Geotechnical Engineering ASCE* 112 (8), pp. 823–826.
- Gray, D. and Al-Rafeai, T. O. (1986). "Behavior of fabric versus fiber reinforced sand". *Journal of Geo-technical Engineering*, vol. 112, no. 8, pp. 804-820.
- Gray, D. H. and Ohashi, H. (1983). "Mechanics of fiber reinforcement in sand". *Journal of Geotechnical and Geoenvironmental Engineering*, ASCE, vol. 109, no. 3, pp. 335-353.
- Huang, J.T., Airey, D.W., 1998. Properties of artificially cemented carbonate sand. *Journal of Geotechnical and Geoenvironmental Engineering* 124 (6), 492 – 499.
- Ismail, M.A., Joer, H.A., Sim, W.h., Randolph, M., 2002. Effect of cement type on shear behavior of cemented calcareous soil. *Journal of Geotechnical and Geoenvironmental Engineering* 128 (6), 520 – 529.
- Lorenzo, G. A. and Bergado, D. T. (2004). "Fundamental parameters of cement-admixed clay – New approach". *Journal of Geotechnical and Geoenvironmental Engineering*, Vol. 130, No. 10, pp. 1-9.
- Michalowski, R. L., Cermak, J. (2002), "Strength anisotropy of fiber-reinforced sand". *Computers and Geotechnics*, Vol. 29, No. 4, pp. 279-299.
- Kaniraj, S. R. and Havanagi, V. G. (2001). "Behavior of cement-stabilization fiber-reinforced fly ash-soil mixtures. *Journal of Geo-technical and Geo-environmental Engineering*, vol. 127, no. 7, pp. 574-584.
- Maher, M. H., Ho, Y. C. (1994), "Mechanical-properties of kaolinite fiber soil composite". *J. of Geotech. Engrg*, ASCE, Vol. 120, No. 8, pp. 1381-1393.
- Nataraj, M. S., Mcmanis, K. L. (1997), "Strength and deformation properties of soils reinforced with fibrillated fibers.", *Geosynthetics Int.*, Vol. 4, No. 1, pp. 65-79.
- Sivakumar Babu, G.L., Vasudevan, A.K. and Haldar, S. (2008) Numerical simulation of fiber-reinforced sand behaviour, *Geotextiles and Geomembranes* 26, pp. 181–188.
- Tremblay, H., Duchesne, J., Locat, J., Leroueil, S., 2002. Influence of the nature of organic compounds on fine soil

- stabilization with cement. *Canadian Geotechnical Journal* 39, 535 – 546.
- Sherwood, P., 1993. Soil stabilization with cement and lime. State of the art review, Transport Research Laboratory.
- Yetimoglu, T. and Salbas, O. (2003) "A study on shear strength of sands reinforced with randomly distributed discrete fibers", *Geotextiles and Geomembranes* 21 (2), pp. 103–110.
- Ziegler, S., Leshchinsky, D., Ling, H. I., and Perry, E. B. (1998) "Effect of short polymeric fibers on crack development in clays. *Soils and Foundations*", *J of Applied clay science*, Vol. 38, No. 1, pp. 247-253.
- Zornberg, J. G., Cabral, A. R. and Viratjandr, C. (2004) "Behavior of tire shred-sand mixtures", *Canadian Geotechnical Journal* 41 (2), pp. 227–241.
- Zornberg, J. G. (2002) "discrete framework for limit equilibrium analysis of fiber-reinforcement", *Geotechnique Journal* 52 (8), pp. 227–241.

Randomly Distributed Fiber Effect on Compaction of Composite Sand

Amin Chegenizadeh

PhD candidate, Department of Civil Engineering, Curtin University of Technology, Perth, Australia; Tel: +61-413165961; Fax: +61 8 9266 2681; Email: amin.chegenizadeh@postgrad.curtin.edu.au

Professor Hamid Nikraz

Head of the Department of Civil Engineering, Curtin University of Technology, Perth, Australia; Tel: +61 8 9266 7573; Fax: +61 8 9266 2681; Email: H.Nikraz@curtin.edu.au

ABSTRACT: Composite soils have been widely used in civil engineering applications, especially in slopes, embankment dam and landfills. This paper aims to investigate effect of fiber inclusion on compaction characteristic of composite soil (i.e. sand composite). A series of laboratory tests carried out to evaluate fiber effect on optimum water content and maximum dry unit weight of composite soils. Sand was selected as soil part of the composite and plastic fiber was used as reinforcement. The fiber parameters differed from one test to another, as fiber length varied from 10 mm to 30mm and fiber content were selected as 0.5% and 1%. For each test, compaction curved derived and the results were compared. The results proved that inclusion of fiber affected compaction behaviour of samples so that increasing in fiber content and length caused increasing in Optimum Moisture Content (OMC) and slightly decreased maximum dry unit weight.

1 INTRODUCTION

Fletcher and Humphries (1991) investigated influence of fiber inclusion on compaction of silty clay soil. Unlike the case of sandy gravel reported by Hoare (1977), the test results indicated that increasing the fiber content causes a modest decrease in the maximum dry unit weight. The optimum water content was found to increase by increasing fiber content. Other researchers (Nataraj and McManis, 1997; Al Wahab and El-Kedrah, 1995; Puppala et al., 2006; Miller and Rifai, 2004; Ozkul et al., 2007; Kumar Tabor, 2003) also reported similar results. In contrast, some researchers such as Ozkul et al, 2007 reported not significant changes on compaction parameter by fiber inclusion. Therefore, the problem of effect of fiber inclusion on compaction parameter needs to be investigated precisely. Authors believe that different research results are due to different material which each researcher has used. This paper aims to inves-

tigate influences that are induced by fiber inclusion on compaction characteristics.

2 MATERIAL

Composite soils consist of two parts. The first part is soil part which can be dealt as normal soil. The second part is reinforcement part which can be made up of any material which helps soil to have better performance. Usage of additional material with soil is mainly because of tensile strength of the soil.

2.1 Soil Type

The soil type in this study was Western Australian Sand. The Particle Size Distribution (PSD) of used sand is presented in figure 1. This type of sand is widely used in industrial project and research activities in Western Australia.

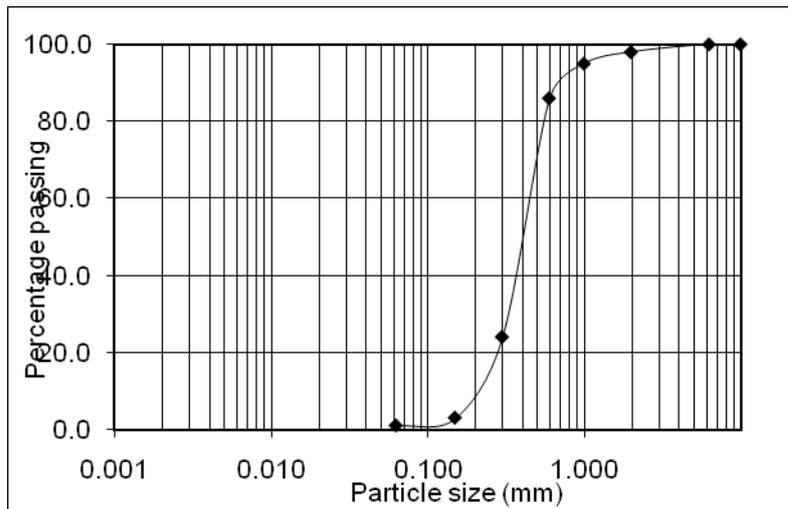


Fig. 1 Particle Size Distribution of Sand

2.2 Fiber Type

The plastic fiber has been used for this investigation. Figure 2 shows the used fiber. The used fiber has good potential to absorb energy and good adhesion with soil particle.



Fig. 2 Plastic fiber

3 TEST PROGRAM

A series of compaction test have been performed on reinforced sand composite.

3.1 Compaction test

Soil compaction is a mean to increase the density of soil. In geotechnical projects, soil density is an important parameter. Any difficulty related to compaction may cause settlement of the soil and as a consequence unnecessary maintenance costs or structure failure. Therefore, all types of construction sites and construction projects take special care in mechanical compaction method.

3.2 Main Equipments

To run the test, tools are needed as:

- Proctor mould with a detachable collar assembly and base plate.
- Manual rammer weighing 2.5 kg and equipped with height of drop to a free fall of 30 cm (for standard method)
- Sample Extruder.
- A sensitive balance.
- Straight edge.
- Moisture cans.
- Drying Oven

Figure 3 shows rammer which was used to compact the soil. Figure 4 shows the used mould and base.



Fig. 3 Standard compaction rammer



Fig. 4 Mould and Base

4 TEST METHODOLOGY AND PROCEDURE

The test procedure can be listed as:

1. About 4.5 kg of air-dried soil was put in the mixing pan so that it could pass No. 4 sieve.
2. The moisture content was increased by about 5%.
3. The weight of empty mould without the base plate and the collar was recorded as W_1 (gr).
4. The collar and base plate was fixed and the first soil part was compacted with 25 blows in proctor mould
5. Some scratches were put with a spatula forming a grid to ensure uniformity in distribution of compaction energy to the subsequent layer. The second and third layer was placed and 25 blows were applied 25 blows.
6. The final layer was placed so that the compacted soil is just above the rim of the compaction mould when the collar is still attached.
7. The collar carefully was detached without disturbing the compacted soil inside the mould and edge was used to trim the excess soil leveling to the mould.
8. The weight of the mould with the moist soil W_2 , (gr) was determined.
9. Sample was extruded the sample and evaluated for water content in some cans

10. The rest of the compacted soil was broken with hand to pass US Sieve No.4. and moisture content was increased by 2%.

11. Steps 1 to 10 repeated again for different moisture contents.

12. The dry density plotted versus moisture contents

5 TEST DESIGN

The tests were designed systematically so that the effect of each fiber parameters (i.e. length and content) can be obtained. For reinforced samples, special care was taken for achieving uniformity of mixture while compaction procedure. First series of the test was related to effect of fiber content. In these test fiber content changed while fiber length was constant. The fiber percentage were 0.5% and 1% with constant fiber length of 10mm.

The second round was related to effect of fiber length. Therefore, different fiber length (i.e. 10 and 30mm) with constant fiber content of 0.5% were evaluated. Finally all results compared with unreinforced samples.

6 RESULTS AND DISCUSSIONS

Figure 5 and 6 present the results of compaction test on reinforced sand composite.

Figure 5 shows the effect of fiber content on maximum dry density and Optimum Moisture Content (OMC). As can be seen increasing in fiber content caused decreasing in maximum dry density and increasing in OMC

Figure 6 indicates the effect of fiber length (aspect ratio) on compaction curve. The results proved that increasing in fiber aspect ratio caused decreasing in maximum dry density and increasing OMC.

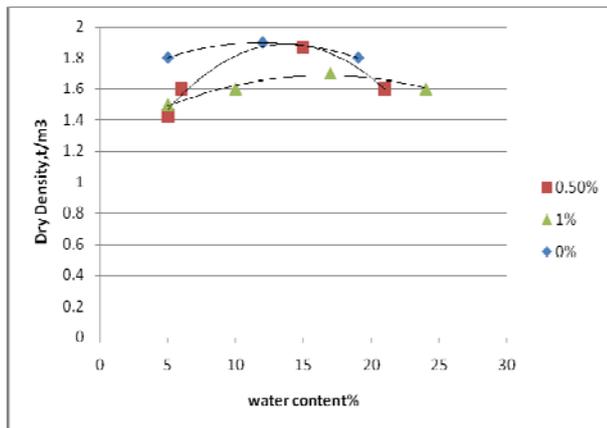


Fig. 5 Compaction test results with different fiber content

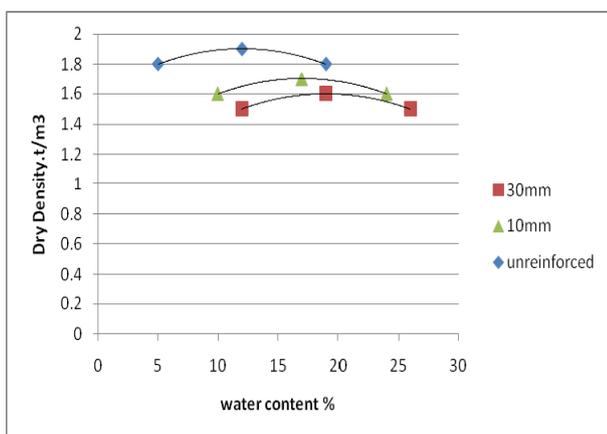


Fig. 6 Compaction test results with different fiber length

7 CONCLUSION

A series of compaction test were performed to evaluate the effect of fiber inclusion on OMC and maximum dry density of composite sand. The following results were derived:

- Increasing in fiber percentage increased OMC of sand samples and decreased maximum dry density.
- The results proved that with increasing in fiber length, the OMC of composite sand was increased and decreased maximum dry density.

ACKNOWLEDGEMENTS

The technical support from the Curtin University Laboratory is gratefully acknowledged

References

- [1] Akbulut, S., Arasan, S. and Kalkan, E. (2007) "Modification of clayey soils using scrap tire rubber and synthetic fibers", *Journal of Applied Clay Science* 38, 23-32.
- [2] Al Refeai, T.O. (1991) "Behaviour of granular soils reinforced with discrete randomly oriented inclusions", *Journal of Geotextiles and Geomembranes*, 10, pp. 319-333.
- [3] Cai, Y., Shi, B., Charles, W.W. Ng. & Tang, C. (2006) "Effect of polypropylene fiber and lime admixture on engineering properties of clayey soil", *Engineering Geology* 87, 230- 240.
- [4] Consoli, N.C., Vendruscolo, M.A., Fonini, A. and Dalla Rosa, F. (2009) "Fiber reinforcement effects on sand considering a wide cementation range", *Geotextiles and Geomembranes* 27, pp. 196-203.
- [5] Dvorak, G.K. and Bahei-El-Din, Y.A. (1982) "Plasticity analysis of fibrous composites", *Journal of Applied Mechanics* 49, pp. 327-335.
- [6] Freitag, D.R. (1986) "Soil randomly reinforced with fibers", *Journal of Geotechnical Engineering ASCE* 112 (8), pp. 823-826.
- [7] Gray, D. and Al-Rafeai, T. O. (1986). "Behavior of fabric versus fiber reinforced sand". *Journal of Geo-technical Engineering*, vol. 112, no. 8, pp. 804-820.
- [8] Gray, D. H. and Ohashi, H. (1983). "Mechanics of fiber reinforcement in sand". *Journal of Geotechnical and Geo-environmental Engineering, ASCE*, vol. 109, no. 3, pp. 335-353.
- [9] Lorenzo, G. A. and Bergado, D. T. (2004). "Fundamental parameters of cement-admixed clay - New approach". *Journal of Geotechnical and Geo-environmental Engineering*, Vol. 130, No. 10, pp. 1-9.
- [10] Michalowski, R. L., Cermak, J. (2002), "Strength anisotropy of fiber-reinforced sand". *Computers and Geotechnics*, Vol. 29, No. 4, pp. 279-299.
- [11] Kaniraj, S. R. and Havanagi, V. G. (2001). "Behavior of cement-stabilization fiber-reinforced fly ash-soil mixtures. *Journal of Geo-technical and Geo-environmental Engineering*, vol. 127, no. 7, pp. 574-584.
- [12] Maher, M. H., Ho, Y. C. (1994), "Mechanical-properties of kaolinite fiber soil composite". *J. of Geotech. Engrg, ASCE*, Vol. 120, No. 8, pp. 1381-1393.
- [13] Nataraj, M. S., Mcmanis, K. L. (1997), "Strength and deformation properties of soils reinforced with fibrillated fibers.", *Geo-synthetics Int.*, Vol. 4, No. 1, pp. 65-79.
- [14] Sivakumar Babu, G.L., Vasudevan, A.K. and Haldar, S. (2008) Numerical simulation of fiber-reinforced sand behaviour, *Geotextiles and Geomembranes* 26, pp. 181-188.
- [15] Waldron, L. J. (1977). "Shear resistance of root-permeated homogeneous and stratified soil." *Soil Society. Of American Journal* 41 (5), pp. 843-849.
- [16] Yetimoglu, T. and Salbas, O. (2003) "A study on shear strength of sands reinforced with randomly distributed discrete fibers", *Geotextiles and Geomembranes* 21 (2), pp. 103-110.
- [17] Ziegler, S., Leshchinsky, D., Ling, H. I., and Perry, E. B. (1998) "Effect of short polymeric fibers on crack development in clays. *Soils and Foundations*", *J of Applied clay science*, Vol. 38, No. 1, pp. 247-253.

- [18] Zornberg, J. G., Cabral, A. R. and Viratjandr, C. (2004) "Behavior of tire shred-sand mixtures", *Canadian Geotechnical Journal* 41 (2), pp. 227–241.
- [19] Zornberg, J. G. (2002) "discrete framework for limit equilibrium analysis of fiber-reinforcement", *Geotechnique Journal* 52 (8), pp. 227–241.

Compaction Characteristics of Reinforced Clayey Sand

Amin Chegenizadeh

PhD candidate of Civil Engineering

Curtin University

Perth, Australia

e-mail: : amin.chegenizadeh@postgrad.curtin.edu.au

Professor Hamid Nikraz

Head of dept. Civil Engineering

Curtin University

Perth, Australia

e-mail: H.Nikraz@curtin.edu.au

Abstract— Composite soils have been widely used in civil engineering applications, especially in slopes, embankment dam and landfills. This paper aims to investigate effect of fibre inclusion on compaction characteristic of composite soil (i.e. clayey sand composite). A series of laboratory tests carried out to evaluate fibre effect on optimum water content and maximum dry unit weight of composite soils. Clayey sand was selected as soil part of the composite and plastic fibre was used as reinforcement. The fibre parameters differed from one test to another, as fibre length varied from 10 mm to 35mm and fibre content were selected as 1%, 4% and 5%. For each test, compaction curved derived and the results were compared. The results proved that inclusion of fibre affected compaction behaviour of samples so that increasing in fibre content and length caused increasing in Optimum Moisture Content (OMC) and slightly decreased maximum dry unit weight.

Keywords- *Compaction, Reinforced, Fiber, Clayey sand*

I. INTRODUCTION

Fletcher and Humphries (1991) investigated influence of fiber inclusion on compaction of silty clay soil. Unlike the case of sandy gravel reported by Hoare (1977), the test results indicated that increasing the fiber content causes a modest decrease in the maximum dry unit weight. The optimum water content was found to increase by increasing fiber content. Other researchers (Nataraj and McManis, 1997; Al Wahab and El-Kedrah, 1995; Puppala et al., 2006; Miller and Rifai, 2004; Ozkul et al., 2007; Kumar Tabor, 2003) also reported similar results. In contrast, some researchers such as Ozkul et al, 2007 reported not significant changes on compaction parameter by fiber inclusion. Therefore, the problem of effect of fiber inclusion on compaction parameter needs to be investigated precisely. Authors believe that different research results are due to different material which each researcher has used. This paper aims to investigate influences that are induced by fiber inclusion on compaction characteristics.

II. MATERIAL

Composite soils consist of two parts. The first component is soil part which can be dealt as normal soil. The second part is reinforcement part which can be made up of any material which helps soil to have better performance.

A. Soil Type

The soil type in this study was Western Australian sand. The properties of the added clay are presented in table 1. The sand distribution curve is presented in Fig 1. The soil part was reconstituted in lab by using sand with 15% of kaolin clay.

Table1. Clay properties

No.	Type	
1	Soil type	Clay
2	Liquid Limit	49
3	Plastic Limit	23
4	Pl. Index	26

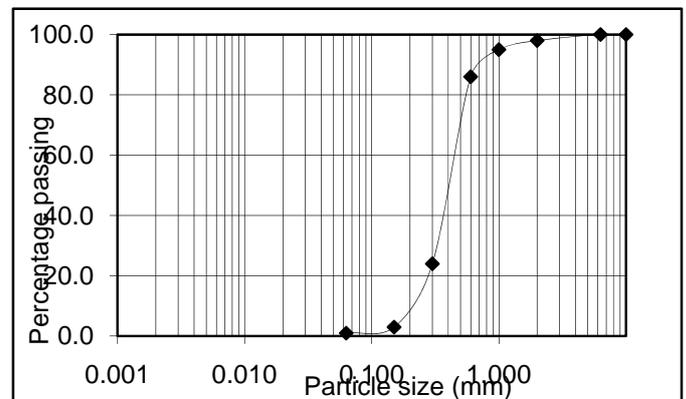


Fig. 1 Sand Particle Distribution

B. Fiber Type

The plastic fiber has been used for this study. Figure 2 shows the used fiber. The used fiber has good potential to absorb energy and good adhesion with soil particle.



Fig. 2 Plastic fiber

III. TEST PROGRAM

A series of compaction tests have been performed on reinforced sand composite.

A. Compaction Test

A series of compaction tests have been conducted. The results of the tests have been presented and well discussed.

B. Main Equipments

- Proctor mould with a detachable collar assembly and base plate.
- Manual rammer weighing 2.5 kg and equipped with height of drop to a free fall of 30 cm.
- Sample Extruder.
- A sensitive balance.
- Straight edge.
- Moisture cans.
- Drying Oven

Figure 3 shows rammer which was used to compact the soil. Figure 4 shows the used mould and base.



Fig. 3 Standard compaction rammer



Fig. 4 Mould and Base

IV. TEST METHODOLOGY AND PROCEDURE

The test procedure can be listed as:

- About 4.5 kg of air-dried soil was put in the mixing pan so that it could pass No. 4 sieve.
- The moisture content was increased by about 5%.
- The weight of empty mould without the base plate and the collar was recorded as W1 (gr).
- The collar and base plate was fixed and the first soil part was compacted with 25 blows in proctor mould
- Some scratches were put with a spatula forming a grid to ensure uniformity in distribution of compaction energy to the subsequent layer. The

second and third layer was placed and 25 blows were applied.

- The final layer was placed so that the compacted soil is just above the rim of the compaction mould when the collar is still attached.
- The collar carefully was detached without disturbing the compacted soil inside the mould and edge was used to trim the excess soil leveling to the mould.
- The weight of the mould with the moist soil W_2 (gr) was determined.
- Sample was extruded the sample and evaluated for water content in some cans
- The rest of the compacted soil was broken with hand to pass US Sieve No.4. and moisture content was increased by 2%.
- Steps 1 to 10 repeated again for different moisture contents.
- The dry density plotted versus moisture contents

V. RESULTS AND DISCUSSIONS

The results of compaction investigation are presented in this section. As the tests were designed systematically the effect of each fiber parameter can be observed in this study. The first engineering graph is related to effect of fiber dosage on compaction curve of composite soil. Respectively, second part is focused on effect of fiber length (aspect ratio) on soil composite compaction characteristics.

The results from laboratory compaction test were interpreted and figure 5 shows the effect of fiber content on maximum dry density and optimum moisture content while the fiber length kept constant at 10mm. Respectively, figure 6 indicates effect of fiber length on maximum dry density and optimum moisture content while the fiber content is constant at 1%.

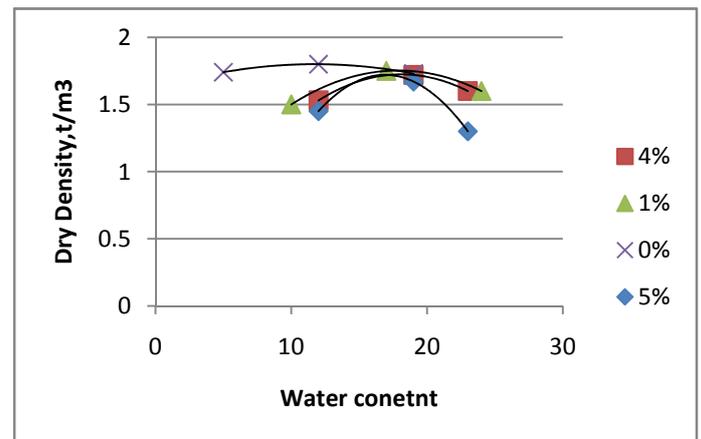


Fig. 5 Results of compaction test in different fiber content (at 10mm)

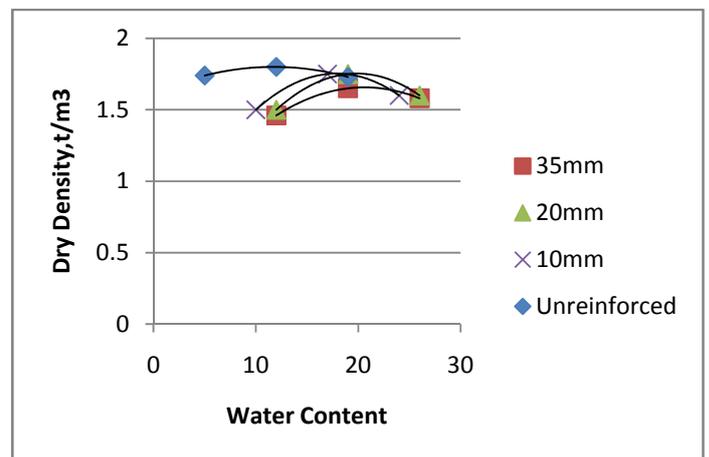


Fig. 6 Results of compaction test in different fiber length (Fiber content 1%)

VI. CONCLUSION

Compaction tests were conducted on composite clayey sand. This investigation proved that:

- Induction of fiber caused decrease in maximum dry density
- Optimum Moisture Content (OMC) increased with increasing in fiber content
- During these tests, it was observed that increasing in compaction effort causes increasing maximum dry density; this fact was observed for composite soil as well.
- Plastic fiber showed to be good material to be used in practical projects

ACKNOWLEDGEMENTS

The technical support from the Curtin University Laboratory is gratefully acknowledged.

REFERENCES

- [1] Akbulut, S., Arasan, S. and Kalkan, E. (2007) "Modification of clayey soils using scrap tire rubber and synthetic fibers", *Journal of Applied Clay Science* 38, 23-32.
- [2] Al Refeai, T.O. (1991) "Behaviour of granular soils reinforced with discrete randomly oriented inclusions", *Journal of Geotextiles and Geomembranes*, 10, pp. 319-333.
- [3] Cai, Y., Shi, B., Charles, W.W. Ng. & Tang, C. (2006) "Effect of polypropylene fiber and lime admixture on engineering properties of clayey soil", *Engineering Geology* 87, 230-240.
- [4] Consoli, N.C., Vendruscolo, M.A., Fonini, A. and Dalla Rosa, F. (2009) "Fiber reinforcement effects on sand considering a wide cementation range", *Geotextiles and Geomembranes* 27, pp. 196-203.
- [5] Freitag, D.R. (1986) "Soil randomly reinforced with fibers", *Journal of Geotechnical Engineering ASCE* 112 (8), pp. 823-826.
- [6] Gray, D. and Al-Rafeai, T. O. (1986). "Behavior of fabric versus fiber reinforced sand". *Journal of Geo-technical Engineering*, vol. 112, no. 8, pp. 804-820.
- [7] Gray, D. H. and Ohashi, H. (1983). "Mechanics of fiber reinforcement in sand". *Journal of Geotechnical and Geo-environmental Engineering*, ASCE, vol. 109, no. 3, pp. 335-353.
- [8] Lorenzo, G. A. and Bergado, D. T. (2004). "Fundamental parameters of cement-admixed clay – New approach". *Journal of Geotechnical and Geoenvironmental Engineering*, Vol. 130, No. 10, pp. 1-9.
- [9] Michalowski, R. L., Cermak, J. (2002), "Strength anisotropy of fiber-reinforced sand". *Computers and Geotechnics*, Vol. 29, No. 4, pp. 279-299.
- [10] Kaniraj, S. R. and Havanagi, V. G. (2001). "Behavior of cement-stabilization fiber-reinforced fly ash-soil mixtures. *Journal of Geotechnical and Geo-environmental Engineering*, vol. 127, no. 7, pp. 574-584.
- [11] Maher, M. H., Ho, Y. C. (1994), "Mechanical-properties of kaolinite fiber soil composite". *J. of Geotech. Engrg, ASCE*, Vol. 120, No. 8, pp. 1381-1393.
- [12] Nataraj, M. S., Mcmanis, K. L. (1997), "Strength and deformation properties of soils reinforced with fibrillated fibers.", *Geosynthetics Int.*, Vol. 4, No. 1, pp. 65-79.
- [13] Sivakumar Babu, G.L., Vasudevan, A.K. and Haldar, S. (2008) Numerical simulation of fiber-reinforced sand behaviour, *Geotextiles and Geomembranes* 26, pp. 181-188.
- [14] Yetimoglu, T. and Salbas, O. (2003) "A study on shear strength of sands reinforced with randomly distributed discrete fibers", *Geotextiles and Geomembranes* 21 (2), pp. 103-110.
- [15] Ziegler, S., Leshchinsky, D., Ling, H. I., and Perry, E. B. (1998) "Effect of short polymeric fibers on crack development in clays. *Soils and Foundations*", *J of Applied clay science*, Vol. 38, No. 1, pp. 247-253.
- [16] Zornberg, J. G., Cabral, A. R. and Viratjandr, C. (2004) "Behavior of tire shred-sand mixtures", *Canadian Geotechnical Journal* 41 (2), pp. 227-241.
- [17] Zornberg, J. G. (2002) "discrete framework for limit equilibrium analysis of fiber-reinforcement", *Geotechnique Journal* 52 (8), pp. 227-241.

Study on Strength of Fiber Reinforced Clayey sand

Amin Chegenizadeh

PhD candidate of Civil Engineering
Curtin University
Perth, Australia

e-mail: : amin.chegenizadeh@postgrad.curtin.edu.au

Professor Hamid Nikraz

Head of dept. Civil Engineering
Curtin University
Perth, Australia

e-mail: H.Nikraz@curtin.edu.au

Abstract— Composite soils have been widely used in civil engineering applications, especially in slopes, embankment dam and landfills. This paper aims to investigate effect of fiber inclusion on Unconfined Compressive Strength of composite soil (i.e. sand composite). A series of laboratory Unconfined Compression tests carried out to evaluate fiber effect on strength behavior of composite sand. Clayey sand was selected as soil part of the composite and natural fiber was used as reinforcement to enhance the strength. The fiber parameters changed from one test to another, as fiber length were changed from 10 mm to 30 mm and fiber content were selected as 1% and 4%. For each test, stress-strain graph derived and the results were compared. The results proved that inclusion of fiber affected strength behaviour of sand composite so that increasing in fiber content and length caused increasing in Unconfined Compressive Strength (UCS).

Keywords- UCS, Reinforced, Fiber, .Sand

I. INTRODUCTION

The paper presents the effect of fiber inclusion on unconfined compressive strength of clayey sand. Applications of soil strengthening or stabilization range from the mitigation of complex slope hazards to enhancing the subgrade stability. Together with the many applications for improving soil, there are several widely varied methods. The mixing of randomly oriented fibers to a soil sample may be considered same as other admixtures used to stabilize soil. Material used to make fibers for reinforcement may be obtained from paper, metal, nylon, polyester and other materials having widely varied physical properties. There have been numerous past papers published on the topic of fiber strengthening of soils. Examples include Lee et al., 1973, Hoare,1979, Andersland and Khattac,1979, Freitag,1986, Gray and Ohashi, 1983, Gray and Rafeai, 1986, Maher and Gray 1990, Maher and Ho, 1994, Michalowski and Zhao 2002, Ranjan et al. 1996, Kaniraj and Havanagi 2001, Consoli et al. 2009.

All of the papers listed above have generally shown that; strength of the soil was improved by fiber reinforcement. The investigation on clayey sand is very limited. The purpose of this survey is to evaluate clayey sand behaviour induced by fiber inclusion.

II. MATERIAL

Composite soils consist of two parts. The first part is soil part which can be dealt as normal soil. The second part is reinforcement part which can be made up of any material which helps soil to have better performance.

A. Soil Type

The soil type in this study was Western Australian sand. The properties of clay are presented in table 1. The sand distribution curve is presented in Fig 1. The soil part was reconstituted in lab by using sand with 10% of kaolin clay.

Table1. Clay properties

No.	Type	
1	Soil type	Clay
2	Liquid Limit	49
3	Plastic Limit	23
4	Pl. Index	26

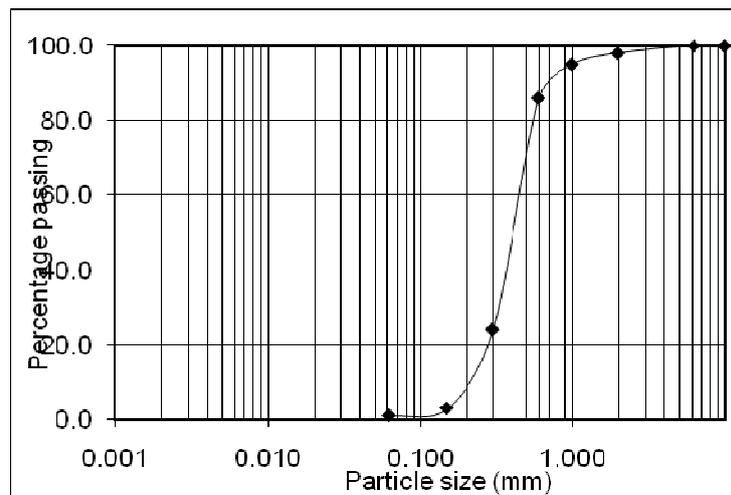


Fig. 1 Sand Particle Distribution

B. Fiber Type

Natural fiber has been used for this investigation. Figure 2 shows the used fiber. The used fiber has good adhesion with soil particle. Accessibility of this fiber and being natural are the advantages of using this fiber



Fig. 2 Natural fiber

III. TEST PROGRAM

A series of unconfined compression have been conducted on reinforced sand composite.

A. Unconfined Compression Test

The unconfined compression test imposes uniaxial stress conditions on a sample of soil, and is therefore a special case of the triaxial test with zero confining stress. The unconfined compression test has a significant cost advantage over triaxial test due to the simpler testing requirement. The limitation of this test can be named as: preparing stable sample for cohesionless material and undrained estimation due to quick test.

B. Main Equipments

- Unconfined compression testing machine (Triaxial Machine)
- Specimen preparation equipment
- Sample extruder
- fiber
- Balance

Figure 3 shows triaxial base which was used to run the UCS test. The device is fully automated so the results easily transferred without any user interference.



Fig. 3 Triaxial Machine

IV. SAMPLE PREPARATION

The samples were prepared by mixing clay and three percentage of fiber. Specimen preparation method was the standard compaction method, which was used in an ongoing experimental research on fiber-reinforced clay at Curtin University. The soils were first oven-dried. The dry soils were then crushed using a hammer. A mixer was used to thoroughly mix the soils with water to obtain the desired water moisture content for compaction. The mixing of soil with fibers was performed mostly by hand rather than using the mixer because the mixer caused the fibers to tangle or break. The fiber-soil mixture was placed in a closed container for 24 hours after mixing was completed. A split mold and a specific hammer were used to compact the specimen. The specimens were prepared in different fiber content (i.e. 1%, 2% and 4%) and different fiber length (aspect ratio) which were 10mm, 20mm, 30mm.

V. TEST METHODOLOGY AND PROCEDURE

- The specimens were prepared in the laboratory with 90% compaction effort, special care was taken during this process
- The size of samples were checked to be suitable for the test purpose
- The samples were put for 24 hours in geotextile and packed
- Special attention was applied for preventing any moisture loose
- The samples were put in triaxial base without any confinement pressure
- According to ASTM 1.27 mm/min were applied through the tests
- The data was collected automatically

The stress-strain curve plot used for strength behavior investigation

VI. RESULTS AND DISCUSSIONS

The unconfined compression tests were conducted in order to determine effect of fiber inclusion on Unconfined Compressive Strength (UCS). Figure 4 showed the stress-strain curve obtained from the tests. The tests were conducted on cylindrical specimen of 60 mm diameter and 170 mm height. The presented results in figure 4 are at fiber length of 10mm.

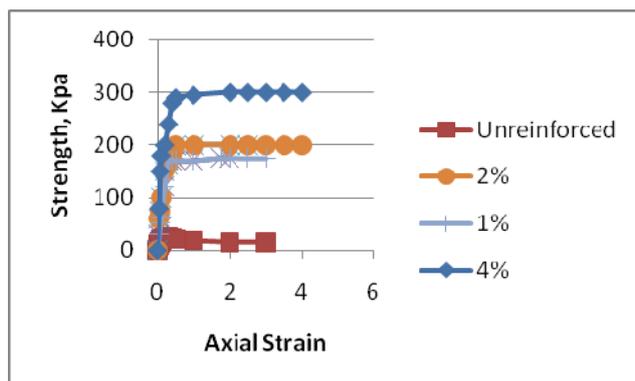


Fig. 4 Results of UCS test in different fiber content

Figure 4 proved increasing in fiber content will increase the strength.

Figure 5 shows the effect of fiber length on strength of composite clayey sand at constant fiber content of 0.5%.

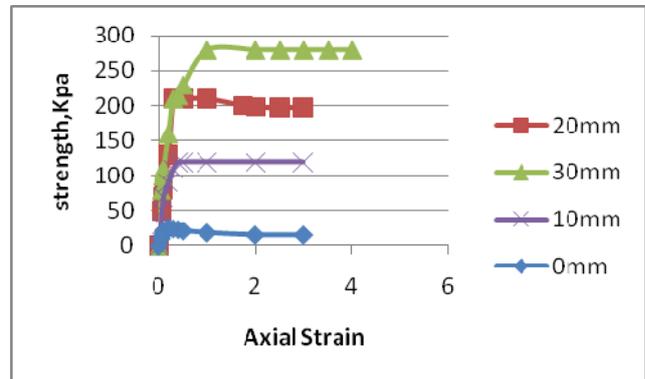


Fig. 5 Results of UCS test in different fiber length

VII. CONCLUSION

- Increasing in fiber percentage increased strength in clayey sand samples
- During the test, it was observed that ductility behaviour of reinforced sand increased because of fiber inclusion.
- The results proved that with increasing in fiber length, the UCS of composite clayey sand was increased.
- Short and randomly Fiber inclusion showed to be reliable in industry projects as it helps to minimize the cost of projects.

ACKNOWLEDGEMENTS

The technical support from the Curtin University Laboratory is gratefully acknowledged.

REFERENCES

- [1] Akbulut, S., Arasan, S. and Kalkan, E. (2007) "Modification of clayey soils using scrap tire rubber and synthetic fibers", *Journal of Applied Clay Science* 38, 23-32.
- [2] Al Refeai, T.O. (1991) "Behaviour of granular soils reinforced with discrete randomly oriented inclusions", *Journal of Geotextiles and Geomembranes*, 10, pp. 319-333.
- [3] Cai, Y., Shi, B., Charles, W.W. Ng. & Tang, C. (2006) "Effect of polypropylene fiber and lime admixture on engineering properties of clayey soil", *Engineering Geology* 87, 230- 240.
- [4] Consoli, N.C., Vendruscolo, M.A., Fonini, A. and Dalla Rosa, F. (2009) "Fiber reinforcement effects on sand considering a wide cementation range", *Geotextiles and Geomembranes* 27, pp. 196-203.

- [5] Freitag, D.R. (1986) "Soil randomly reinforced with fibers", *Journal of Geotechnical Engineering ASCE* 112 (8), pp. 823–826.
- [6] Gray, D. and Al-Rafeai, T. O. (1986). "Behavior of fabric versus fiber reinforced sand". *Journal of Geo-technical Engineering*, vol. 112, no. 8, pp. 804-820.
- [7] Gray, D. H. and Ohashi, H. (1983). "Mechanics of fiber reinforcement in sand". *Journal of Geotechnical and Geo-environmental Engineering, ASCE*, vol. 109, no. 3, pp. 335-353.
- [8] Lorenzo, G. A. and Bergado, D. T. (2004). "Fundamental parameters of cement-admixed clay – New approach". *Journal of Geotechnical and Geo-environmental Engineering*, Vol. 130, No. 10, pp. 1-9.
- [9] Michalowski, R. L., Cermak, J. (2002), "Strength anisotropy of fiber-reinforced sand". *Computers and Geotechnics*, Vol. 29, No. 4, pp. 279-299.
- [10] Kaniraj, S. R. and Havanagi, V. G.(2001). "Behavior of cement-stabilization fiber-reinforced fly ash-soil mixtures. *Journal of Geotechnical and Geo-environmental Engineering*, vol. 127, no. 7,pp. 574-584.
- [11] Maher, M. H., Ho, Y. C. (1994), "Mechanical-properties of kaolinite fiber soil composite". *J. of Geotech. Engrg. ASCE*, Vol. 120, No. 8, pp. 1381-1393.
- [12] Nataraj, M. S., Mcmanis, K. L. (1997)," Strength and deformation properties of soils reinforced with fibrillated fibers.", *Geosynthetics Int.*, Vol. 4, No. 1, pp. 65-79.
- [13] Sivakumar Babu, G.L., Vasudevan, A.K. and Haldar, S. (2008) Numerical simulation of fiber-reinforced sand behaviour, *Geotextiles and Geomembranes* 26, pp. 181–188.
- [14] Yetimoglu, T. and Salbas, O. (2003) "A study on shear strength of sands reinforced with randomly distributed discrete fibers", *Geotextiles and Geomembranes* 21 (2), pp. 103–110.
- [15] Ziegler, S., Leshchinsky, D., Ling, H. I., and Perry, E. B. (1998)" Effect of short polymeric fibers on crack development in clays. *Soils and Foundations*", *J of Applied clay science*,Vol. 38, No. 1, pp. 247-253.
- [16] Zornberg, J. G., Cabral, A. R. and Viratjandr, C. (2004) "Behavior of tire shred-sand mixtures", *Canadian Geotechnical Journal* 41 (2), pp. 227–241.
- [17] Zornberg, J. G. (2002) "discrete framework for limit equilibrium analysis of fiber-reinforcement", *Geotechnique Journal* 52 (8), pp. 227–241.

Investigation on Strength of Reinforced Clayey Sand

Amin Chegenizadeh

PhD candidate of Civil Engineering
Curtin University
Perth, Australia

e-mail: : amin.chegenizadeh@postgrad.curtin.edu.au

Professor Hamid Nikraz

Head of dept. Civil Engineering
Curtin University
Perth, Australia

e-mail: H.Nikraz@curtin.edu.au

Abstract— Composite soils have been widely used in civil engineering applications, especially in slopes, embankment dam and landfills. This paper aims to investigate effect of fiber inclusion on Unconfined Compressive Strength of composite soil (i.e. sand composite). Clayey sand was selected as soil part of the composite and plastic fiber was used as reinforcement. A series of laboratory Unconfined Compression tests carried out to evaluate fiber effect on strength behavior of composite sand. As the test program involved so many degree of freedom in terms of parameter. Test program was designed carefully. While the soil material kept constant, the fiber parameters differed from one test to another. Fiber lengths were changed from 10 mm to 30 mm and fiber content were selected as 0.1% and 0.3%. For each test, stress-strain graph derived and the results were compared. The results proved that inclusion of fiber affected strength behavior of sand composite so that increasing in fiber content and length caused increasing in Unconfined Compressive Strength (UCS).

Keywords- *Compaction, Reinforced, Fiber, .Sand*

I. INTRODUCTION

The paper presents the effect of fiber inclusion on unconfined compressive strength of clayey sand. Applications of soil strengthening or stabilization range from the mitigation of complex slope hazards to enhancing the subgrade stability. Together with the many applications for improving soil, there are several widely varied methods. The mixing of randomly oriented fibers to a soil sample may be considered same as other admixtures used to stabilize soil. Material used to make fibers for reinforcement may be obtained from paper, metal, nylon, polyester and other materials having widely varied physical properties. There have been numerous past papers published on the topic of fiber strengthening of soils. Examples include Lee et al., 1973, Hoare,1979, Andersland and Khattac,1979, Freitag,1986, Gray and Ohashi, 1983, Gray and Rafeai, 1986, Maher and Gray 1990, Maher and Ho, 1994, Michalowski and Zhao 2002, Ranjan et al. 1996, Kaniraj and Havanagi 2001, Consoli et al. 2009.

All of the papers listed above have generally shown that; strength of the soil was improved by fiber reinforcement. The investigation on clayey sand is very limited. The purpose of this survey is to evaluate clayey sand behaviour induced by fiber inclusion..

II. MATERIAL

Composite soils consist of two parts. The first part is soil part which can be dealt as normal soil. The second part is reinforcement part which can be made up of any material which helps soil to have better performance.

A. Soil Type

The soil type in this study was Western Australian sand. The properties of clay are presented in table 1. The sand distribution curve is presented in Fig 1. The soil part was reconstituted in lab by using sand with 10% of kaolin clay.

Table1. Clay properties

No.	Type	Clay
1	Soil type	Clay
2	Liquid Limit	49
3	Plastic Limit	23
4	Pl. Index	26

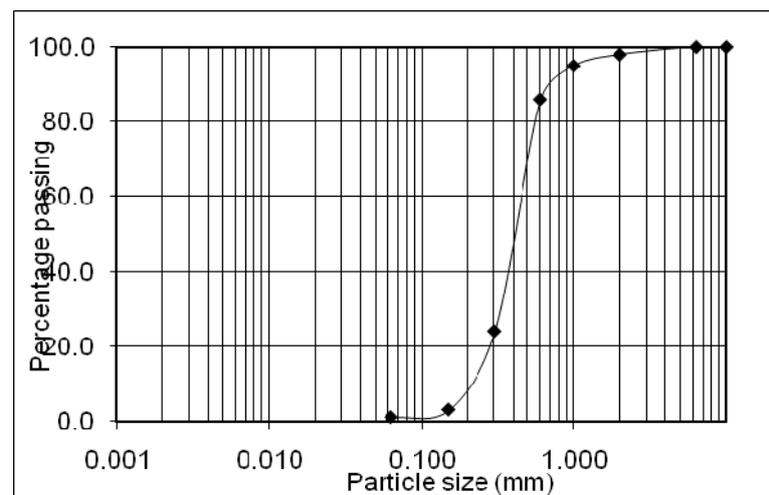


Fig. 1 Sand Particle Distribution

B. Fiber Type

The plastic fiber has been used for this investigation. Figure 2 shows the used fiber. The used fiber has good potential to absorb energy and good adhesion with soil particle.



Fig. 2 Plastic fiber that used as reinforcement

III. TEST PROGRAM

A series of unconfined compression have been conducted on reinforced sand composite.

A. Unconfined Compression Test

The unconfined compression test imposes uniaxial stress conditions on a sample of soil, and is therefore a special case of the triaxial test with zero confining stress. The unconfined compression test has a significant cost advantage over triaxial test due to the simpler testing requirement. The limitation of this test can be named as: preparing stable sample for cohesionless material and undrained estimation due to quick test.

B. Main Equipments

- Unconfined compression testing machine (Triaxial Machine)
- Specimen preparation equipment
- Sample extruder

- fiber
- Balance

Figure 3 shows triaxial base which was used to run the UCS test. The device is fully automated so the results easily transferred without any user interference.



Fig. 3 Automated Triaxial Machine was used to run the tests at Curtin University

IV. SAMPLE PREPARATION

The samples were prepared by mixing clay and three percentage of fiber. Specimen preparation method was the standard compaction method, which was used in an ongoing experimental research on fiber-reinforced clay at Curtin University. The soils were first oven-dried. The dry soils were then crushed using a hammer. A mixer was used to thoroughly mix the soils with water to obtain the desired water moisture content for compaction. The mixing of soil with fibers was performed mostly by hand rather than using the mixer because the mixer caused the fibers to tangle or break. The fiber-soil mixture was placed in a closed container for 24 hours after mixing was completed. A split mold and a specific hammer were used to compact the specimen. The specimens were prepared in different fiber

content (i.e. 0.5%, 1%, 2%.) and different fiber length (aspect ratio) which were 10mm, 20mm, 30mm.

V. TEST METHODOLOGY AND PROCEDURE

- The specimens were prepared in the laboratory with 90% compaction effort, special care was taken during this process
- The size of samples were checked to be suitable for the test purpose
- The samples were put for 24 hours in geotextile and packed
- Special attention was applied for preventing any moisture loose
- The samples were put in triaxial base without any confinement pressure
- According to ASTM 1.27 mm/min were applied through the tests
- The data was collected automatically

The stress-strain curve plot used for strength behavior investigation

VI. RESULTS AND DISCUSSIONS

The unconfined compression tests were conducted in order to determine effect of fiber inclusion on Unconfined Compressive Strength (UCS). As the test program was designed carefully, effect of each parameter can be easily found in this investigation.

Figure 4 showed the stress-strain curve obtained from the tests at fiber length of 10mm. The tests were conducted on cylindrical specimen of 60 mm diameter and 170 mm height. It is good to be mentioned that in each test run special care was taken that sample was uniform. The results indicate that as the fiber percentage increased the strength of composite also increased. It should be noted that as test time for UCS test is quick, the results represent undrained condition of real problem.

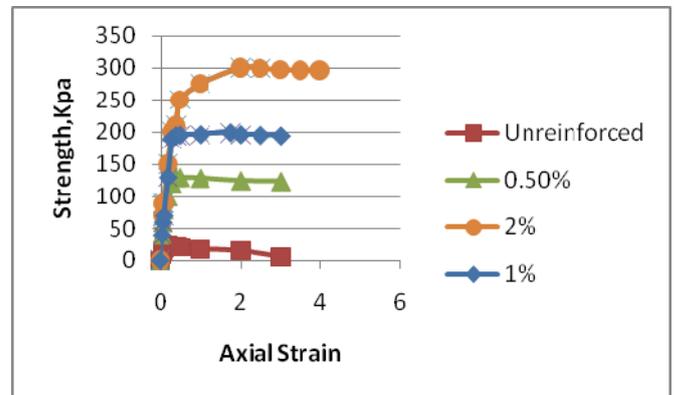


Fig. 4 Results of UCS test in different fiber content (at 10mm fiber length)

Figure 5 shows the effect of fiber length on strength of composite clayey sand at constant fiber content of 0.5%. the results showed increasing in strength of the clayey sand composite due to increasing in fiber length.

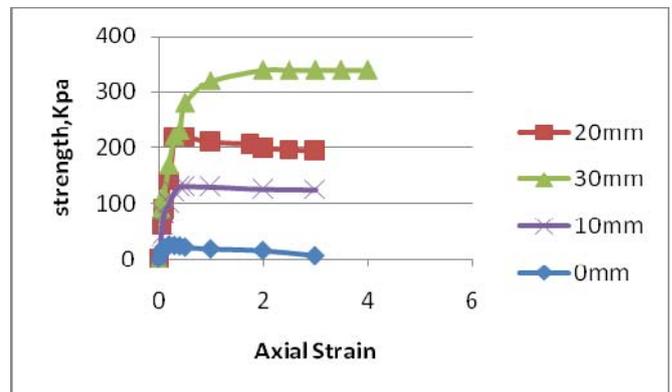


Fig. 5 Results of UCS test in different fiber length (at 0.5% fiber content)

VII. CONCLUSION

Unconfined Compression tests were run to evaluate effect of fiber inclusion on strength of reinforced clayey sand. The following conclusions have been made through this study:

- Increasing in fiber percentage increased strength in clayey sand samples

- During the test, it was observed that ductility behavior of reinforced sand increased because of fiber inclusion.
- The results proved that with increasing in fiber length, the UCS of composite clayey sand was increased.
- Short and randomly Fiber inclusion showed to be reliable in industry projects as it helps to minimize the cost of projects.

ACKNOWLEDGEMENTS

The technical support from the Curtin University Laboratory is gratefully acknowledged.

REFERENCES

- [1] Akbulut, S., Arasan, S. and Kalkan, E. (2007) "Modification of clayey soils using scrap tire rubber and synthetic fibers", *Journal of Applied Clay Science* 38, 23-32.
- [2] Al Refeai, T.O. (1991) "Behaviour of granular soils reinforced with discrete randomly oriented inclusions", *Journal of Geotextiles and Geomembranes*, 10, pp. 319–333.
- [3] Cai, Y., Shi, B., Charles, W.W. Ng. & Tang, C. (2006) "Effect of polypropylene fiber and lime admixture on engineering properties of clayey soil", *Engineering Geology* 87, 230– 240.
- [4] Consoli, N.C., Vendruscolo, M.A., Fonini, A. and Dalla Rosa, F. (2009) "Fiber reinforcement effects on sand considering a wide cementation range", *Geotextiles and Geomembranes* 27, pp. 196–203.
- [5] Freitag, D.R. (1986) "Soil randomly reinforced with fibers", *Journal of Geotechnical Engineering ASCE* 112 (8), pp. 823–826.
- [6] Gray, D. and Al-Rafeai, T. O. (1986). "Behavior of fabric versus fiber reinforced sand". *Journal of Geo-technical Engineering*, vol. 112, no. 8, pp. 804-820.
- [7] Gray, D. H. and Ohashi, H. (1983). "Mechanics of fiber reinforcement in sand". *Journal of Geotechnical and Geo-environmental Engineering*, ASCE, vol. 109, no. 3, pp. 335-353.
- [8] Lorenzo, G. A. and Bergado, D. T. (2004). "Fundamental parameters of cement-admixed clay – New approach". *Journal of Geotechnical and Geo-environmental Engineering*, Vol. 130, No. 10, pp. 1-9.
- [9] Michalowski, R. L., Cermak, J. (2002), "Strength anisotropy of fiber-reinforced sand". *Computers and Geotechnics*, Vol. 29, No. 4, pp. 279-299.
- [10] Kaniraj, S. R. and Havanagi, V. G.(2001). "Behavior of cement-stabilization fiber-reinforced fly ash-soil mixtures. *Journal of Geotechnical and Geo-environmental Engineering*, vol. 127, no. 7,pp. 574-584.
- [11] Maher, M. H., Ho, Y. C. (1994), "Mechanical-properties of kaolinite fiber soil composite". *J. of Geotech. Engrg, ASCE*, Vol. 120, No. 8, pp. 1381-1393.
- [12] Nataraj, M. S., Mcmanis, K. L. (1997)," Strength and deformation properties of soils reinforced with fibrillated fibers.", *Geosynthetics Int.*, Vol. 4, No. 1, pp. 65-79.
- [13] Sivakumar Babu, G.L., Vasudevan, A.K. and Haldar, S. (2008) Numerical simulation of fiber-reinforced sand behaviour, *Geotextiles and Geomembranes* 26, pp. 181–188.
- [14] Yetimoglu, T. and Salbas, O. (2003) "A study on shear strength of sands reinforced with randomly distributed discrete fibers", *Geotextiles and Geomembranes* 21 (2), pp. 103–110.
- [15] Ziegler, S., Leshchinsky, D., Ling, H. I., and Perry, E. B. (1998)" Effect of short polymeric fibers on crack development in clays. *Soils and Foundations*", *J of Applied clay science*, Vol. 38, No. 1, pp. 247-253.
- [16] Zornberg, J. G., Cabral, A. R. and Viratjandr, C. (2004) "Behavior of tire shred-sand mixtures", *Canadian Geotechnical Journal* 41 (2), pp. 227–241.
- [17] Zornberg, J. G. (2002) "discrete framework for limit equilibrium analysis of fiber-reinforcement", *Geotechnique Journal* 52 (8), pp. 227–241.

Compaction Parameters of Reinforced Clayey Sand

Amin Chegenizadeh

PhD candidate of Civil Engineering

Curtin University

Perth, Australia

e-mail: : amin.chegenizadeh@postgrad.curtin.edu.au

Professor Hamid Nikraz

Head of dept. Civil Engineering

Curtin University

Perth, Australia

e-mail: H.Nikraz@curtin.edu.au

Abstract— Composite soils have been widely used in civil engineering applications, especially in slopes, embankment dam and landfills. This paper aims to investigate effect of fiber inclusion on compaction characteristic of composite soil (i.e. sand composite). A series of laboratory tests carried out to evaluate fiber effect on optimum water content and maximum dry unit weight of composite soils. Sand was selected as soil part of the composite and plastic fiber was used as reinforcement. The fiber parameters differed from one test to another, as fiber length varied from 10 mm to 30mm and fiber content were selected as 1% and 3%. For each test, compaction curved derived and the results were compared. The results proved that inclusion of fiber affected compaction behavior of samples so that increasing in fiber content and length caused increasing in Optimum Moisture Content (OMC) and slightly decreased maximum dry unit weight.

Keywords- *Compaction, Reinforced, Fiber, .Sand*

I. INTRODUCTION

Soils have relatively low tensile strength so that they are not able to transfer tensile forces through a foundation system. This problem can be solved using geosynthetics materials - geogrids, geotextiles or geocomposites. Some recent researches have indicated that benefits may be gained by inclusion of discrete fibres in clay. Discrete polypropylene fibres have been found to increase the tensile strength of clays for a range of plasticities, induce more ductile failures, and improve the resistance to desiccation cracking (Ziegler et al. 1998). The concept of fibre-reinforcement in geotechnical projects originally involved the use of plant roots as reinforcement. Gray (1970), Waldron (1977), and Wu et al. (1988) reported that plant roots increase the shear strength of the soil, and consequently the stability of natural slopes. Continuing the previous research, some researchers worked on effect of fibre on strength of composite soil such as Michalowski, R. L., Cermak, J. (2002) and Zornberg, J. G. (2002). Fletcher and Humphries (1991) investigated influence of fiber inclusion on compaction of silty clay soil. Unlike the case of sandy gravel reported by Hoare (1977), the test results indicated that increasing the fiber content causes a modest reduction in the maximum dry unit weight. The optimum water content was found to enhance by increasing fiber content. Other researchers (Nataraj and McManis,

1997; Al Wahab and El-Kedrah, 1995; Puppala et al., 2000; Miller and Rifai, 2004; Ozkul et al., 2007; Kumar Tabor, 2003; Sivakumar et al. 2008) also reported similar results. In contrast, some researchers such as Ozkul et al, 2007 reported not significant changes on compaction parameter by fiber inclusion. Therefore, the problem of effect of fiber inclusion on compaction parameter needs to be investigated precisely. Authors believe that different research results are due to different material which each researcher has used. This paper aims to investigate influences that are induced by fiber inclusion on compaction characteristics.

II. MATERIAL

Composite soils consist of two parts. The first part is soil part which can be dealt as normal soil. The second part is reinforcement part which can be made up of any material which helps soil to have better performance.

A. Soil Type

The soil type in this study was Western Australian sand. The properties of clay are presented in table 1. The sand distribution curve is presented in Fig 1. The soil part was reconstituted in lab by using sand with 15% of kaolin clay.

Table1. Clay properties

No.	Type	
1	Soil type	Clay
2	Liquid Limit	49
3	Plastic Limit	23
4	Pl. Index	26

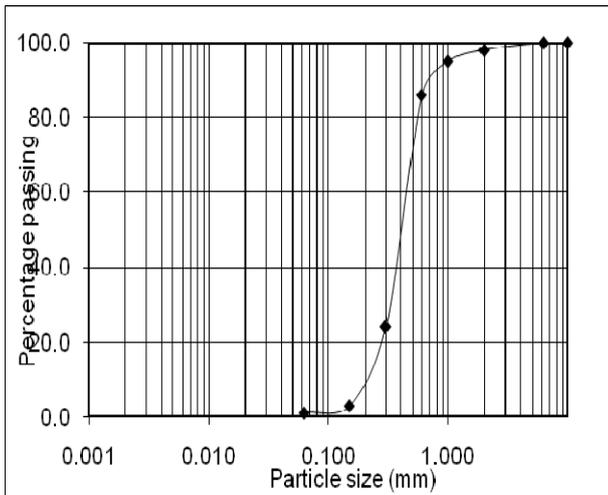


Fig. 1 Sand Particle Distribution

B. Fiber Type

Natural fiber has been used for this investigation. Figure 2 shows the used fiber. The used fiber has good adhesion with soil particle. Accessibility of this fiber and being natural are the advantages of using this fiber.



Fig. 2 Natural fiber

III. TEST PROGRAM

A series of compaction test have been performed on reinforced sand composite.

A. Compaction test

Soil compaction is a mean to increase the density of soil. In geotechnical projects, soil density is an important parameter. Any difficulty related to compaction may cause settlement of the soil and as a consequence unnecessary maintenance costs or structure failure. Therefore, all types of construction sites and construction projects take special care in mechanical compaction method.

B. Main Equipments

To run the test, tools are needed as:

- Proctor mould with a detachable collar assembly and base plate.
- Manual rammer weighing 2.5 kg and equipped with height of drop to a free fall of 30 cm (for standard method)
- Sample Extruder.
- A sensitive balance.
- Straight edge.
- Moisture cans.
- Drying Oven

Figure 3 shows rammer which was used to compact the soil. Figure 4 shows the used mould and base.



Fig. 3 Standard compaction rammer



Fig. 4 Mould and Base

IV. TEST METHODOLOGY AND PROCEDURE

The test procedure can be listed as:

- About 4.5 kg of air-dried soil was put in the mixing pan so that it could pass No. 4 sieve.
- The moisture content was increased by about 5%.
- The weight of empty mould without the base plate and the collar was recorded as W1 (gr).
- The collar and base plate was fixed and the first soil part was compacted with 25 blows in proctor mould
- Some scratches were put with a spatula forming a grid to ensure uniformity in distribution of compaction energy to the subsequent layer. The second and third layer was placed and 25 blows were applied.
- The final layer was placed so that the compacted soil is just above the rim of the compaction mould when the collar is still attached.
- The collar carefully was detached without disturbing the compacted soil inside the mould and edge was used to trim the excess soil levelling to the mould.
- The weight of the mould with the moist soil W2, (gr) was determined.
- Sample was extruded the sample and evaluated for water content in some cans
- The rest of the compacted soil was broken with hand to pass US Sieve No.4. and moisture content was increased by 2%.
- Steps 1 to 10 repeated again for different moisture contents.
- The dry density plotted versus moisture contents

V. TEST DESIGN

The tests were designed systematically so that the effect of each fiber parameters (i.e. length and content) can be obtained. For reinforced samples, special care was taken for achieving uniformity of mixture while compaction procedure. First series of the test was related to effect of fiber content. In these test fiber content changed while fiber length was constant. The fiber percentage were 1%, 2% and 3% with constant fiber length of 10mm.

The second round was related to effect of fiber length. Therefore, different fiber length (i.e. 10, 20mm and 30mm) with constant fiber content of 1% were evaluated. Finally all results compared with unreinforced samples.

VI. RESULTS AND DISCUSSIONS

Compaction tests were conducted in order to determine effect of natural fiber inclusion on compaction characteristics of reinforced clayey sand. Figure 5 showed the compaction curve obtained from the tests. The presented results in figure 5 are at fiber length of 10mm.

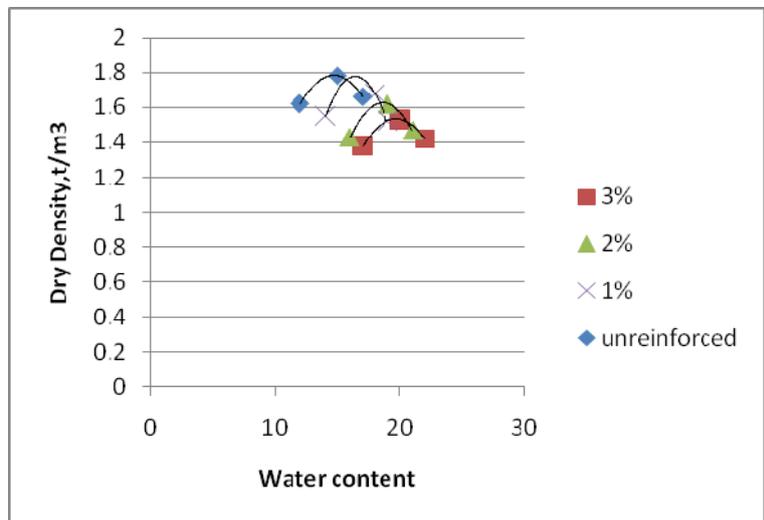


Fig. 5 Results of compaction test in different fiber content(at 10mm)

Figure 5 proved increasing in fiber content will decrease the maximum dry density and increased OMC.

Figure 6 shows the effect of fiber length on composite clayey sand at constant fiber content of 1%. The results

showed that fiber length increasing caused decreasing in maximum dry density and increasing in OMC.

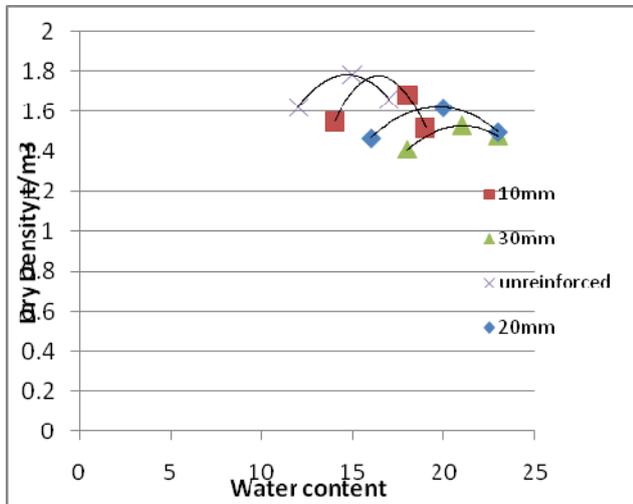


Fig. 5 Results of compaction test in different fiber length (at 1%)

VII. CONCLUSION

Compaction tests were conducted on composite clayey sand. The importance of this investigation is usage of natural material to serve the geotechnical project. This investigation proved that:

- 1-Maximum dry density showed slight decrease due to induction of the natural fiber
- 2-Optimum Moisture Content (OMC) increased with increasing in natural fiber content
- 3-Increasing in compaction effort causes increasing maximum dry density, this fact was observed for composite soil as well.
- 4-Natural fiber showed to be good material to be used in practical projects
- 5- Use of natural fiber is highly recommended due to environmental issues

ACKNOWLEDGEMENTS

The technical support from the Curtin University Laboratory is gratefully acknowledged.

REFERENCES

- [1] Akbulut, S., Arasan, S. and Kalkan, E. (2007) "Modification of clayey soils using scrap tire rubber and synthetic fibers", *Journal of Applied Clay Science* 38, 23-32.
- [2] Al Refeai, T.O. (1991) "Behaviour of granular soils reinforced with discrete randomly oriented inclusions", *Journal of Geotextiles and Geomembranes*, 10, pp. 319-333. .
- [3] Freitag, D.R. (1986) "Soil randomly reinforced with fibers", *Journal of Geotechnical Engineering ASCE* 112 (8), pp. 823-826.
- [4] Gray, D. and Al-Rafeai, T. O. (1986). "Behavior of fabric versus fiber reinforced sand". *Journal of Geo-technical Engineering*, vol. 112, no. 8, pp. 804-820.
- [5] Gray, D. H. and Ohashi, H. (1983). "Mechanics of fiber reinforcement in sand". *Journal of Geotechnical and Geo-environmental Engineering*, ASCE, vol. 109, no. 3, pp. 335-353.
- [6] Michalowski, R. L., Cermak, J. (2002), "Strength anisotropy of fiber-reinforced sand". *Computers and Geotechnics*, Vol. 29, No. 4, pp. 279-299.
- [7] Kaniraj, S. R. and Havanagi, V. G.(2001). "Behavior of cement-stabilization fiber-reinforced fly ash-soil mixtures. *Journal of Geotechnical and Geo-environmental Engineering*, vol. 127, no. 7,pp. 574-584.
- [8] Maher, M. H., Ho, Y. C. (1994), "Mechanical-properties of kaolinite fiber soil composite". *J. of Geotech. Engrg, ASCE*, Vol. 120, No. 8, pp. 1381-1393.
- [9] Miller, J. and Rifai, S. (2004) "Fiber reinforcement for waste containment soil liners", *Journal of Environmental Engineering* 130(8), pp. 891-896
- [10] Nataraj, M. S., Mcmanis, K. L. (1997)," Strength and deformation properties of soils reinforced with fibrillated fibers.", *Geosynthetics Int.*, Vol. 4, No. 1, pp. 65-79.
- [11] Ozkul, Z. H., and Baykal, G. (2007) "Shear behavior of compacted rubber fibre-clay composite in drained and undrained loading.", *Journal of Geotechnical and Geoenvironmental Engineering ASCE* 7, pp. 767-781.
- [12] Puppala, A. J. and Musenda, C. (2000) "Effects of fibre reinforcement on strength and volume change in expansive soils", *Transportation Res. Rec.*(1736), pp.134- 140.
- [13] Sivakumar Babu, G.L., Vasudevan, A.K. and Haldar, S. (2008) Numerical simulation of fiber-reinforced sand behaviour, *Geotextiles and Geomembranes* 26, pp. 181-188.
- [14] Waldron, L. J. (1977). "Shear resistance of root-permeated homogeneous and stratified soil." *Soil Society. Of American Journal*41 (5), pp. 843-849.
- [15] Yetimoglu, T. and Salbas, O. (2003) "A study on shear strength of sands reinforced with randomly distributed discrete fibers", *Geotextiles and Geomembranes* 21 (2), pp. 103-110.
- [16] Ziegler, S., Leshchinsky, D., Ling, H. I., and Perry, E. B. (1998)" Effect of short polymeric fibers on crack development in clays. *Soils and Foundations*", *J of Applied clay science*,Vol. 38, No. 1, pp. 247-253.
- [17] Zornberg, J. G., Cabral, A. R. and Viratjandr, C. (2004) "Behavior of tire shred-sand mixtures", *Canadian Geotechnical Journal* 41 (2), pp. 227-241.
- [18] Zornberg, J. G. (2002) "discrete framework for limit equilibrium analysis of fiber-reinforcement", *Geotechnique Journal* 52 (8), pp. 227-241

Compaction Characteristics of Reinforced Soil

Amin Chegenizadeh¹, Prof. Hamid Nikraz²,

¹ *PhD candidate, Department of Civil Engineering, Curtin University of Technology, Perth, Australia; ahegenizadeh@yahoo.com* ² *Prof. Hamid Nikraz, Head of the Department of Civil Engineering, Curtin University of Technology, Perth, Australia*
h.nikraz@curtin.edu.au

Paper Reference Number: 1120-150

Name of the Presenter: Amin Chegenizadeh



Abstract

Composite soils have been widely used in geotechnical engineering applications, especially in slopes, embankment dam and landfills. This paper aims to study effect of fiber inclusion on compaction characteristic of composite soil (i.e. silty sand composite). A series of laboratory tests carried out to evaluate fiber effect on optimum water content and maximum dry unit weight of composite soils. Silty sand was selected as soil part of the composite and plastic fiber was used as reinforcement. The fiber parameters differed from one test to another, as fiber length varied from 10 mm to 25mm and fiber content were selected as 0.1% and 0.3%. For each test, compaction curved derived and the results were compared. The results proved that inclusion of fiber affected compaction behaviour of samples so that increasing in fiber content and length caused increasing in Optimum Moisture Content (OMC) and slightly decreased maximum dry unit weight.

Key words: Fiber, Silty sand, Compaction

1. Introduction

Fletcher and Humphries (1991) investigated influence of fiber inclusion on compaction of silty clay soil. Unlike the case of sandy gravel reported by Hoare (1977), the test results indicated that increasing the fiber content causes a modest decrease in the maximum dry unit weight. The optimum water content was found to increase by increasing fiber content. Other researchers (Nataraj and McManis, 1997; Al Wahab and El-Kedrah, 1995; Puppala et al., 2006; Miller and Rifai, 2004; Ozkul et al., 2007; Kumar Tabor, 2003) also reported similar results. In contrast, some researchers such as Ozkul et al, 2007 reported not significant changes on compaction parameter by fiber inclusion. Therefore, the problem of effect of fiber inclusion on compaction parameter needs to be investigated precisely. Authors believe that different research results are due to different material which each researcher has used. This paper aims to investigate influences that are induced by fiber inclusion on compaction characteristics.

2. Material

Composite soils consist of two parts. The first part is soil part which can be dealt as normal soil. The second part is reinforcement part which can be made up of any material which helps soil to have better performance. Usage of additional material with soil is mainly because of tensile strength of the soil.

Soil Type

The soil type in this study was Western Australian Sand. The Particle Size Distribution (PSD) of used sand is presented in figure 1. This type of sand is widely used in industrial project and research activities in Western Australia. Ten percentage of silt also was used to reconstruct mixture.

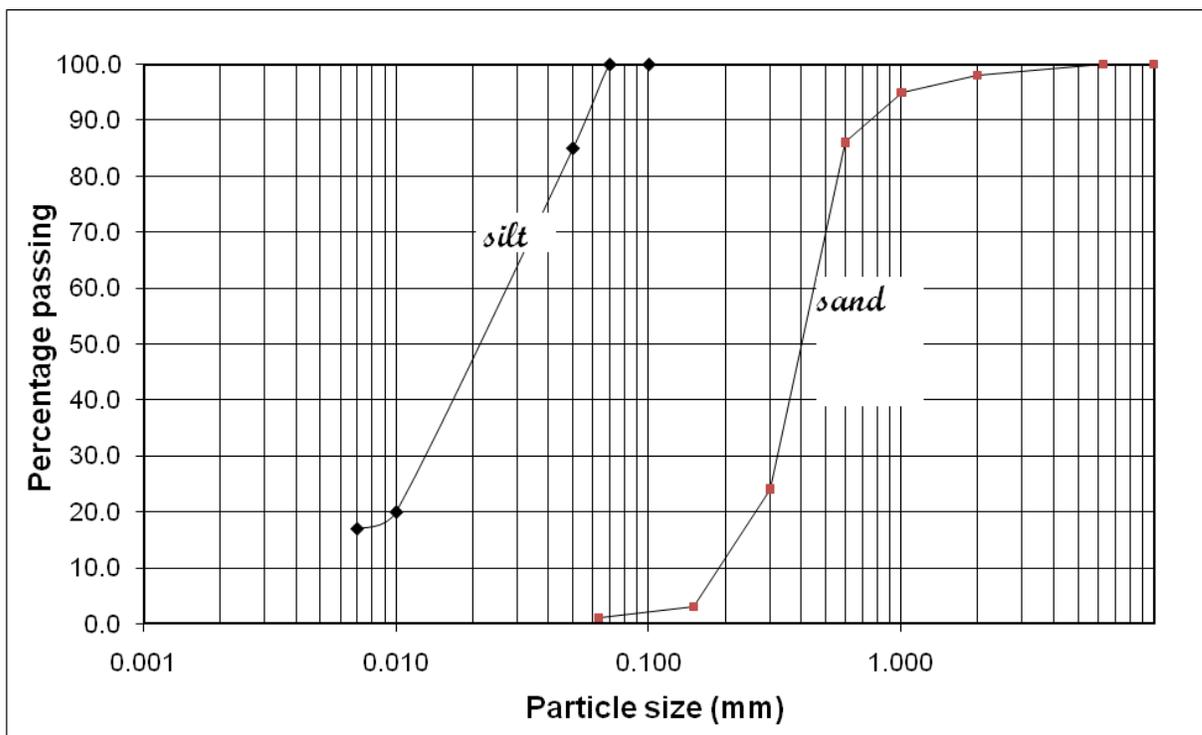


Fig. 1 Particle Size Distribution for Sand and Silt

Fiber Type

The plastic fiber has been used for this investigation. Figure2 shows the used fiber. The used fiber has good potential to absorb energy and good adhesion with soil particle.



Fig. 2 Plastic fiber

3. Test Program

A series of compaction test have been performed on reinforced silty sand composite.

Compaction test

Soil compaction is a mean to increase the density of soil. In geotechnical projects, soil density is an important parameter. Any difficulty related to compaction may cause settlement of the soil and as a consequence unnecessary maintenance costs or structure failure. Therefore, all types of construction sites and construction projects take special care in mechanical compaction method.

Main Equipments

To run the test, tools are needed as:

- Proctor mould with a detachable collar assembly and base plate.
- Manual rammer weighing 2.5 kg and equipped with height of drop to a free fall of 30 cm (for standard method)
- Sample Extruder.
- A sensitive balance.
- Straight edge.
- Moisture cans.
- Drying Oven

Figure 3 shows rammer which was used to compact the soil. Figure 4 shows the used mould and base.



Fig. 3 Standard compaction rammer



Fig. 4 Mould and Base

4. Test Methodology and Procedure

The test procedure can be listed as:

1. About 4.5 kg of air-dried soil was put in the mixing pan so that it could pass No. 4 sieve.
2. The moisture content was increased by about 5%.
3. The weight of empty mould without the base plate and the collar was recorded as W_1 (gr).

4. The collar and base plate was fixed and the first soil part was compacted with 25 blows in proctor mould
5. Some scratches were put with a spatula forming a grid to ensure uniformity in distribution of compaction energy to the subsequent layer. The second and third layer was placed and 25 blows were applied 25 blows.
6. The final layer was placed so that the compacted soil is just above the rim of the compaction mould when the collar is still attached.
7. The collar carefully was detached without disturbing the compacted soil inside the mould and edge was used to trim the excess soil leveling to the mould.
8. The weight of the mould with the moist soil W_2 , (gr) was determined.
9. Sample was extruded the sample and evaluated for water content in some cans
10. The rest of the compacted soil was broken with hand to pass US Sieve No.4. and moisture content was increased by 2%.
11. Steps 1 to 10 repeated again for different moisture contents.
12. The dry density plotted versus moisture contents

5. Test Design

The tests were designed systematically so that the effect of each fiber parameters (i.e. length and content) can be obtained. For reinforced samples, special care was taken for achieving uniformity of mixture while compaction procedure. First series of the test was related to effect of fiber content. In these test fiber content changed while fiber length was constant. The fiber percentages were 0.1%, 0.2% and 0.3% with constant fiber length of 10mm.

The second round was related to effect of fiber length. Therefore, different fiber length (i.e. 10 mm and 25mm) with constant fiber content of 0.1% were evaluated. Finally all results compared with unreinforced samples.

6. Results and discussions

Figure 5 and 6 present the results of compaction test on reinforced silty sand composite.

Figure 5 shows the effect of fiber content on maximum dry density and Optimum Moisture Content (OMC). As can be seen increasing in fiber content caused decreasing in maximum dry density and increasing in OMC.

Figure 6 indicates the effect of fiber length (aspect ratio) on compaction curve. The results proved that increasing in fiber aspect ratio caused decreasing in maximum dry density and increasing OMC.

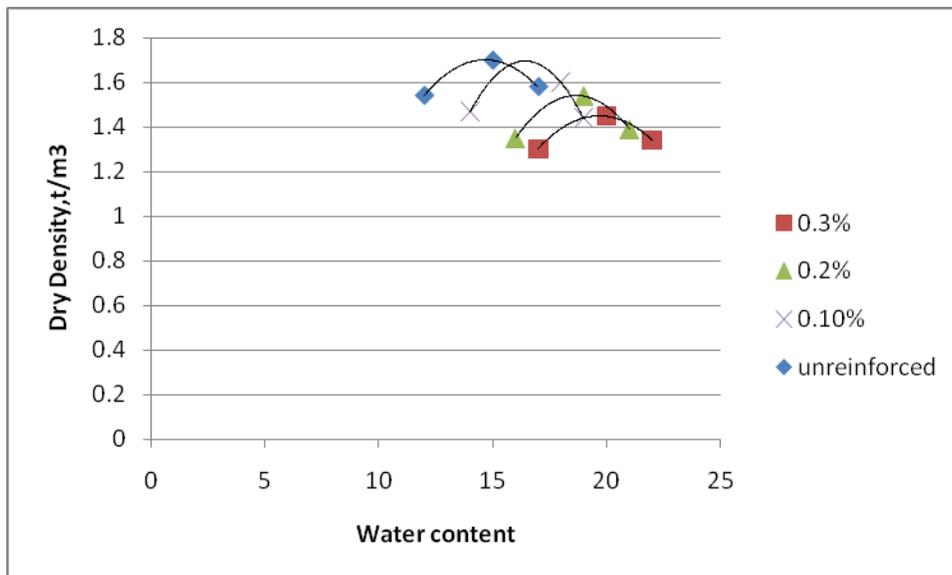


Fig. 5 Compaction Curve with different fiber content(at 10mm fiber length)

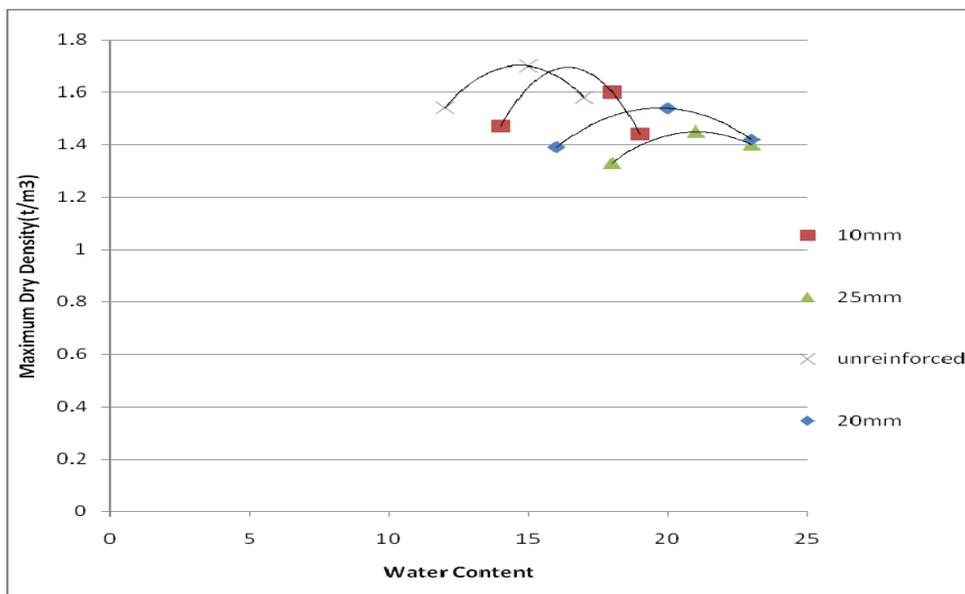


Fig. 6 Compaction Curve with different fiber length(at 0.1% fiber content)

7. Conclusion

A series of compaction test were performed to evaluate the effect of fiber inclusion on OMC and maximum dry density of composite silty sand. The following results were derived:

- Increasing in fiber percentage increased OMC of silty sand samples and decreased maximum dry density.

- The results proved that with increasing in fiber length, the OMC of composite silty sand was increased and decreased maximum dry density.

Acknowledgements

The technical support from the Curtin University Laboratory is gratefully acknowledged.

References

- Akbulut, S., Arasan, S. and Kalkan, E. (2007) *Modification of clayey soils using scrap tire rubber and synthetic fibers*, Journal of Applied Clay Science 38, 23-32.
- Al Refeai, T.O. (1991) *Behaviour of granular soils reinforced with discrete randomly oriented inclusions*, Journal of Geotextiles and Geomembranes, 10, pp. 319–333.
- AlWahab, R.M. and Al Quirma, H.H. (1995) *Fibre Reinforced Cohesive Soils for Application in Compacted Earth Structures*, Proceedings of Geosynthetics '95, IFAI, Vol. 2, Nashville, Tennessee, USA, March 1995, pp. 433-476.
- Cai, Y., Shi, B., Charles, W.W. Ng. & Tang, C. (2006) *Effect of polypropylene fiber and lime admixture on engineering properties of clayey soil*, Engineering Geology 87, 230– 240.
- Consoli, N.C., Vendruscolo, M.A., Fonini, A. and Dalla Rosa, F. (2009) *Fiber reinforcement effects on sand considering a wide cementation range*, Geotextiles and Geomembranes 27, pp. 196–203.
- Dvorak, G.K. and Bahei-El-Din, Y.A. (1982) *Plasticity analysis of fibrous composites*, Journal of Applied Mechanics 49, pp. 327–335.
- Freitag, D.R. (1986) *Soil randomly reinforced with fibers*, Journal of Geotechnical Engineering ASCE 112 (8), pp. 823–826.
- Gray, D. and Al-Rafeai, T. O. (1986). *Behavior of fabric versus fiber reinforced sand*. Journal of Geo-technical Engineering, vol. 112, no. 8, pp. 804-820.
- Gray, D. H. and Ohashi, H. (1983). *Mechanics of fiber reinforcement in sand*. Journal of Geotechnical and Geo-environmental Engineering, ASCE, vol. 109, no. 3, pp. 335-353.
- Lorenzo, G. A. and Bergado, D. T. (2004). *Fundamental parameters of cement-admixed clay – New approach*. Journal of Geotechnical and Geoenvironmental Engineering, Vol. 130, No. 10, pp. 1-9.
- Michalowski, R. L., Cermak, J. (2002), *Strength anisotropy of fiber-reinforced sand*. Computers and Geotechnics, Vol. 29, No. 4, pp. 279-299.
- Kaniraj, S. R. and Havanagi, V. G.(2001). *Behavior of cement-stabilization fiber-reinforced fly ash-soil mixtures*. Journal of Geo-technical and Geo-environmental Engineering, vol. 127, no. 7,pp. 574-584.
- Maher, M. H., Ho, Y. C. (1994), *Mechanical-properties of kaolinite fiber soil composite*. J. of Geotech. Engrg, ASCE, Vol. 120, No. 8, pp. 1381-1393.
- Nataraj, M. S., Mcmanis, K. L. (1997), *Strength and deformation properties of soils reinforced with fibrillated fibers.*, Geosynthetics Int., Vol. 4, No. 1, pp. 65-79.

Sivakumar Babu, G.L., Vasudevan, A.K. and Haldar, S. (2008) *Numerical simulation of fiber-reinforced sand behaviour*, Geotextiles and Geomembranes 26, pp. 181–188.

Waldron, L. J. (1977). *Shear resistance of root-permeated homogeneous and stratified soil*. Soil Society. Of American Journal 41 (5), pp. 843–849.

Yetimoglu, T. and Salbas, O. (2003) *A study on shear strength of sands reinforced with randomly distributed discrete fibers*, Geotextiles and Geomembranes 21 (2), pp. 103–110.

Ziegler, S., Leshchinsky, D., Ling, H. I., and Perry, E. B. (1998) *Effect of short polymeric fibers on crack development in clays*. *Soils and Foundations*, J of Applied clay science, Vol. 38, No. 1, pp. 247-253.

Zornberg, J. G., Cabral, A. R. and Viratjandr, C. (2004) *Behavior of tire shred-sand mixtures*, Canadian Geotechnical Journal 41 (2), pp. 227–241.

Modulus of Elasticity of Reinforced Silty Sand

Amin Chegenizadeh¹, Prof. Hamid Nikraz²,

¹ *PhD candidate, Department of Civil Engineering, Curtin University of Technology, Perth, Australia; ahegenizadeh@yahoo.com* ² *Prof. Hamid Nikraz, Head of the Department of Civil Engineering, Curtin University of Technology, Perth, Australia*
h.nikraz@curtin.edu.au

Paper Reference Number: 1120-152

Name of the Presenter: Amin Chegenizadeh



Abstract

Reinforced soil has been among the most effective soil modification materials. Its use has been expanded dramatically into civil engineering, geotechnical engineering and pavement engineering. Reinforcing subgrade in pavement systems has always been an issue. This study focuses on effect of fibre inclusion on the modulus of elasticity of subgrade material. Plastic fibre was used for this investigation. Fibre contents and aspect ratio have been changed during these tests. The fibre percentage varied from 0 % (for unreinforced samples) to 0.3%. Silty sand was used as sub grade material. Unconfined compression tests were carried out to investigate behaviour of the composite under different loading condition. The results showed that the modulus of elasticity of fibre reinforced composite has increased by fibre inclusion. The fibre length and fibre content found to play important rule on the modulus of elasticity of fibre.

Key words: Fiber, Silty sand, Modulus, UCS

1. Introduction

In conventional application of reinforcement in soil, the inclusion of tire, bars, grids etc are usually in a preferred orientation. The advances of these materials have usually been considered by an increase in their applications. The randomly discrete fibers are easily added and mixed randomly with soil part, the same way as cement, lime or other additives. Some researches have been done on cement additive (Consoli et.al. 2009; Cai et.al 2006; Lorenzo and Bergado, 2004) and can be used as a pattern of additive usage in soil. Fibre reinforced composite shows more ductility and small losses of peak strength i.e. in compared to unreinforced material. Therefore, fiber-reinforced soil composite is a practical solution in civil engineering projects. The main application of composite soil can be in embankment, subgrade, subbase, and slope stability problems. However, the data concerning the impact due to the addition of random discrete fibers on the characteristics of compacted native or virgin soils are limited, (Maher and Ho, 1993). This shortage is more considerable in pavement engineering therefore research on fibre inclusion in pavement systems needs to be more performed.

2. Material

Composite soils consist of two parts. The first part is soil part which can be dealt as normal soil. The second part is reinforcement part which can be made up of any material which helps

soil to have better performance. Usage of additional material with soil is mainly because of tensile strength of the soil.

Soil Type

The soil type in this study was Western Australian Sand. The Particle Size Distribution (PSD) of used sand is presented in figure 1. This type of sand is widely used in industrial project and research activities in Western Australia. Ten percentage of silt also was used to reconstruct mixture.

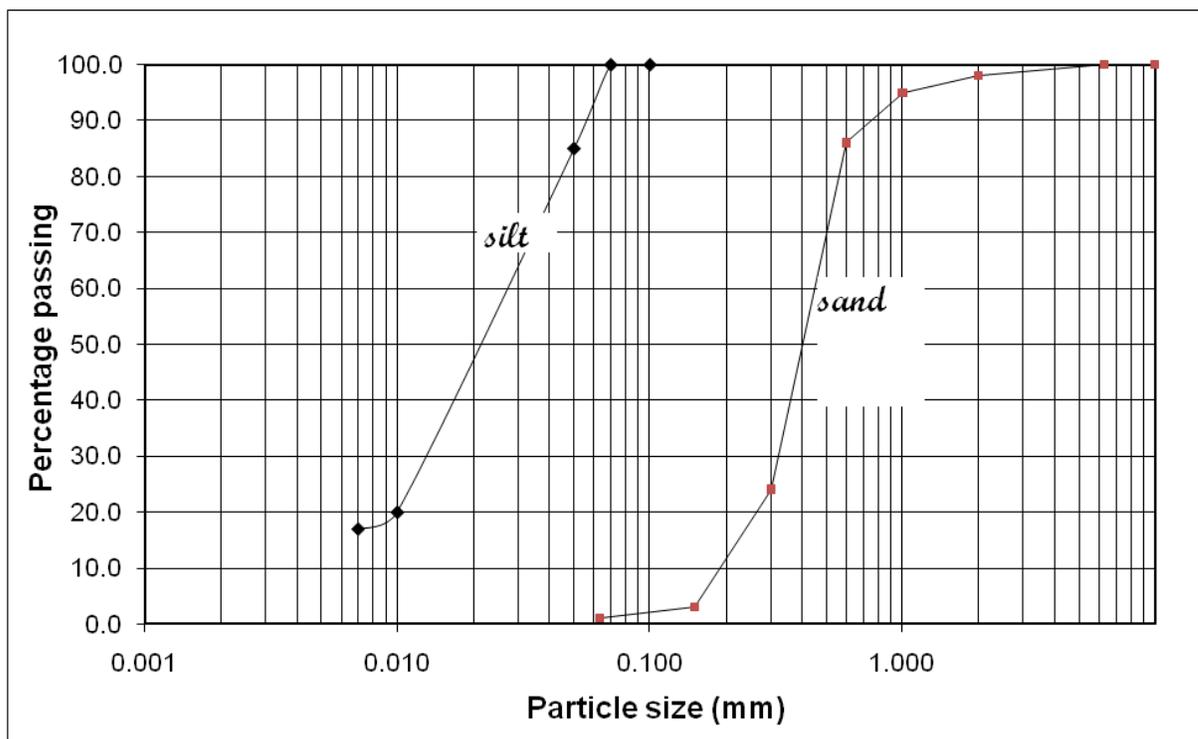


Fig. 1 Particle Size Distribution for Sand and Silt

Fiber Type

The plastic fiber has been used for this investigation. Figure2 shows the used fiber. The used fiber has good potential to absorb energy and good adhesion with soil particle.



Fig. 2 Plastic fiber

3. Test Program

A series of unconfined compression tests have been conducted to verify effect of fibre content on elasticity modulus.

Unconfined Compression Test Principle

Aim of Unconfined Compression test is to obtain unconfined compressive strength of soil. This can be applied to fine grade and cohesive soil and will represent very fast response in practical condition as the test time is very quick in respect to confined one. This test is widely used for slope stability and embankment dam applications.

Main Equipments

- Unconfined compression testing machine (Triaxial Machine) as shown in figure 3
- Specimen preparation equipment
- Sample extruder
- Fibre
- Balance

Figure 3 shows triaxial base which was used to conduct the tests.



Fig. 3 Triaxial machine

Sample Preparation

The samples were prepared by mixing silty sand and three percentage of fibre. Specimen preparation method was the standard compaction method, which was used in an ongoing experimental research on fiber-reinforced soil at Curtin University. The soils were first oven-dried. The dry soils were then crushed using a hammer. A mixer was used to thoroughly mix the soils with water to obtain the desired water moisture content for compaction. The mixing of soil with fibers was performed mostly by hand rather than using the mixer because the mixer caused the fibers to tangle or break. The fiber-soil mixture was placed in a closed container for 24 hours after mixing was completed. A split mold and a specific hammer were used to compact the specimen. The specimens were prepared in different fibre content (i.e. 0.1%, 0.2% and 0.3%) and different fibre length (aspect ratio) which were 10mm, 20mm, 25mm.

4. Test Methodology and Procedure

The test procedure can be listed as:

- The specimens were prepared in the laboratory with 90% compaction effort, special care was taken during this process

- The size of samples were checked to be suitable for the test purpose
- The samples were put for 24 hours in geotxtile and packed
- Special attention was applied for preventing any moisture loose
- The samples were put in triaxial base without any confinement pressure
- According to ASTM 1.27 mm/min were applied through the tests
- The data was collected automatically
- The stress-strain curve plot used for modulus elasticity investigation

5. Results and discussions

The unconfined compression tests were conducted in order to determine the modulus of elasticity (E-value). The E values were calculated based on the initial tangent of the stress-strain curve. The tests were conducted on cylindrical specimen of 60 mm diameter and 170 mm height.

Table 1 provides values of elastic modulus of soil with and without fiber reinforcement. The maximum E-value of silty sand was 10260 kPa obtained at the aspect ratio of 25mm and fiber content 0.3% percent. It was observed that modulus of elasticity was increased with increasing in fibre length and fibre content.

Fibre length(mm)	Fiber content %	E value
-----	0.00	6000
10	0.1	7010
	0.2	8266
	0.3	8500
20	0.1	7418
	0.2	8630
	0.3	9370
25	0.1	8293
	0.2	9240
	0.3	10260

Table 1 E-Values (kPa) for Reinforced and Unreinforced Soils

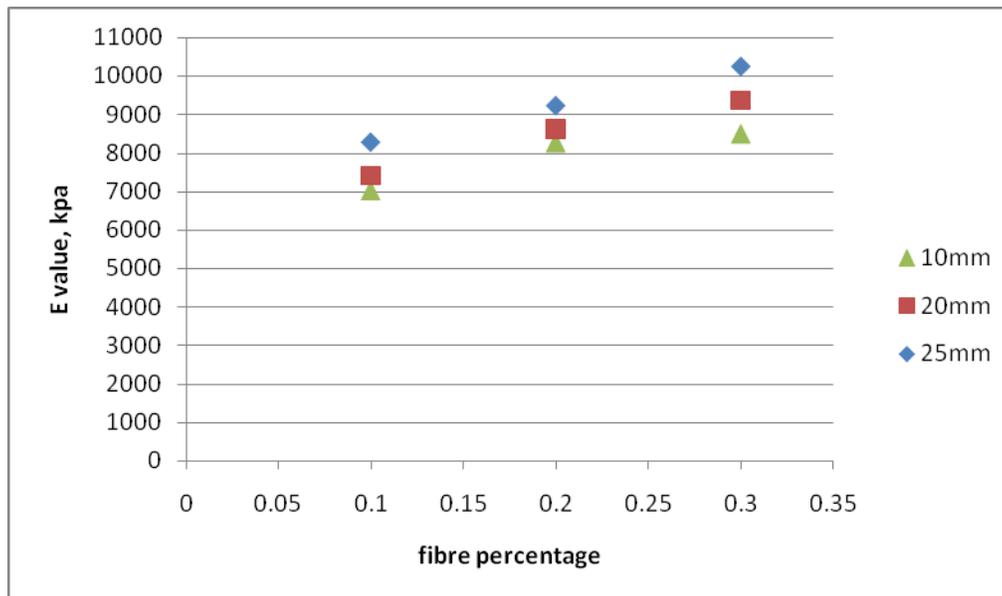


Fig. 4 Effect of fibre percentage and length on modulus of elasticity

6. Conclusion

A series of Unconfined Compression tests were performed and conclusions can be listed as:

- Increasing in fibre percentage increased modulus of elasticity
- Increasing in fibre aspect ratio increased modulus of elasticity
- During the test, it was observed that ductility behavior of reinforced silty sand increased because of fibre inclusion.
- Short and randomly fibre inclusion showed to be reliable solution to enhance strength of the composites.

Acknowledgements

The technical support from the Curtin University Laboratory is gratefully acknowledged.

References

- Akbulut, S., Arasan, S. and Kalkan, E. (2007) *Modification of clayey soils using scrap tire rubber and synthetic fibers*, Journal of Applied Clay Science 38, 23-32.
- Al Refeai, T.O. (1991) *Behaviour of granular soils reinforced with discrete randomly oriented inclusions*, Journal of Geotextiles and Geomembranes, 10, pp. 319–333.
- Cai, Y., Shi, B., Charles, W.W. Ng. & Tang, C. (2006) *Effect of polypropylene fiber and lime admixture on engineering properties of clayey soil*, Engineering Geology 87, 230– 240.

- Consoli, N.C., Vendruscolo, M.A., Fonini, A. and Dalla Rosa, F. (2009) *Fiber reinforcement effects on sand considering a wide cementation range*, Geotextiles and Geomembranes 27, pp. 196–203.
- Dvorak, G.K. and Bahei-El-Din, Y.A. (1982) *Plasticity analysis of fibrous composites*, Journal of Applied Mechanics 49, pp. 327–335.
- Freitag, D.R. (1986) *Soil randomly reinforced with fibers*, Journal of Geotechnical Engineering ASCE 112 (8), pp. 823–826.
- Gray, D. and Al-Rafeai, T. O. (1986). *Behavior of fabric versus fiber reinforced sand*. Journal of Geo-technical Engineering, vol. 112, no. 8, pp. 804-820.
- Gray, D. H. and Ohashi, H. (1983). *Mechanics of fiber reinforcement in sand*. Journal of Geotechnical and Geo-environmental Engineering, ASCE, vol. 109, no. 3, pp. 335-353.
- Lorenzo, G. A. and Bergado, D. T. (2004). *Fundamental parameters of cement-admixed clay – New approach*. Journal of Geotechnical and Geoenvironmental Engineering, Vol. 130, No. 10, pp. 1-9.
- Michalowski, R. L., Cermak, J. (2002), *Strength anisotropy of fiber-reinforced sand*. Computers and Geotechnics, Vol. 29, No. 4, pp. 279-299.
- Kaniraj, S. R. and Havanagi, V. G.(2001). *Behavior of cement-stabilization fiber-reinforced fly ash-soil mixtures*. Journal of Geo-technical and Geo-environmental Engineering, vol. 127, no. 7,pp. 574-584.
- Maher, M. H., Ho, Y. C. (1994), *Mechanical-properties of kaolinite fiber soil composite*. J. of Geotech. Engrg, ASCE, Vol. 120, No. 8, pp. 1381-1393.
- Nataraj, M. S., Mcmanis, K. L. (1997), *Strength and deformation properties of soils reinforced with fibrillated fibers.*, Geosynthetics Int., Vol. 4, No. 1, pp. 65-79.
- Sivakumar Babu, G.L., Vasudevan, A.K. and Haldar, S. (2008) *Numerical simulation of fiber-reinforced sand behaviour*, Geotextiles and Geomembranes 26, pp. 181–188.
- Waldron, L. J. (1977). *Shear resistance of root-permeated homogeneous and stratified soil*. Soil Society. Of American Journal 41 (5), pp. 843–849.
- Yetimoglu, T. and Salbas, O. (2003) *A study on shear strength of sands reinforced with randomly distributed discrete fibers*, Geotextiles and Geomembranes 21 (2), pp. 103–110.
- Ziegler, S., Leshchinsky, D., Ling, H. I., and Perry, E. B. (1998) *Effect of short polymeric fibers on crack development in clays*. Soils and Foundations, J of Applied clay science, Vol. 38, No. 1, pp. 247-253.
- Zornberg, J. G., Cabral, A. R. and Viratjandr, C. (2004) *Behavior of tire shred-sand mixtures*, Canadian Geotechnical Journal 41 (2), pp. 227–241.

Laboratory Study on Strength of Reinforced Clayey Sand

Amin Chegenizadeh¹, Prof. Hamid Nikraz²

Abstract—Composite soils have been widely used in civil engineering applications, especially in slopes, embankment dam and landfills. This paper aims to investigate effect of fibre inclusion on Unconfined Compressive Strength of composite soil (i.e. sand composite). A series of laboratory Unconfined Compression tests carried out to evaluate fibre effect on strength behavior of composite sand. Clayey sand was selected as soil part of the composite and plastic fibre was used as reinforcement. The fibre parameters differed from one test to another, as fibre length were changed from 10 mm to 40 mm and fibre content were selected as 0.6% and 3.5%. For each test, stress-strain graph derived and the results were compared. The results proved that inclusion of fibre affected strength behaviour of sand composite so that increasing in fibre content and length caused increasing in Unconfined Compressive Strength (UCS).

Keywords—UCS, Reinforced, Fibre, Sand

I. INTRODUCTION

The paper presents the effect of fibre inclusion on unconfined compressive strength of clayey sand. Applications of soil strengthening or stabilization range from the mitigation of complex slope hazards to enhancing the subgrade stability. Together with the many applications for improving soil, there are several widely varied methods. The mixing of randomly oriented fibers to a soil sample may be considered same as other admixtures used to stabilize soil. Material used to make fibers for reinforcement may be obtained from paper, metal, nylon, polyester and other materials having widely varied physical properties. There have been numerous past papers published on the topic of fiber strengthening of soils. Examples include Lee et al., 1973, Hoare, 1979, Andersland and Khattac, 1979, Freitag, 1986, Gray and Ohashi, 1983, Gray and Rafeai, 1986, Maher and Gray 1990, Maher and Ho, 1994, Michalowski and Zhao 2002, Ranjan et al. 1996, Kaniraj and Havanagi 2001, Consoli et al. 2009.

All of the papers listed above have generally shown that; strength of the soil was improved by fiber reinforcement. The investigation on clayey sand is very limited. The purpose of this survey is to evaluate clayey sand behaviour induced by fibre inclusion.

¹F. A. Author is with the Curtin University of Technology, Perth, Australia Tel: +61-413165961; Email: amin.chegenizadeh@postgrad.curtin.edu.au

²S. B. Author, Head of the Department of Civil Engineering, Curtin University of Technology, Perth, Australia; Tel: +61 8 9266 7573; Fax: +61 8 9266 2681; Email: H.Nikraz@curtin.edu.au

II. MATERIAL

Composite soils consist of two parts. The first part is soil part which can be dealt as normal soil. The second part is reinforcement part which can be made up of any material which helps soil to have better performance.

A. Soil Type

The soil type in this study was Western Australian sand. The properties of clay are presented in table 1. The sand distribution curve is presented in Fig 1. The soil part was reconstituted in lab by using sand with 15% of kaolin clay.

Table 1. Clay properties

No.	Type	
1	Soil type	Clay
2	Liquid Limit	49
3	Plastic Limit	23
4	Pl. Index	26

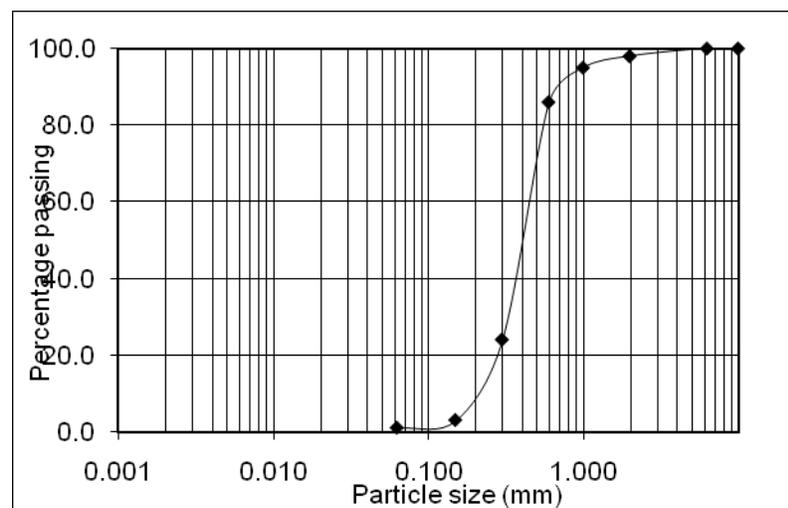


Fig. 1 Sand Particle Distribution

B. Fibre Type

The plastic fibre has been used for this investigation. Figure 2 shows the used fibre. The used fibre has good potential to absorb energy and good adhesion with soil particle.



Fig. 2 Plastic fibre

III. TEST PROGRAM

A series of unconfined compression have been conducted on reinforced sand composite.

A. Unconfined Compression Test

The unconfined compression test imposes uniaxial stress conditions on a sample of soil, and is therefore a special case of the triaxial test with zero confining stress. The unconfined compression test has a significant cost advantage over triaxial test due to the simpler testing requirement. The limitation of this test can be named as: preparing stable sample for cohesionless material and undrained estimation due to quick test.

B. Main Equipments

- Unconfined compression testing machine (Triaxial Machine)
- Specimen preparation equipment
- Sample extruder
- fibre
- Balance

Figure 3 shows triaxial base which was used to run the UCS test. The device is fully automated so the results easily transferred without any user interference.



Fig. 3 Triaxial Machine

IV. SAMPLE PREPARATION

The samples were prepared by mixing clay and three percentage of fibre. Specimen preparation method was the standard compaction method, which was used in an ongoing experimental research on fiber-reinforced clay at Curtin University. The soils were first oven-dried. The dry soils were then crushed using a hammer. A mixer was used to thoroughly mix the soils with water to obtain the desired water moisture content for compaction. The mixing of soil with fibers was performed mostly by hand rather than using the mixer because the mixer caused the fibers to tangle or break. The fiber-soil mixture was placed in a closed container for 24 hours after mixing was completed. A split mold and a specific hammer were used to compact the specimen. The specimens were prepared in different fibre content (i.e. 0.6%, 1.5%, 3.5 %) and different fibre length (aspect ratio) which were 10mm, 25mm, 40mm.

V. TEST METHODOLOGY AND PROCEDURE

- The specimens were prepared in the laboratory with 90% compaction effort, special care was taken during this process
- The size of samples were checked to be suitable for the test purpose
- The samples were put for 24 hours in geotextile and packed
- Special attention was applied for preventing any moisture loose
- The samples were put in triaxial base without any confinement pressure
- According to ASTM 1.27 mm/min were applied through the tests
- The data was collected automatically

The stress-strain curve plot used for strength behavior investigation

VI. RESULTS AND DISCUSSIONS

The unconfined compression tests were conducted in order to determine effect of fibre inclusion on Unconfined Compressive Strength (UCS). Figure 4 showed the stress-strain curve obtained from the tests. The tests were conducted on cylindrical specimen of 60 mm diameter and 170 mm height. The presented results in figure 4 are at fibre length of 10mm.

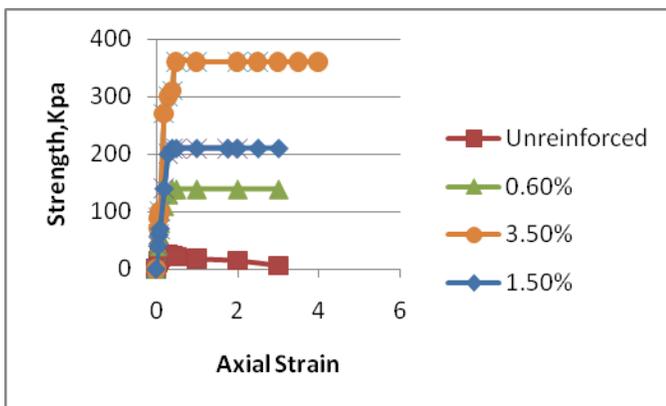


Fig. 4 Results of UCS test in different fibre content

Figure 4 proved increasing in fibre content will increase the strength.

Figure 5 shows the effect of fibre length on strength of composite clayey sand at constant fibre content of 0.6%.

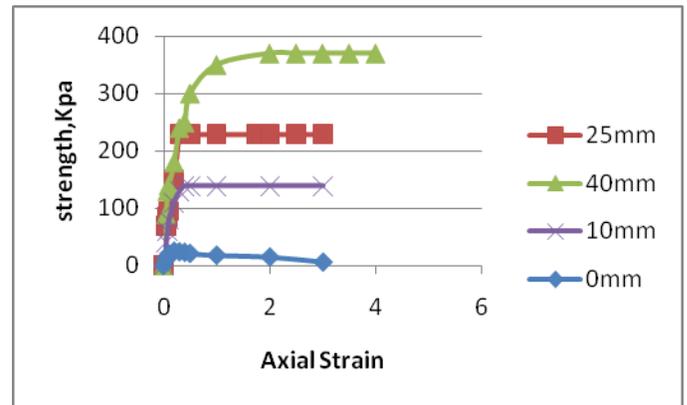


Fig. 5 Results of UCS test in different fibre length

VII. CONCLUSION

- Increasing in fibre percentage increased strength in clayey sand samples
- During the test, it was observed that ductility behaviour of reinforced sand increased because of fibre inclusion.
- The results proved that with increasing in fibre length, the UCS of composite clayey sand was increased.
- Short and randomly Fibre inclusion showed to be reliable in industry projects as it helps to minimize the cost of projects.

ACKNOWLEDGEMENTS

The technical support from the Curtin University Laboratory is gratefully acknowledged.

REFERENCES

- [1] Akbulut, S., Arasan, S. and Kalkan, E. (2007) "Modification of clayey soils using scrap tire rubber and synthetic fibres", *Journal of Applied Clay Science* 38, 23-32.
- [2] Al Rafeai, T.O. (1991) "Behaviour of granular soils reinforced with discrete randomly inclusions", *Journal of Geotextiles and Geomembranes*, 10, pp. 319-333.
- [3] Cai, Y., Shi, B., Charles, W.W. Ng. & Tang, C. (2006) "Effect of polypropylene fibre and lime admixture on engineering properties of clayey soil", *Engineering Geology* 87, 230- 240.
- [4] Consoli, N.C., Vendruscolo, M.A., Fonini, A. and Dalla Rosa, F. (2009) "Fibre reinforcement effects on sand considering a wide cementation range", *Geotextiles and Geomembranes* 27, pp. 196-203.
- [5] Freitag, D.R. (1986) "Soil randomly reinforced with fibres", *Journal of Geotechnical Engineering ASCE* 112 (8), pp. 823-826.
- [6] Gray, D. and Al-Rafeai, T. O. (1986). "Behavior of fabric versus fiber reinforced sand". *Journal of Geo-technical Engineering*, vol. 112, no. 8, pp. 804-820.

- [7] Gray, D. H. and Ohashi, H. (1983). "Mechanics of fiber reinforcement in sand". *Journal of Geotechnical and Geo-environmental Engineering*, ASCE, vol. 109, no. 3, pp. 335-353.
- [8] Lorenzo, G. A. and Bergado, D. T. (2004). "Fundamental parameters of cement-admixed clay – New approach". *Journal of Geotechnical and Geoenvironmental Engineering*, Vol. 130, No. 10, pp. 1-9.
- [9] Michalowski, R. L., Cermak, J. (2002), "Strength anisotropy of fiber-reinforced sand". *Computers and Geotechnics*, Vol. 29, No. 4, pp. 279-299.
- [10] Kaniraj, S. R. and Havanagi, V. G.(2001). "Behavior of cement-stabilization fiber-reinforced fly ash-soil mixtures. *Journal of Geotechnical and Geo-environmental Engineering*, vol. 127, no. 7,pp. 574-584.
- [11] Maher, M. H., Ho, Y. C. (1994), "Mechanical-properties of kaolinite fiber soil composite". *J. of Geotech. Engrg, ASCE*, Vol. 120, No. 8, pp. 1381-1393.
- [12] Nataraj, M. S., Mcmanis, K. L. (1997)," Strength and deformation properties of soils reinforced with fibrillated fibers.", *Geosynthetics Int.*, Vol. 4, No. 1, pp. 65-79.
- [13] Sivakumar Babu, G.L., Vasudevan, A.K. and Haldar, S. (2008) Numerical simulation of fibre-reinforced sand behaviour, *Geotextiles and Geomembranes* 26, pp. 181–188.
- [14] Yetimoglu, T. and Salbas, O. (2003) "A study on shear strength of sands reinforced with randomly distributed discrete fibres", *Geotextiles and Geomembranes* 21 (2), pp. 103–110.
- [15] Ziegler, S., Leshchinsky, D., Ling, H. I., and Perry, E. B. (1998)" Effect of short polymeric fibers on crack development in clays. *Soils and Foundations*", *J of Applied clay science*, Vol. 38, No. 1, pp. 247-253.
- [16] Zornberg, J. G., Cabral, A. R. and Viratjandr, C. (2004) "Behavior of tire shred-sand mixtures", *Canadian Geotechnical Journal* 41 (2), pp. 227–241.
- [17] Zornberg, J. G. (2002) "discrete framework for limit equilibrium analysis of fibre-reinforcement", *Geotechnique Journal* 52 (8), pp. 227–241.

Direct Shear Test on Reinforced Clay

Amin Chegenizadeh¹, Prof. Hamid Nikraz²

Abstract—Composite soils have been widely used in civil engineering applications, especially in slopes, embankment dam and landfills. This paper aims to investigate effect of fiber inclusion on shear stress of composite soil (i.e. clay composite). A series of laboratory direct shear tests carried out to evaluate fiber effect on strength behavior of composite clay. Clay was selected as soil part of the composite and plastic fiber was used as reinforcement. The fiber parameters differed from one test to another, as fiber length were changed from 10 mm to 40 mm and fiber content were varied from 0.2% and 1%. Normal stress kept constant at 100 kpa. For each test, stress_ displacement graph derived and the results were compared. The results proved that inclusion of fiber affected shear stress behaviour of clay composite so that increasing in fiber content and length caused increasing in shear stress.

Keywords—Direct shear, Reinforced, Fiber, Clay

I. INTRODUCTION

The direct shear test is one of the oldest strength tests for soils. In this study, a direct shear device will be used to determine the shear strength of a fiber reinforced soil. Applications of soil strengthening or stabilization range from the mitigation of complex slope hazards to enhancing the subgrade stability. Together with the many applications for improving soil, there are several widely varied methods. The mixing of randomly oriented fibers to a soil sample may be considered same as other admixtures used to stabilize soil. Material used to make fibers for reinforcement may be obtained from paper, metal, nylon, polyester and other materials having widely varied physical properties. There have been numerous past papers published on the topic of fiber strengthening of soils. Examples include Lee et al., 1973, Hoare, 1979, Andersland and Khattac, 1979, Freitag, 1986, Gray and Ohashi, 1983, Gray and Rafeai, 1986, Maher and Gray 1990, Maher and Ho, 1994, Michalowski and Zhao 2002, Ranjan et al. 1996, Kaniraj and Havanagi 2001, Consoli et al. 2009.

All of the papers listed above have generally shown that; strength of the soil was improved by fiber reinforcement. The investigation on clay is very limited. The purpose of this survey is to evaluate clayey behaviour induced by fiber inclusion.

¹F. A. Author is with the Curtin University of Technology, Perth, Australia
Tel: +61-413165961; Email: amin.chegenizadeh@postgrad.curtin.edu.au

²S. B. Author, Head of the Department of Civil Engineering, Curtin University of Technology, Perth, Australia; Tel: +61 8 9266 7573; Fax: +61 8 9266 2681; Email: H.Nikraz@curtin.edu.au

II. MATERIAL

Composite soils consist of two parts. The first part is soil part which can be dealt as normal soil. The second part is reinforcement part which can be made up of any material which helps soil to have better performance.

A. Soil Type

The soil type in this study was Western Australian kaolin clay. The properties of clay are presented in table 1.

Table 1. Clay properties

No.	Type	
1	Soil type	Clay
2	Liquid Limit	49
3	Plastic Limit	23
4	Pl. Index	26

B. Fiber Type

Plastic fiber was used in this study. Figure 2 shows the used fiber. The used fiber has good potential to absorb energy and good adhesion with soil particle.



Fig. 2 Plastic fiber

III. TEST PROGRAM

A series of direct shear tests have been conducted on reinforced clay composite.

A. Direct Shear Test

The test is carried out on either undisturbed samples or remoulded samples. To facilitate the remoulding purpose, a soil sample may be compacted at optimum moisture content in a compaction mould. Then specimen for the direct shear test could be obtained using the correct cutter provided. Alternatively, clay sample can be placed in a dry state at a required density, in the assembled shear box.

A normal load is applied to the specimen and the specimen is sheared across the pre-determined horizontal plane between the two halves of the shear box. Measurements of shear load, shear displacement and normal displacement are recorded. From the results, the shear strength parameters can be determined.

B. Main Equipments

- Direct Shear Test Machine
- Specimen preparation equipment
- Natural fiber and plastic fiber
- Balance

Figure 3 shows automated direct shear which was used to run shear test. The device is fully automated so the results easily transferred without any user interference.

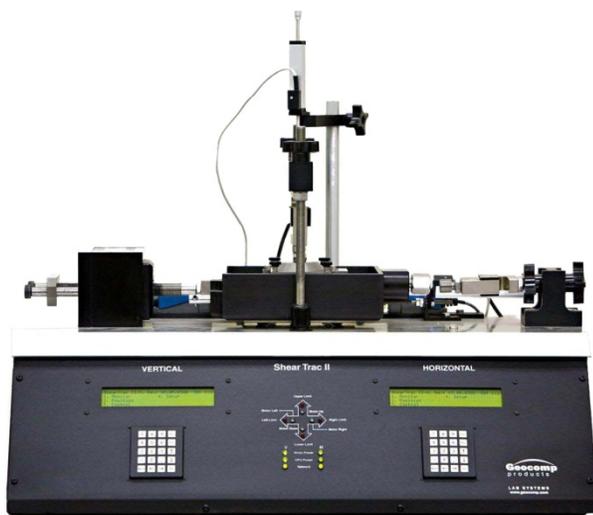


Fig. 3 Direct Shear Test Machine

IV. SAMPLE PREPARATION

The samples were prepared by mixing clay and three percentage of fiber (i.e. 0.2%, 0.3%, and 1%). The soil was first dried under laboratory air-dried conditions then ground and passed through a 2 mm sieve. The dry powder was carefully wetted with a spray gun to the standard optimum moisture content. The moist soil was then put in sealed plastic bags in a humidity room for about two days before use. The moist residual soil was then compacted in a 300 mm x 300 mm shear box mould by machine compaction to the appropriate height and unit weight at the optimum moisture content.

V. TEST METHODOLOGY AND PROCEDURE

1. The shear box was assembled and the specimen was put into the shear box. Special care was made that the alignment screws working well.
2. The shear box was placed into the shearing device.
3. Normal load was applied to the specimen using the load transfer plate and the loading hanger.
4. Set the shearing device the advance at a rate of 0.50 mm/min.
7. The data acquisition system was run.
8. Once data acquisition has begun, the shearing device was started.
9. The Shear Stress-Displacement curve plot used for strength behavior investigation

VI. RESULTS AND DISCUSSIONS

The direct shear tests were performed in order to determine effect of fiber inclusion on shear strength of reinforced clay. Figure 4 showed the stress-displacement curve obtained from the tests at 10mm fiber length and constant normal stress of 100 kpa.

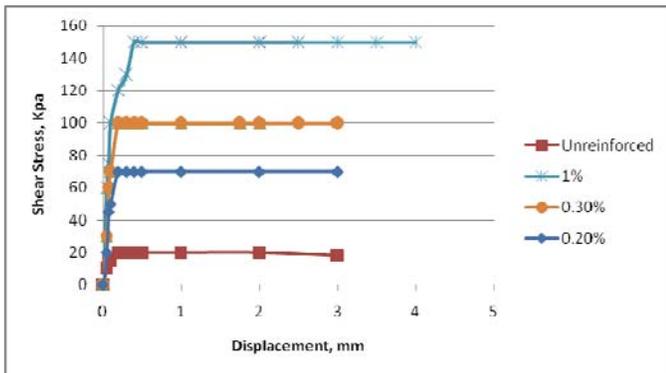


Fig. 4 Results of direct shear test in different fiber content (at 10mm, Normal stress 100 kpa)

Figure 4 proved increasing in fiber content will increase the strength.

Figure 5 shows the effect of fiber length on strength of composite clay at constant fiber content of 0.2% and normal stress of 100 kpa.

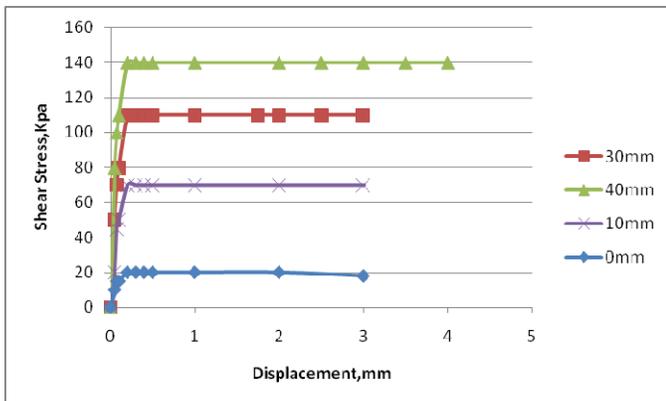


Fig. 5 Results of direct shear test in different fiber length (at 0.2% fiber content, Normal stress 100 kpa)

VII. CONCLUSION

The direct shear tests were conducted. Following conclusions were derived:

- Increasing in fiber percentage increased shear strength in clay samples
- During the test, it was observed that ductility behaviour of reinforced clay increased because of fiber inclusion.
- The results proved that with increasing in fiber length, the shear stress of composite clay was increased.

- Short and randomly Fiber inclusion showed to be reliable in industry projects as it helps to minimize the cost of projects.

ACKNOWLEDGEMENTS

The technical support from the Curtin University Laboratory is gratefully acknowledged.

REFERENCES

- [1] Akbulut, S., Arasan, S. and Kalkan, E. (2007) "Modification of clayey soils using scrap tire rubber and synthetic fibers", *Journal of Applied Clay Science* 38, 23-32.
- [2] Al Refeai, T.O. (1991) "Behaviour of granular soils reinforced with discrete randomly oriented inclusions", *Journal of Geotextiles and Geomembranes*, 10, pp. 319-333.
- [3] Cai, Y., Shi, B., Charles, W.W. Ng. & Tang, C. (2006) "Effect of polypropylene fiber and lime admixture on engineering properties of clayey soil", *Engineering Geology* 87, 230-240.
- [4] Consoli, N.C., Vendruscolo, M.A., Fonini, A. and Dalla Rosa, F. (2009) "Fiber reinforcement effects on sand considering a wide cementation range", *Geotextiles and Geomembranes* 27, pp. 196-203.
- [5] Freitag, D.R. (1986) "Soil randomly reinforced with fibers", *Journal of Geotechnical Engineering ASCE* 112 (8), pp. 823-826.
- [6] Gray, D. and Al-Rafeai, T. O. (1986). "Behavior of fabric versus fiber reinforced sand". *Journal of Geo-technical Engineering*, vol. 112, no. 8, pp. 804-820.
- [7] Gray, D. H. and Ohashi, H. (1983). "Mechanics of fiber reinforcement in sand". *Journal of Geotechnical and Geo-environmental Engineering, ASCE*, vol. 109, no. 3, pp. 335-353.
- [8] Lorenzo, G. A. and Bergado, D. T. (2004). "Fundamental parameters of cement-admixed clay - New approach". *Journal of Geotechnical and Geoenvironmental Engineering*, Vol. 130, No. 10, pp. 1-9.
- [9] Michalowski, R. L., Cermak, J. (2002), "Strength anisotropy of fiber-reinforced sand". *Computers and Geotechnics*, Vol. 29, No. 4, pp. 279-299.
- [10] Kaniraj, S. R. and Havanagi, V. G.(2001). "Behavior of cement-stabilization fiber-reinforced fly ash-soil mixtures. *Journal of Geotechnical and Geo-environmental Engineering*, vol. 127, no. 7, pp. 574-584.
- [11] Maher, M. H., Ho, Y. C. (1994), "Mechanical-properties of kaolinite fiber soil composite". *J. of Geotech. Engrg, ASCE*, Vol. 120, No. 8, pp. 1381-1393.
- [12] Nataraj, M. S., Mcmanis, K. L. (1997), "Strength and deformation properties of soils reinforced with fibrillated fibers.", *Geosynthetics Int.*, Vol. 4, No. 1, pp. 65-79.
- [13] Sivakumar Babu, G.L., Vasudevan, A.K. and Haldar, S. (2008) Numerical simulation of fiber-reinforced sand behaviour, *Geotextiles and Geomembranes* 26, pp. 181-188.
- [14] Yetimoglu, T. and Salbas, O. (2003) "A study on shear strength of sands reinforced with randomly distributed discrete fibers", *Geotextiles and Geomembranes* 21 (2), pp. 103-110.
- [15] Ziegler, S., Leshchinsky, D., Ling, H. I., and Perry, E. B. (1998) "Effect of short polymeric fibers on crack development in clays. *Soils and Foundations*", *J of Applied clay science*, Vol. 38, No. 1, pp. 247-253.
- [16] Zornberg, J. G., Cabral, A. R. and Viratjandr, C. (2004) "Behavior of tire shred-sand mixtures", *Canadian Geotechnical Journal* 41 (2), pp. 227-241.
- [17] Zornberg, J. G. (2002) "discrete framework for limit equilibrium analysis of fiber-reinforcement", *Geotechnique Journal* 52 (8), pp. 227-241.

Effect of fibre content on compressive strength of reinforced soil

Amin Chegenizadeh¹, Hamid Nikraz²

¹PhD Candidate, Curtin University

²Professor and Head of Civil Engineering, Curtin University

Synopsis: This paper aims to investigate effect of using fibre on strength of composite. A series of laboratory tests has been carried out to investigate the using of plastic fibre as reinforcement to increase the strength of the soil composite. Fibre percentage varied from 0% (for unreinforced samples) to 0.3%. Two methods of compaction test were used (i.e. Standard and Modified compaction methods). Unconfined compression tests were conducted in this study. The objective of using unconfined compression test was to determine the UU (unconsolidated, undrained) strength of a cohesive soil in an inexpensive manner. The results showed that fibre dosage was significant factor that affected the strength of the soil specimens. The results also indicated increasing in fibre content caused increase in compressive strength. The strength and ductility considerably increased with increasing the fibre content. Furthermore, Unconfined Compression Strength (UCS) found to be slightly greater for Modified method than Standard one. In addition, a series of tests have been conducted to examine permeability coefficient of the specimens. The results showed that length and fibre dosage had considerable effects on permeability of samples. It was proved that increase in fibre content and length caused increase in hydraulic conductivity.

Keywords: ucs, reinforced, fibre, clay, permeability

1. Introduction

The paper presents the effect of fibre inclusion on unconfined compressive strength and permeability of clay composite. Applications of soil strengthening or stabilization range from the mitigation of complex slope hazards to enhancing the subgrade stability. Together with the many applications for improving soil, there are several widely varied methods. The mixing of randomly oriented fibres to a soil sample may be considered same as other admixtures used to stabilize soil. Material used to make fibres for reinforcement may be obtained from paper, metal, nylon, polyester and other materials having widely varied physical properties. However, there have been some papers published on the topic of fibre strengthening of sand. [e.g., 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15], The investigation on clay composite is very limited. All of the papers listed above indicated that; strength of the soil, mainly sand, was improved by fibre reinforcement. The purpose of this survey is to evaluate clay behaviour induced by fibre inclusion.

Second part of this paper deals with permeability of composite clay. The permeability test is one of the oldest tests for soils. In this study, permeability test will be used to determine the hydraulic conductivity of a fibre reinforced soil. Effect of fibre inclusion on the hydraulic conductivity of a kaolinite-fibre composite investigated with different type of material and concluded that hydraulic conductivity of the soil increases as the percentage of fibre increases [e.g., 13, 1]. The originality of this study is using rough fibre rather than smooth one. This study will focus on effect of fibre on both permeability and Unconfined Compression Strength (UCS) of composite clay.

2. Material

Composite soils consist of two parts. The first part is soil part which can be dealt as pure soil. The second part is reinforcement part which can be made up of any material which helps soil to have better performance.

2.1 Soil type

The soil type in this study was Western Australian kaolin clay. The properties of clay are presented in Table 1.

Table1. Clay properties

No.	Type	
1	Soil type	Clay
2	Liquid Limit	49
3	Plastic Limit	23
4	Pl. Index	26

2.2 Fibre Type

The plastic fibre has been used for this investigation. The fibre is commercially available and is called fibre Meyco FIB SP 65 macro structural synthetic polypropylene fibre which generates a very high energy absorption rate when used in the matrix. Table 2 shows the used fibre properties.

Table2. fibre properties

No.	Type	
1	Material	Polypropylene
2	Specific Gravity	0.92
3	Width	1.6825 mm

3. Effect of fibre on Unconfined Compressive Strength of Composite clay

A series of unconfined compression have been conducted on reinforced clay composite.

3.1 Unconfined Compression Test principle

The unconfined compression test imposes uniaxial stress conditions on a sample of soil, and is therefore a special case of the triaxial test with zero confining stress. The unconfined compression test has a significant cost advantage over triaxial test due to the simpler testing requirement. The limitation of this test can be named as: preparing stable sample for cohesionless material and undrained estimation due to quick test

3.2 Main Equipment

The following equipments were used:

- Unconfined compression testing machine (Triaxial Machine)
- Specimen preparation equipment
- Sample extruder
- Balance

3.3 Sample Preparation

The samples were prepared by mixing clay and three percentage of fibre. Specimen preparation method was the standard and modified compaction method, which was used in an ongoing experimental research on fibre-reinforced clay at Curtin University. The soils were first oven-dried. The dry soils were then crushed using a hammer. A mixer was used to thoroughly mix the soils with water to obtain the desired water moisture content for compaction. The fibre-soil mixture was placed in a closed container for 24 hours after mixing was completed. A split mold and a specific hammer were used to compact the specimen. The specimens were prepared in different fibre content (i.e. 2% and 3%,) and different fibre length (aspect ratio) which were 10mm, 20mm, 30mm.

3.4 Test Methodology and Procedure

Following procedure performed to conduct the tests:

- The specimens were prepared in the laboratory with 90% compaction effort, special care was taken during this process(this step has been done with two methods (i.e. standard and modified))
- The size of samples were checked to be suitable for the test purpose
- The samples were put for 24 hours in geotxtile and packed
- Special attention was applied for preventing any moisture loose
- The samples were put in triaxial base without any confinement pressure
- According to ASTM 1.27 mm/min were applied through the tests
- The data was collected automatically

The stress-strain curve plot used for strength behavior investigation

3.5. Results and discussions

The result of the test can be analyzed in to two parts. The first part is regarding to use of standard method for deriving maximum dry density and therefore assuming 90% of compaction effort. The second part is related to results from UCS for sample provided with target dry density achieved from modified method.

3.5.1 Standard results

The unconfined compression tests were conducted in order to determine effect of fibre inclusion on Unconfined Compressive Strength (UCS). Figure 3 showed the stress-strain curve obtained from the tests. The tests were conducted on cylindrical specimen of 60 mm diameter and 170 mm height. The presented results in Figure 3 are at fibre length of 10mm.

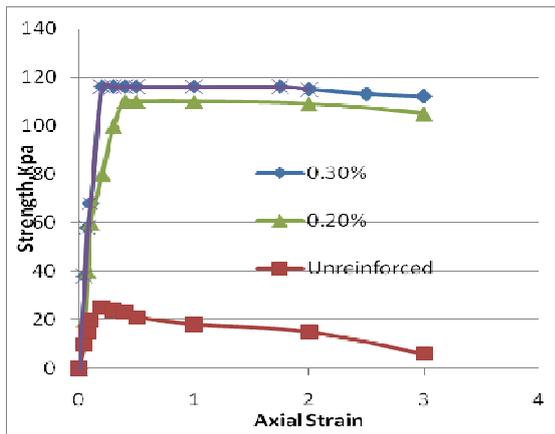


Figure 3. Effect of fibre content at 10mm

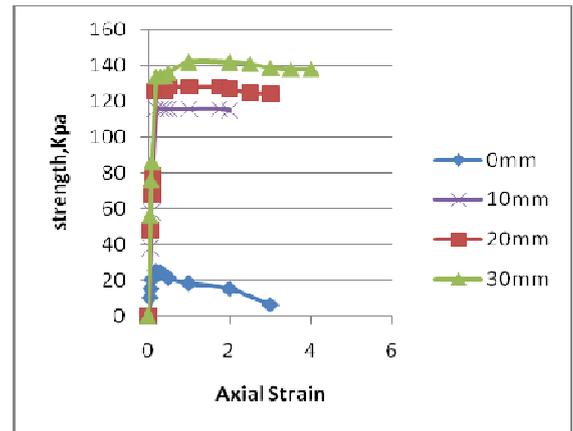


Figure 4. effect of fibre length at 0.3%

Figure 3 proved increasing in fibre content will increase the strength. As can be observed with increasing in fibre content from zero (unreinforced) to 0.2% the peak strength increased from 26 Kpa to 117 Kpa. The second increase in fibre content from 0.2% to 0.3% also showed increasing in peak strength. Figure 4 evaluated the effect of fibre length on UCS strength and showed that with increasing in fibre length UCS strength also increased.

3.5.2 Modified results

This section is related to results from UCS test for samples were provided with more compaction effort (i.e. modified method). Similar procedure as standard one performed and results are presented in Figure 5 and Figure 6. Figure 5 indicated that with increasing in fibre content the UCS increased (same results as standard) and Figure 6 showed that with increasing in fibre length UCS increased (same as standard one).

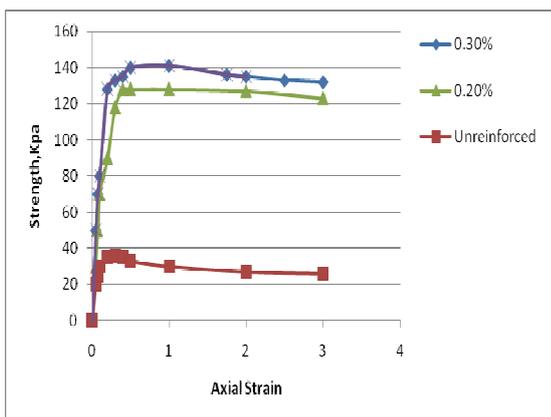


Figure 5. Effect of fibre content at 10mm

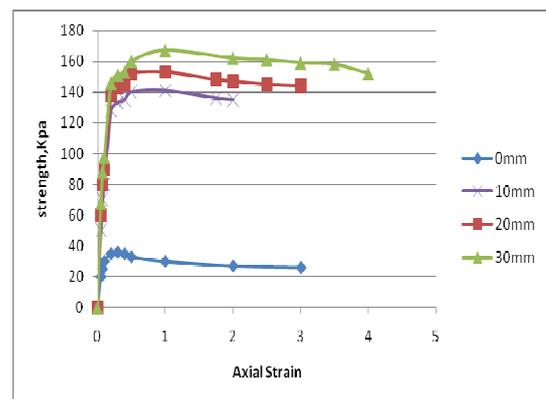


Figure 6. Effect of fibre length at 0.3%

4. Effect of fibre inclusion on permeability of reinforced clay composite

Effect of fibre inclusion on composite clay sample permeability is investigated in this section.

4.1 Permeability Test

Permeability is a measure of the ease in which water can flow through a soil volume. It is one of the most important geotechnical parameters. However, it is probably the most difficult parameter to determine. In large part, it controls the strength and deformation behavior of soils. It directly affects the following:

- Quantity of water that will flow toward an excavation
- Design of cutoffs beneath dams on permeable foundations
- Design of the clay layer for a landfill liner.

For fine grained soil Falling head permeability test is done, whereas constant head permeability test is done for the coarse grained soil.

4.2 Falling Head Permeability Test Application

- Settlements in structures
- Methods for lowering the ground water Table during construction
- Design grouting pressures and quantities for soil stabilization
- Freeze Thaw movements in soils (Note that coefficient of permeability (k) varies with temperature as the viscosity of the fluids changes with temperature, Curtin laboratory temperature was 23 ° c)
- Design of recharge pits

4.3 Main Equipment

The main equipments used for the permeability tests are:

- Sample Chamber
- Specimen preparation equipments such as compaction tools
- Balance
- Falling head device

4.4 Test Methodology and Procedure

- the sample was compacted in the lower chamber section of the Permeameter, in layers approximately 1.5 cm deep, to within about 2 cm of the lower chamber rim. An appropriate tamping device was used to compact the sample to the desired density.(90% compaction effort made for the tests)
- the length of the specimen was measured and recorded.
- the clamp was used to attach the falling head burette to the support rod. the burette was placed as high as is possible for practicality. the meter stick was put directly behind the burette, so the height of water in the burette above the chamber outflow port can be read.

- the specimen was saturated, following the steps outlined above.
- the heights of the two levels from the outflow level were measured.
- After a stable flow has been established, the drop in head (Δh) in 2 hours was recorded.

4.5 Analysing the results

The following equation was used for calculating the results from Falling head:

$$K = \frac{a \times L}{A \times t} \ln \frac{h_0}{h_1} \quad (1)$$

Where,

K = Coefficient of permeability

a = Area of the burette

L = Length of soil column

A = Area of the soil column

h_0 = Initial height of water

h_1 = Final height of water = $h_0 - \Delta h$

t = Time required to get head drop of Δh

4.6 Results and discussion

The permeability tests were performed in order to determine effect of fibre inclusion on hydraulic conductivity of reinforced clayey composite. Table 3 shows the effect of fibre on hydraulic conductivity of the samples.

Table 3: hydraulic conductivity of the samples

Sample type	Coefficient of permeability (Cm/S)
Unreinforced sample	1 E- 8
Reinforced with 0.1 % of fibre at 15mm	2.2 E -8
Reinforced with 0.2% of fibre at 15mm	2.6 E -8
Reinforced with 0.3 % of fibre at 15mm	3.1 E -8
Reinforced with 10mm of fibre at 0.1% content	2.05 E -8
Reinforced with 25mm of fibre at 0.1% content	2.68 E -8

Figure 8 and Figure 9 visualize the results of the tests. The results proved with increasing in fibre content and length the hydraulic conductivity increased. The best line which could represent the laboratory data was derived and regression of that was determined. A series of permeability test performed. The methodology which applied to the test was falling head method. The clayey soil was reinforced by short plastic fibre .The results from the tests presented in this paper which showed effect of each fibre parameters on permeability characteristics of composite samples. It was proved that increase in fibre content and length caused increase in hydraulic conductivity. The value of coefficient of permeability jumped from 1 E- 8 (cm/s) to 3.1 E -8 (cm/s) with increasing in fibre content from zero to 0.3% and also with increasing in fibre length from 10mm to 15 mm the value of coefficient of permeability increased from 2.05 E -8 (cm/s) to 2.2 E -8 (cm/s). The behaviour of composite soil in terms of hydraulic conductivity was

not linear due to change in fibre content and fibre length. Interaction of fibre and soil could be reason of increasing hydraulic conductivity as may cause creating some paths for water to escape in soil matrix.

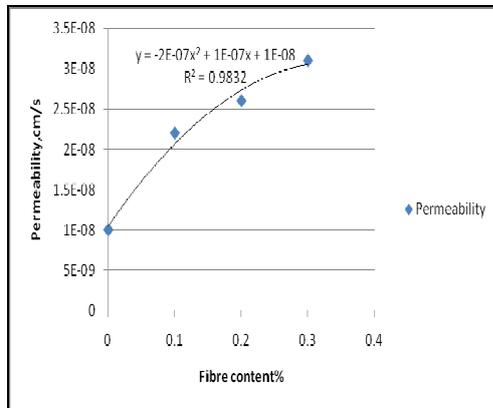


Figure 8. Permeability (at 15mm length)

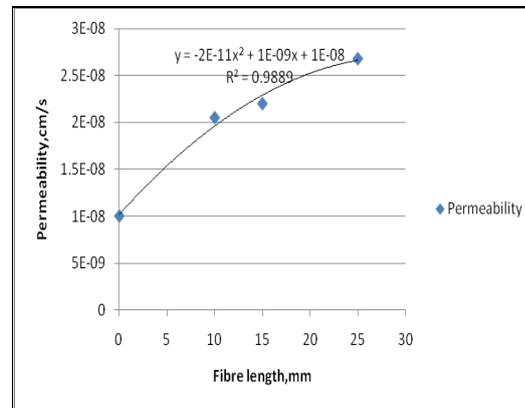


Figure 9. Permeability Test (at 0.1% fibre content)

5. Conclusions

Unconfined Compressive test and permeability test were conducted on composite clay and following results were derived:

- Increasing in fibre percentage increased strength in clayey samples
- The results proved that with increasing in fibre length, the UCS of composite clay was increased.
- Two methods of compactions applied (i.e. Standard and Modified). The results from both methods showed good agreement in case of behavior of composite clay.
- The strength from modified method was slightly greater than standard one.
- Permeability of composite samples was increased with increasing in fibre percentage and length
- Short and randomly fibre inclusion showed to be reliable in industry projects as it helps to minimize the cost of projects

6. References

1. Akbulut, S., Arasan, S. and Kalkan, E. (2007) "Modification of clayey soils using scrap tire rubber and synthetic fibres", *Journal of Applied Clay Science* 38, 23-32.
2. Al Refeai, T.O. (1991) "Behaviour of granular soils reinforced with discrete randomly oriented inclusions", *Journal of Geotextiles and Geomembranes*, 10, pp. 319-333.
3. Cai, Y., Shi, B., Charles, W.W. Ng. & Tang, C. (2006) "Effect of polypropylene fibre and lime admixture on engineering properties of clayey soil", *Engineering Geology* 87, 230-240.
4. Consoli, N.C., Vendruscolo, M.A., Fonini, A. and Dalla Rosa, F. (2009) "Fibre reinforcement effects on sand considering a wide cementation range", *Geotextiles and Geomembranes* 27, pp. 196-203.
5. Freitag, D.R. (1986) "Soil randomly reinforced with fibres", *Journal of Geotechnical Engineering ASCE* 112 (8), pp. 823-826.
6. Fletcher, C.S. and Humphries, W.K., 1991, "California Bearing Ratio Improvement of Remolded Soils by the Addition of Polypropylene Fibre Reinforcement", *Proceedings of Seventieth Annual Meeting, Transportation Research Board, Washington, DC, USA*, pp. 80-86
7. Gray, D. and Al-Rafeai, T. O. (1986). "Behavior of fabric versus fibre reinforced sand". *Journal of Geo-technical Engineering*, vol. 112, no. 8, pp. 804-820.

8. Gray, D. H. and Ohashi, H. (1983). "Mechanics of fibre reinforcement in sand". Journal of Geotechnical and Geo-environmental Engineering, ASCE, vol. 109, no. 3, pp. 335-353.
9. Hoare, D.J., 1979, "Laboratory Study of Granular Soils Reinforced with Randomly Oriented Discrete Fibres", Proceedings of International Conference on the Use of Fabrics in Geotechnics, Vol. 1, Paris, France, pp. 47-52
10. Michalowski, R. L., Cermak, J. (2002), "Strength anisotropy of fibre-reinforced sand". Computers and Geotechnics, Vol. 29, No. 4, pp. 279-299.
11. Kaniraj, S. R. and Havanagi, V. G.(2001). "Behavior of cement-stabilization fibre-reinforced fly ash-soil mixtures. Journal of Geo-technical and Geo-environmental Engineering, vol. 127, no. 7,pp. 574-584.
12. Maher, M. H., Ho, Y. C. (1994), "Mechanical-properties of kaolinite fibre soil composite". J. of Geotech. Engrg, ASCE, Vol. 120, No. 8, pp. 1381-1393.
13. Nataraj, M. S., Mcmanis, K. L. (1997)," Strength and deformation properties of soils reinforced with fibrillated fibres.", Geosynthetics Int., Vol. 4, No. 1, pp. 65-79.
14. Sivakumar Babu, G.L., Vasudevan, A.K. and Haldar, S. (2008) Numerical simulation of fibre-reinforced sand behaviour, Geotextiles and Geomembranes 26, pp. 181–188.
15. Zornberg, J. G., Cabral, A. R. and Viratjandr, C. (2004) "Behavior of tire shred-sand mixtures", Canadian Geotechnical Journal 41 (2), pp. 227–241.

CBR Test on Reinforced Clayey Sand

Amin Chegenizadeh¹, Prof. Hamid Nikraz²

Abstract—Composite soils have been widely used in civil engineering applications, especially in slopes, embankment dam and landfills. This paper aims to investigate effect of fiber inclusion on CBR values of composite soil (i.e. sand composite). A series of laboratory CBR tests carried out to evaluate fiber effect on CBR values behavior of composite sand. Clayey sand was selected as soil part of the composite and natural fiber was used as reinforcement. The fiber parameters differed from one test to another, as fiber length were changed from 20 mm to 50 mm and fiber content were varied from 1% and 3%. For each test, CBR values were calculated and compared. The results proved that inclusion of fiber affected CBR values of sand composite so that increasing in fiber content and length caused increasing in CBR.

Keywords—CBR, Reinforced, Fiber, Sand

I. INTRODUCTION

CBR test is the ratio of force per unit area required to penetrate a soil mass with standard circular piston at the rate of 1.25 mm/min. to that required for the corresponding penetration of a standard material. The California Bearing Ratio Test (CBR Test) is a penetration test developed by California State Highway Department (U.S.A.) for evaluating the bearing capacity of subgrade soil for design of flexible pavement. Tests are carried out on natural or compacted soils in water soaked or un-soaked conditions and the results so obtained are compared with the curves of standard test to have an idea of the soil strength of the subgrade soil. Applications of soil strengthening or stabilization range from the mitigation of complex slope hazards to enhancing the subgrade stability. Together with the many applications for improving soil, there are several widely varied methods. The mixing of randomly oriented fibers to a soil sample may be considered same as other admixtures used to stabilize soil. Material used to make fibers for reinforcement may be obtained from paper, metal, nylon, polyester and other materials having widely varied physical properties. There have been numerous past papers published on the topic of fiber strengthening of soils. Examples include Lee et al., 1973, Hoare,1979, Andersland and Khattac,1979, Freitag,1986, Gray and Ohashi, 1983, Gray and Rafeai, 1986, Maher and Gray 1990, Maher and Ho, 1994, Michalowski and Zhao 2002, Ranjan et al. 1996, Kaniraj and Havanagi 2001, Consoli et al. 2009.

¹F. A. Author is with the Curtin University of Technology, Perth, Australia Tel: +61-413165961;Email: amin.chegenizadeh@postgrad.curtin.edu.au

²S. B. Author, Head of the Department of Civil Engineering, Curtin University of Technology, Perth, Australia; Tel: +61 8 9266 7573; Fax: +61 8 9266 2681; Email: H.Nikraz@curtin.edu.au

All of the papers listed above have generally shown that; strength of the soil was improved by fiber reinforcement. The investigation on clayey sand is very limited. The purpose of this survey is to evaluate of CBR values of clayey sand induced by fiber inclusion. The CBR tests were conducted as per ASTM D1883 on the selected soils with and without reinforcement to investigate the influence of length and fiber content on CBR values. Moreover, the obtained CBR values were taken as indication of improvement in the soil strength due to fiber reinforcement. For different length and fiber contents, the dry weight required to fill the CBR mould was calculated based upon maximum dry densities of the soil and the volume of the mould. The water corresponding to Optimum Moisture Content (OMC) was put and mixed thoroughly. The water was added prior to fiber to prevent floating problems.

II. MATERIAL

Composite soils consist of two parts. The first part is soil part which can be dealt as normal soil. The second part is reinforcement part which can be made up of any material which helps soil to have better performance.

A. Soil Type

The soil type in this study was Western Australian sand. The properties of clay are presented in table 1. The sand distribution curve is presented in Fig 1. The soil part was reconstituted in lab by using sand with 20% of kaolin clay.

Table1. Clay properties

No.	Type	
1	Soil type	Clay
2	Liquid Limit	49
3	Plastic Limit	23
4	Pl. Index	26

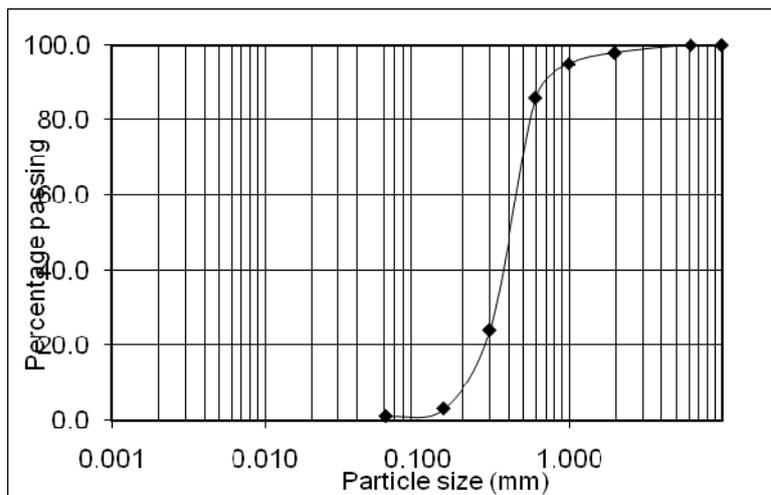


Fig. 1 Sand Particle Distribution

B. Fiber Type

The natural fiber has been used for this investigation. Figure 2 shows the used fiber. The used fiber has good potential to absorb energy and good adhesion with soil particle.



Fig. 2 Natural fiber

III. TEST PROGRAM

A series of CBR tests have been conducted on reinforced sand composite.

A. CBR Test

The California Bearing Ratio (CBR) test was developed by the California Division of Highways as a method of classifying and evaluating soil- subgrade and base course materials for flexible pavements. CBR is a measure of resistance of a material to penetration of standard plunger under controlled density and moisture conditions. CBR test may be conducted in remoulded or undisturbed sample. Test consists of causing a cylindrical plunger of 50mm diameter to penetrate a pavement component material at 1.25mm/minute. The loads for 2.5mm and 5mm are recorded. This load is expressed as a percentage of standard load value at a respective deformation level to obtain CBR value.

B. Main Equipments

- Mould
- Steel Cutting collar
- Spacer Disc
- Surcharge weight
- Dial gauges
- IS Sieves
- Penetration Plunger
- Loading Machine
- Miscellaneous Apparatus

Figure 3 shows the mechanism of CBR test machine.

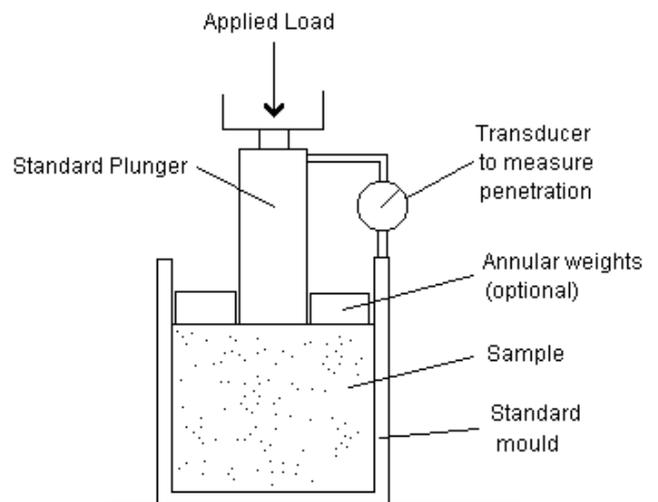


Fig. 3 Mechanism of CBR Test Machine(Gray,1983)

IV. TEST METHODOLOGY AND PROCEDURE

The sample was sieved through 20mm IS sieve. 5kg of the sample of soil specimen was taken. Water was added to the soil in the quantity such that optimum moisture content or field moisture content was reached. Then soil and water were mixed thoroughly. Spacer disc was placed over the baseplate at the bottom of mould and a coarse filter paper was placed over the spacer disc. The prepared soil water mix was divided into five. The mould was cleaned and oil was applied. Then was filled one fifth of the mould with the prepared soil. That layer was compacted by giving 56 evenly distributed blows using a hammer of weight 4.89kg. The top layer of the compacted soil was scratched. Again second layer was filled and process was repeated. After 3rd layer, collar was also attached to the mould and process was continued. After fifth layer collar was removed and excess soil was struck off. The base plate was removed and the mould was inverted. Then it was clamped to baseplate. Then the normal load was applied and CBR values recorded. The fibre content and length were varied during the tests. Fibre contents were selected as 1%, 2% and 3%. On other hand, fibre lengths were varied from 20mm up to 50mm.

V. RESULTS AND DISCUSSIONS

The CBR tests were performed in order to determine effect of fiber inclusion on CBR values of reinforced clayey sand. Figure 4 showed the CBR values obtained from the tests at different fiber length and content. The maximum CBR value obtained for an length of 50mm and 3 percent fiber content

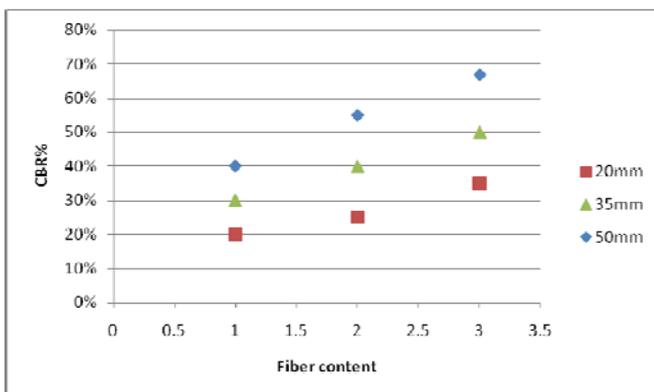


Fig. 4 Results of CBR test in different fiber content and lengths

VI. CONCLUSION

Two important parameters have been well investigated in this paper. The first parameter is fiber content and the second one

is aspect ratio. The effect of these two parameters studied on CBR values. Following results were derived:

- Increasing in fiber percentage increased CBR values in clayey sand samples
- The results proved that with increasing in fiber length, the CBR values of composite clayey sand were increased.
- Short and randomly Fiber inclusion showed to be reliable in industry projects as it helps to minimize the cost of projects.

ACKNOWLEDGEMENTS

The technical support from the Curtin University Laboratory is gratefully acknowledged.

REFERENCES

- [1] Akbulut, S., Arasan, S. and Kalkan, E. (2007) "Modification of clayey soils using scrap tire rubber and synthetic fibers", *Journal of Applied Clay Science* 38, 23-32.
- [2] Allan, M. L., Kukacka, L. E. (1995) "Permeability of microcracked fibre-reinforced containment barriers." *Waste Management* 15 (2), pp. 171-177.
- [3] Al Refeai, T.O. (1991) "Behaviour of granular soils reinforced with discrete randomly oriented inclusions", *Journal of Geotextiles and Geomembranes*, 10, pp. 319-333.
- [4] Cai, Y., Shi, B., Charles, W.W. Ng. & Tang, C. (2006) "Effect of polypropylene fiber and lime admixture on engineering properties of clayey soil", *Engineering Geology* 87, 230-240.
- [5] Consoli, N.C., Vendruscolo, M.A., Fonini, A. and Dalla Rosa, F. (2009) "Fiber reinforcement effects on sand considering a wide cementation range", *Geotextiles and Geomembranes* 27, pp. 196-203.
- [6] Freitag, D.R. (1986) "Soil randomly reinforced with fibers", *Journal of Geotechnical Engineering ASCE* 112 (8), pp. 823-826.
- [7] Gray, D. and Al-Rafeai, T. O. (1986). "Behavior of fabric versus fiber reinforced sand". *Journal of Geo-technical Engineering*, vol. 112, no. 8, pp. 804-820.
- [8] Gray, D. H. and Ohashi, H. (1983). "Mechanics of fiber reinforcement in sand". *Journal of Geotechnical and Geo-environmental Engineering*, ASCE, vol. 109, no. 3, pp. 335-353.
- [9] Kaniraj, S. R., Havanagi, V. G. (2001). "Behaviour of cement-stabilized fibre reinforced fly ash-soil Mixtures", *Journal of Geotech. and Geoenvironmental. Engineering* 127 (7), pp. 574-584.
- [10] Lorenzo, G. A. and Bergado, D. T. (2004). "Fundamental parameters of cement-admixed clay - New approach". *Journal of Geotechnical and Geoenvironmental Engineering*, Vol. 130, No. 10, pp. 1-9.
- [11] Michalowski, R. L., Cermak, J. (2002), "Strength anisotropy of fiber-reinforced sand". *Computers and Geotechnics*, Vol. 29, No. 4, pp. 279-299.
- [12] Kaniraj, S. R. and Havanagi, V. G. (2001). "Behavior of cement-stabilization fiber-reinforced fly ash-soil mixtures. *Journal of Geotechnical and Geo-environmental Engineering*, vol. 127, no. 7, pp. 574-584.
- [13] Maher, M. H., Ho, Y. C. (1994), "Mechanical-properties of kaolinite fiber soil composite". *J. of Geotech. Engrg. ASCE*, Vol. 120, No. 8, pp. 1381-1393.
- [14] Nataraj, M. S., Mcmanis, K. L. (1997), "Strength and deformation properties of soils reinforced with fibrillated fibers.", *Geosynthetics Int.*, Vol. 4, No. 1, pp. 65-79.
- [15] Sivakumar Babu, G.L., Vasudevan, A.K. and Haldar, S. (2008) Numerical simulation of fiber-reinforced sand behaviour, *Geotextiles and Geomembranes* 26, pp. 181-188.

- [16] Yetimoglu, T. and Salbas, O. (2003) "A study on shear strength of sands reinforced with randomly distributed discrete fibers", *Geotextiles and Geomembranes* 21 (2), pp. 103–110.
- [17] Ziegler, S., Leshchinsky, D., Ling, H. I., and Perry, E. B. (1998)" Effect of short polymeric fibers on crack development in clays. *Soils and Foundations*", *J of Applied clay science*, Vol. 38, No. 1, pp. 247-253.
- [18] Zornberg, J. G., Cabral, A. R. and Viratjandr, C. (2004) "Behavior of tire shred-sand mixtures", *Canadian Geotechnical Journal* 41 (2), pp. 227–241.
- [19] Zornberg, J. G. (2002) "discrete framework for limit equilibrium analysis of fiber-reinforcement", *Geotechnique Journal* 52 (8), pp. 227–241.

Compaction Parameters of Reinforced Clayey Sand

Amin Chegenizadeh¹, Prof. Hamid Nikraz²

Abstract— Composite soils have been widely used in civil engineering applications, especially in slopes, embankment dam and landfills. This paper aims to investigate effect of fibre inclusion on compaction characteristic of composite soil (i.e. clayey sand composite). A series of laboratory tests carried out to evaluate fibre effect on optimum water content and maximum dry unit weight of composite soils. Clayey sand was selected as soil part of the composite and natural fibre was used as reinforcement. The fibre parameters differed from one test to another, as fibre length varied from 15 mm to 30 mm and fibre content were selected as 0.5% and 0.7%. For each test, compaction curved derived and the results were compared. The results proved that inclusion of fibre affected compaction behaviour of samples so that increasing in fibre content and length caused increasing in Optimum Moisture Content (OMC) and slightly decreased maximum dry unit weight.

Keywords—Direct shear, Reinforced, Fiber, Sand

I. INTRODUCTION

Fletcher and Humphries (1991) investigated influence of fibre inclusion on compaction of silty clay soil. Unlike the case of sandy gravel reported by Hoare (1977), the test results indicated that increasing the fibre content causes a modest decrease in the maximum dry unit weight. The optimum water content was found to increase by increasing fibre content. Other researchers (Nataraj and McManis, 1997; Al Wahab and El-Kedrah, 1995; Puppala et al., 2006; Miller and Rifai, 2004; Ozkul et al., 2007; Kumar Tabor, 2003) also reported similar results. In contrast, some researchers such as Ozkul et al, 2007 reported not significant changes on compaction parameter by fibre inclusion. Therefore, the problem of effect of fibre inclusion on compaction parameter needs to be investigated precisely. Authors believe that different research results are due to different material which each researcher has used. This paper aims to investigate influences that are induced by fibre inclusion on compaction characteristics of clayey sand.

¹F. A. Author is with the Curtin University of Technology, Perth, Australia Tel: +61-413165961; Email: amin.chegenizadeh@postgrad.curtin.edu.au

²S. B. Author, Head of the Department of Civil Engineering, Curtin University of Technology, Perth, Australia; Tel: +61 8 9266 7573; Fax: +61 8 9266 2681; Email: H.Nikraz@curtin.edu.au

II. MATERIAL

Composite soils consist of two parts. The first part is soil part which can be dealt as normal soil. The second part is reinforcement part which can be made up of any material which helps soil to have better performance.

A. Soil Type

The soil type in this study was Western Australian sand. The properties of clay are presented in table 1. The sand distribution curve is presented in Fig 1. The soil part was reconstituted in lab by using sand with 20% of kaolin clay.

Table1. Clay properties

No.	Type	
1	Soil type	Clay
2	Liquid Limit	49
3	Plastic Limit	23
4	Pl. Index	26

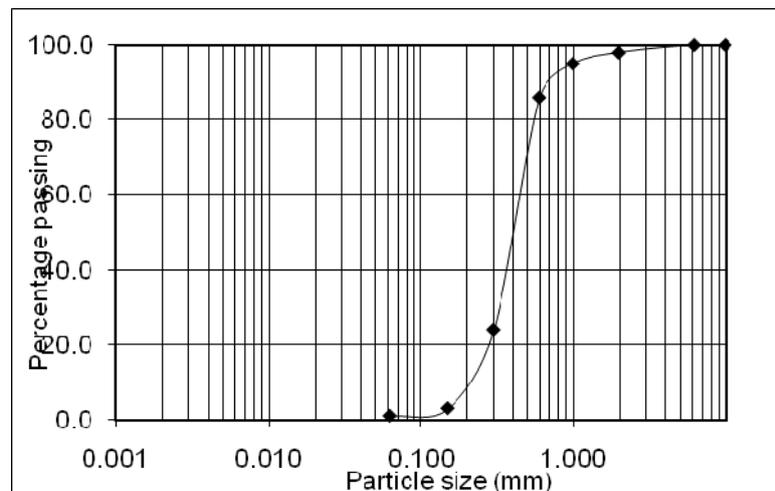


Fig. 1 Sand Particle Distribution

B. Fiber Type

The natural fiber has been used for this investigation. Figure 2 shows the used fiber. The used fiber has good potential to absorb energy and good adhesion with soil particle.



Fig. 2 Natural fiber

III. TEST PROGRAM

A series of compaction tests have been conducted.

A. Compaction test

Soil compaction is a mean to increase the density of soil. In geotechnical projects, soil density is an important parameter. Any difficulty related to compaction may cause settlement of the soil and as a consequence unnecessary maintenance costs or structure failure. Therefore, all types of construction sites and construction projects take special care in mechanical compaction method.

B. Main Equipments

- Proctor mould with a detachable collar assembly and base plate.
- Manual rammer weighing 2.5 kg and equipped with height of drop to a free fall of 30 cm (for standard method)
- Sample Extruder.
- A sensitive balance.
- Straight edge.

- Moisture cans.
- Drying Oven

IV. TEST METHODOLOGY AND PROCEDURE

1. About 4.5 kg of air-dried soil was put in the mixing pan so that it could pass No. 4 sieve.
2. The moisture content was increased by about 5%.
3. The weight of empty mould without the base plate and the collar was recorded as W1 (gr).
4. The collar and base plate was fixed and the first soil part was compacted with 25 blows in proctor mould
5. Some scratches were put with a spatula forming a grid to ensure uniformity in distribution of compaction energy to the subsequent layer. The second and third layer was placed and 25 blows were applied 25 blows.
6. The final layer was placed so that the compacted soil is just above the rim of the compaction mould when the collar is still attached.
7. The collar carefully was detached without disturbing the compacted soil inside the mould and edge was used to trim the excess soil leveling to the mould.
8. The weight of the mould with the moist soil W2, (gr) was determined.
9. Sample was extruded the sample and evaluated for water content in some cans
10. The rest of the compacted soil was broken with hand to pass US Sieve No.4. and moisture content was increased by 2%.
11. Steps 1 to 10 repeated again for different moisture contents.
12. The dry density plotted versus moisture contents.

V. RESULTS AND DISCUSSIONS

The results of laboratory investigation are presented in this section. As the tests were designed systematically the effect of each fibre parameter can be observed in this study. The first engineering graph is related to effect of fibre dosage on compaction curve of composite soil. Respectively, second part is focused on effect of fibre length (aspect ratio) on soil composite compaction characteristics.

The results from laboratory compaction test was interpreted and figure 3 shows the effect of fibre content on maximum dry density and optimum moisture content while the fibre length kept constant at 15mm. Respectively, figure 4 indicates effect

of fibre length on maximum dry density and optimum moisture content while the fibre content is constant at 0.5%.

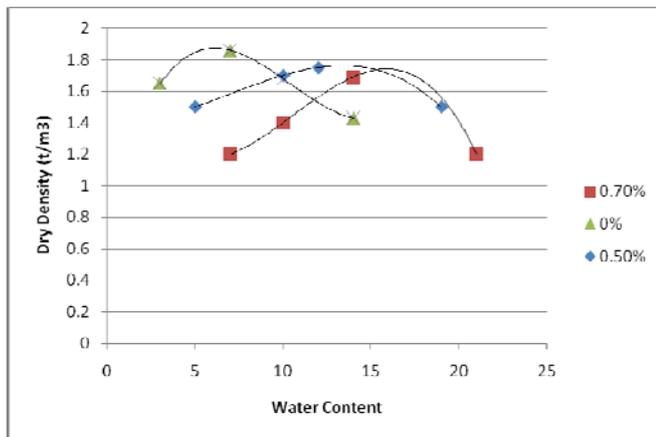


Fig. 3 Effect of fibre content on compaction curve (fibre length 15mm)

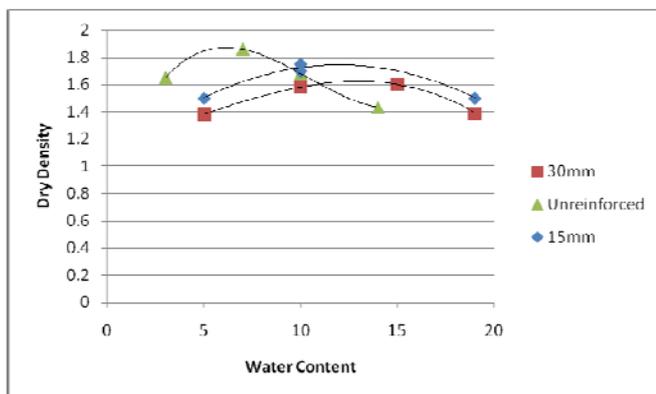


Fig. 4 Effect of fibre length on compaction curve (fibre content 0.5%)

VI. CONCLUSION

Compaction tests were conducted on composite clayey sand. This investigation proved that:

- Maximum dry density showed slight decrease due to induction of fibre
- Optimum Moisture Content (OMC) increased with increasing in fibre content

- Increasing in compaction effort causes increasing maximum dry density, this fact was observed for composite soil as well.
- Natural fibre showed to be good material to be used in practical projects

ACKNOWLEDGEMENTS

The technical support from the Curtin University Laboratory is gratefully acknowledged.

REFERENCES

- [1] Akbulut, S., Arasan, S. and Kalkan, E. (2007) "Modification of clayey soils using scrap tire rubber and synthetic fibers", *Journal of Applied Clay Science* 38, 23-32.
- [2] AlWahab, R.M. and Al Quirma, H.H. (1995) Fibre Reinforced Cohesive Soils for Application in Compacted Earth Structures, *Proceedings of Geosynthetics '95*, IFAI, Vol. 2, Nashville, Tennessee, USA, March 1995, pp. 433-476.
- [3] Al Refeai, T.O. (1991) "Behaviour of granular soils reinforced with discrete randomly oriented inclusions", *Journal of Geotextiles and Geomembranes*, 10, pp. 319-333.
- [4] Cai, Y., Shi, B., Charles, W.W. Ng. & Tang, C. (2006) "Effect of polypropylene fiber and lime admixture on engineering properties of clayey soil", *Engineering Geology* 87, 230-240.
- [5] Consoli, N.C., Vendruscolo, M.A., Fonini, A. and Dalla Rosa, F. (2009) "Fiber reinforcement effects on sand considering a wide cementation range", *Geotextiles and Geomembranes* 27, pp. 196-203.
- [6] Fletcher, C.S. and Humphries, W.K. (1991) California Bearing Ratio Improvement of Remoulded Soils by the Addition of Polypropylene Fibre Reinforcement, *Transportation Research Record* 1295, Washington, DC, USA, pp. 80-86.
- [7] Freitag, D.R. (1986) "Soil randomly reinforced with fibers", *Journal of Geotechnical Engineering ASCE* 112 (8), pp. 823-826.
- [8] Gray, D. and Al-Rafeai, T. O. (1986). "Behavior of fabric versus fiber reinforced sand". *Journal of Geo-technical Engineering*, vol. 112, no. 8, pp. 804-820.
- [9] Gray, D. H. and Ohashi, H. (1983). "Mechanics of fiber reinforcement in sand". *Journal of Geotechnical and Geo-environmental Engineering, ASCE*, vol. 109, no. 3, pp. 335-353.
- [10] Lorenzo, G. A. and Bergado, D. T. (2004). "Fundamental parameters of cement-admixed clay - New approach". *Journal of Geotechnical and Geoenvironmental Engineering*, Vol. 130, No. 10, pp. 1-9.
- [11] Michalowski, R. L., Cermak, J. (2002), "Strength anisotropy of fiber-reinforced sand". *Computers and Geotechnics*, Vol. 29, No. 4, pp. 279-299.
- [12] Kaniraj, S. R. and Havanagi, V. G. (2001). "Behavior of cement-stabilization fiber-reinforced fly ash-soil mixtures. *Journal of Geotechnical and Geo-environmental Engineering*, vol. 127, no. 7, pp. 574-584.
- [13] Maher, M. H., Ho, Y. C. (1994), "Mechanical-properties of kaolinite fiber soil composite". *J. of Geotech. Engrg, ASCE*, Vol. 120, No. 8, pp. 1381-1393.
- [14] Nataraj, M. S., Mcmanis, K. L. (1997), "Strength and deformation properties of soils reinforced with fibrillated fibers.", *Geosynthetics Int.*, Vol. 4, No. 1, pp. 65-79.
- [15] Sivakumar Babu, G.L., Vasudevan, A.K. and Haldar, S. (2008) Numerical simulation of fiber-reinforced sand behaviour, *Geotextiles and Geomembranes* 26, pp. 181-188.
- [16] Yetimoglu, T. and Salbas, O. (2003) "A study on shear strength of sands reinforced with randomly distributed discrete fibers", *Geotextiles and Geomembranes* 21 (2), pp. 103-110.

- [17] Ziegler, S., Leshchinsky, D., Ling, H. I., and Perry, E. B. (1998) "Effect of short polymeric fibers on crack development in clays. Soils and Foundations", *J of Applied clay science*, Vol. 38, No. 1, pp. 247-253.
- [18] Zornberg, J. G., Cabral, A. R. and Viratjandr, C. (2004) "Behavior of tire shred-sand mixtures", *Canadian Geotechnical Journal* 41 (2), pp. 227-241.
- [19] Zornberg, J. G. (2002) "discrete framework for limit equilibrium analysis of fiber-reinforcement", *Geotechnique Journal* 52 (8), pp. 227-241.

Shear Test on Reinforced Clayey Sand

Amin Chegenizadeh¹, Prof. Hamid Nikraz²

Abstract—Composite soils have been widely used in civil engineering applications, especially in slopes, embankment dam and landfills. This paper aims to investigate effect of fiber inclusion on shear stress of composite soil (i.e. sand composite). A series of laboratory direct shear tests carried out to evaluate fiber effect on strength behavior of composite sand. Clayey sand was selected as soil part of the composite and natural fiber was used as reinforcement. The fiber parameters differed from one test to another, as fiber length were changed from 10 mm to 35 mm and fiber content were varied from 0.6% and 3%. Normal stress kept constant at 100 kpa. For each test, stress_ displacement graph derived and the results were compared. The results proved that inclusion of fiber affected strength behaviour of sand composite so that increasing in fiber content and length caused increasing in shear stress.

Keywords—Direct shear, Reinforced, Fiber, Sand

I. INTRODUCTION

The direct shear test is one of the oldest strength tests for soils. In this study, a direct shear device will be used to determine the shear strength of a fiber reinforced soil. Applications of soil strengthening or stabilization range from the mitigation of complex slope hazards to enhancing the subgrade stability. Together with the many applications for improving soil, there are several widely varied methods. The mixing of randomly oriented fibers to a soil sample may be considered same as other admixtures used to stabilize soil. Material used to make fibers for reinforcement may be obtained from paper, metal, nylon, polyester and other materials having widely varied physical properties. There have been numerous past papers published on the topic of fiber strengthening of soils. Examples include Lee et al., 1973, Hoare, 1979, Andersland and Khattac, 1979, Freitag, 1986, Gray and Ohashi, 1983, Gray and Rafeai, 1986, Maher and Gray 1990, Maher and Ho, 1994, Michalowski and Zhao 2002, Ranjan et al. 1996, Kaniraj and Havanagi 2001, Consoli et al. 2009.

All of the papers listed above have generally shown that; strength of the soil was improved by fiber reinforcement. The investigation on clayey sand is very limited. The purpose of this survey is to evaluate clayey sand behaviour induced by fiber inclusion.

II. MATERIAL

Composite soils consist of two parts. The first part is soil part which can be dealt as normal soil. The second part is reinforcement part which can be made up of any material which helps soil to have better performance.

A. Soil Type

The soil type in this study was Western Australian sand. The properties of clay are presented in table 1. The sand distribution curve is presented in Fig 1. The soil part was reconstituted in lab by using sand with 20% of kaolin clay.

No.	Type	Clay
1	Soil type	Clay
2	Liquid Limit	49
3	Plastic Limit	23
4	Pl. Index	26

Table 1. Clay properties

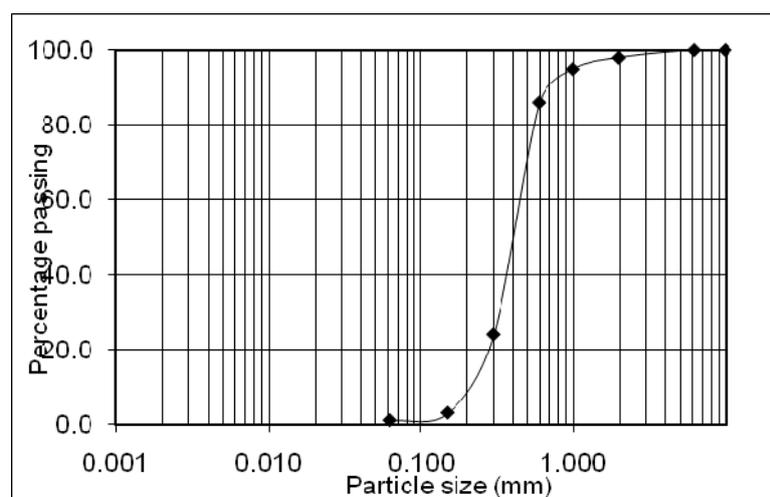


Fig. 1 Sand Particle Distribution

¹F. A. Author is with the Curtin University of Technology, Perth, Australia Tel: +61-413165961; Email: amin.chegenizadeh@postgrad.curtin.edu.au

²S. B. Author, Head of the Department of Civil Engineering, Curtin University of Technology, Perth, Australia; Tel: +61 8 9266 7573; Fax: +61 8 9266 2681; Email: H.Nikraz@curtin.edu.au

B. Fiber Type

The natural fiber has been used for this investigation. Figure 2 shows the used fiber. The used fiber has good potential to absorb energy and good adhesion with soil particle.



Fig. 2 Natural fiber

III. TEST PROGRAM

A series of direct shear tests have been conducted on reinforced sand composite.

A. Direct Shear Test

The test is carried out on either undisturbed samples or remoulded samples. To facilitate the remoulding purpose, a soil sample may be compacted at optimum moisture content in a compaction mould. Then specimen for the direct shear test could be obtained using the correct cutter provided. Alternatively, sand sample can be placed in a dry state at a required density, in the assembled shear box.

A normal load is applied to the specimen and the specimen is sheared across the pre-determined horizontal plane between the two halves of the shear box. Measurements of shear load, shear displacement and normal displacement are recorded. From the results, the shear strength parameters can be determined.

B. Main Equipments

- Direct Shear Test Machine
- Specimen preparation equipment
- fiber
- Balance

Figure 3 shows automated direct shear which was used to run shear test. The device is fully automated so the results easily transferred without any user interference.



Fig. 3 Direct Shear Test Machine

IV. SAMPLE PREPARATION

The samples were prepared by mixing clay and three percentage of fiber (i.e. 0.6%, 0.8%, 1.5%, 3%) The soil was first dried under laboratory air-dried conditions then ground and passed through a 2 mm sieve. The dry powder was carefully wetted with a spray gun to the standard optimum moisture content. The moist soil was then put in sealed plastic bags in a humidity room for about two days before use. The moist residual soil was then compacted in a 300 mm x 300 mm shear box mould by machine compaction to the appropriate height and unit weight at the optimum moisture content.

V. TEST METHODOLOGY AND PROCEDURE

1. The shear box was assembled and the specimen was put into the shear box. Special care was made that the alignment screws working well.
2. The shear box was placed into the shearing device.
3. Normal load was applied to the specimen using the load transfer plate and the loading hanger.
4. Set the shearing device the advance at a rate of 0.50 mm/min.

7. The data acquisition system was run.
8. Once data acquisition has begun, the shearing device was started.
9. The Shear Stress-Displacement curve plot used for strength behavior investigation

VI. RESULTS AND DISCUSSIONS

The direct shear tests were performed in order to determine effect of fiber inclusion on shear strength of reinforced clayey sand. Figure 4 showed the stress-displacement curve obtained from the tests at 10mm fiber length and constant normal stress of 100 kpa.

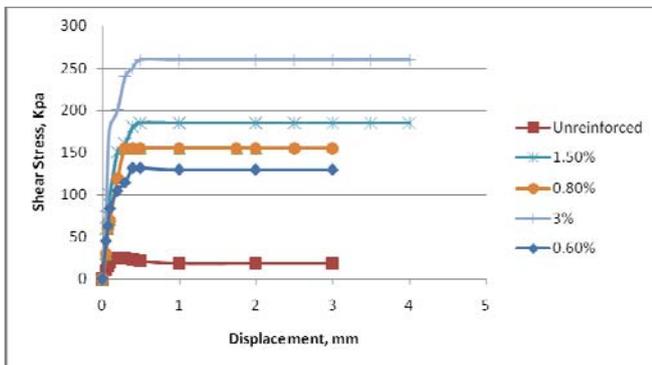


Fig. 4 Results of direct shear test in different fiber content (at 10mm, Normal stress 100 kpa)

Figure 4 proved increasing in fiber content will increase the strength.

Figure 5 shows the effect of fiber length on strength of composite clayey sand at constant fiber content of 0.6% and normal stress of 100 kpa.

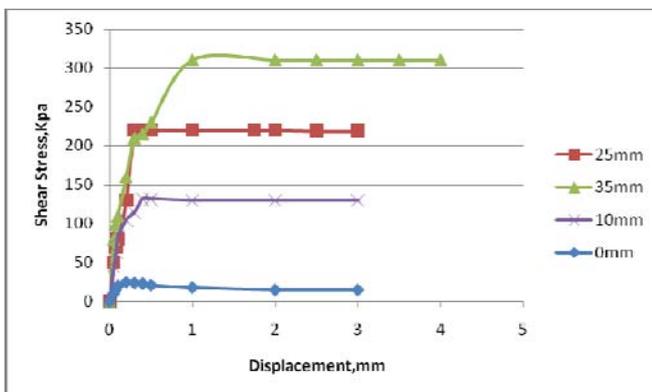


Fig. 5 Results of direct shear test in different fiber length (at 0.6% fiber content, Normal stress 100 kpa)

VII. CONCLUSION

- Increasing in fiber percentage increased shear strength in clayey sand samples
- During the test, it was observed that ductility behaviour of reinforced sand increased because of fiber inclusion.
- The results proved that with increasing in fiber length, the shear stress of composite clayey sand was increased.
- Short and randomly Fiber inclusion showed to be reliable in industry projects as it helps to minimize the cost of projects.

ACKNOWLEDGEMENTS

The technical support from the Curtin University Laboratory is gratefully acknowledged.

REFERENCES

- [1] Akbulut, S., Arasan, S. and Kalkan, E. (2007) "Modification of clayey soils using scrap tire rubber and synthetic fibers", *Journal of Applied Clay Science* 38, 23-32.
- [2] Al Refeai, T.O. (1991) "Behaviour of granular soils reinforced with discrete randomly oriented inclusions", *Journal of Geotextiles and Geomembranes*, 10, pp. 319-333.
- [3] Cai, Y., Shi, B., Charles, W.W. Ng. & Tang, C. (2006) "Effect of polypropylene fiber and lime admixture on engineering properties of clayey soil", *Engineering Geology* 87, 230- 240.
- [4] Consoli, N.C., Vendruscolo, M.A., Fonini, A. and Dalla Rosa, F. (2009) "Fiber reinforcement effects on sand considering a wide cementation range", *Geotextiles and Geomembranes* 27, pp. 196-203.
- [5] Freitag, D.R. (1986) "Soil randomly reinforced with fibers", *Journal of Geotechnical Engineering ASCE* 112 (8), pp. 823-826.
- [6] Gray, D. and Al-Rafeai, T. O. (1986). "Behavior of fabric versus fiber reinforced sand". *Journal of Geo-technical Engineering*, vol. 112, no. 8, pp. 804-820.
- [7] Gray, D. H. and Ohashi, H. (1983). "Mechanics of fiber reinforcement in sand". *Journal of Geotechnical and Geo-environmental Engineering*, ASCE, vol. 109, no. 3, pp. 335-353.
- [8] Lorenzo, G. A. and Bergado, D. T. (2004). "Fundamental parameters of cement-admixed clay - New approach". *Journal of Geotechnical and Geo-environmental Engineering*, Vol. 130, No. 10, pp. 1-9.
- [9] Michalowski, R. L., Cermak, J. (2002), "Strength anisotropy of fiber-reinforced sand". *Computers and Geotechnics*, Vol. 29, No. 4, pp. 279-299.
- [10] Kaniraj, S. R. and Havanagi, V. G.(2001). "Behavior of cement-stabilization fiber-reinforced fly ash-soil mixtures. *Journal of Geotechnical and Geo-environmental Engineering*, vol. 127, no. 7,pp. 574-584.
- [11] Maher, M. H., Ho, Y. C. (1994), "Mechanical-properties of kaolinite fiber soil composite". *J. of Geotech. Engrg. ASCE*, Vol. 120, No. 8, pp. 1381-1393.

- [12] Nataraj, M. S., Mcmanis, K. L. (1997),” Strength and deformation properties of soils reinforced with fibrillated fibers.”, *Geosynthetics Int.*, Vol. 4, No. 1, pp. 65-79.
- [13] Sivakumar Babu, G.L., Vasudevan, A.K. and Haldar, S. (2008) Numerical simulation of fiber-reinforced sand behaviour, *Geotextiles and Geomembranes* 26, pp. 181–188.
- [14] Yetimoglu, T. and Salbas, O. (2003) “A study on shear strength of sands reinforced with randomly distributed discrete fibers”, *Geotextiles and Geomembranes* 21 (2), pp. 103–110.
- [15] Ziegler, S., Leshchinsky, D., Ling, H. I., and Perry, E. B. (1998)” Effect of short polymeric fibers on crack development in clays. *Soils and Foundations*”, *J of Applied clay science*, Vol. 38, No. 1, pp. 247-253.
- [16] Zornberg, J. G., Cabral, A. R. and Viratjandr, C. (2004) “Behavior of tire shred-sand mixtures”, *Canadian Geotechnical Journal* 41 (2), pp. 227–241.
- [17] Zornberg, J. G. (2002) “discrete framework for limit equilibrium analysis of fiber-reinforcement”, *Geotechnique Journal* 52 (8), pp. 227–241.

Investigation on compaction characteristics of reinforced soil

Amin Chegenizadeh¹ and Prof. Hamid Nikraz²

¹ PhD candidate, Department of Civil Engineering, Curtin University of Technology, Perth, Australia; Tel: +60-413165961; Fax: +61 8 9266 2681; Email: amin.chezenizadeh@postgrad.curtin.edu.au

² Prof. Hamid Nikraz, Head of the Department of Civil Engineering, Curtin University of Technology, Perth, Australia; Tel: +61 8 9266 7573; Fax: +61 8 9266 2681; Email: H.Nikraz@curtin.edu.au

ABSTRACT

Composite soils have been widely used in civil engineering applications, especially in slopes, embankment dam and landfills. This paper aims to investigate effect of fibre inclusion on compaction characteristic of composite soil (i.e. clay composite). A series of laboratory tests carried out to evaluate fibre effect on optimum water content and maximum dry unit weight of composite soils. Clay was selected as soil part of the composite and plastic fibre was used as reinforcement. The fibre parameters differed from one test to another, as fibre length varied from 10 mm to 25mm and fibre content were selected as 0.1% and 0.3%. For each test, compaction curved derived and the results were compared. The results proved that inclusion of fibre affected compaction behaviour of samples so that increasing in fibre content and length caused increasing in Optimum Moisture Content (OMC) and slightly decreased maximum dry unit weight.

INTRODUCTION

Fletcher and Humphries (1991) investigated influence of fibre inclusion on compaction of silty clay soil. Unlike the case of sandy gravel reported by Hoare (1977), the test results indicated that increasing the fibre content causes a modest increase in the maximum dry unit weight. The optimum water content was found to decrease by increasing fibre content. Other researchers (Nataraj and McManis, 1997; Al Wahab and El-Kedrah, 1995; Puppala et al., 2006; Miller and Rifai, 2004; Ozkul et al., 2007; Kumar Tabor, 2003) also reported similar results. Figure 21 shows results from Miller and Rifai (2004). In contrast, other researcher such as Ozkul et al, 2007 reported not significant changes on compaction parameter by fibre inclusion. Therefore, the problem of effect of fibre inclusion needs to be investigated precisely. Authors believe that different results are due to different material each researcher has used. This paper aims to investigate influences that are induced by fibre inclusion.

MATERIAL

Composite materials consist of two parts. The first part is soil part which can be dealt as normal soil. The second part is reinforcement part which can be made up of any material which helps soil to have better performance.

Soil type

The soil type in this study was clay. The soil has been prepared with mixing sand and kaoline. The properties of kaoline clay are presented in table 1.

Table1. Clay properties

No.	Type	
1	Soil type	clay
2	Liquid Limit	49
3	Plastic Limit	23
4	Pl. Index	26

Fibre type

The plastic fibre has been used for this investigation. Figure1 shows the used fibre.



Fig. 1 Plastic fibre

TEST PROGRAM

A series of compaction tests have been conducted. Two methods were used: standard and modified. The results of both tests have been presented.

Compaction test principle

Soil compaction is defined as the method of mechanically increasing the density of soil. In construction, this is a significant part of the building process. If performed improperly, settlement of the soil could occur and result in unnecessary maintenance costs or structure failure. Almost all types of building sites and construction projects utilize mechanical compaction techniques.

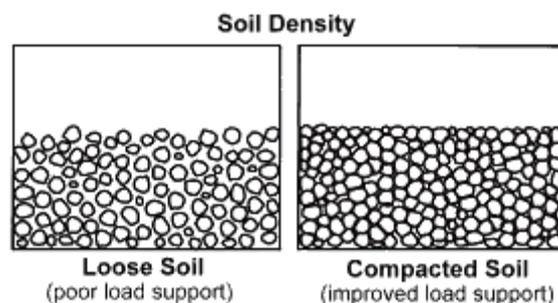


Fig. 1 Structure of loose and compacted soil

Effect of moisture on compaction procedure

Moisture content of the soil is vital to proper compaction. Moisture acts as a lubricant within soil, sliding the particles together. Too little moisture means inadequate compaction - the particles cannot move past each other to achieve density. Too much moisture leaves water-filled voids and subsequently weakens the load-bearing ability. The highest density for most soils is at a certain water content for a given compaction effort. The drier the soil, the more resistant it is to compaction. In a water-saturated state the voids between particles are partially filled with water, creating an apparent cohesion that binds them together. This cohesion increases as the particle size decreases (as in clay-type soils).

Proctor Test

The Proctor, or Modified Proctor Test, determines the maximum density of a soil needed for a specific job site. The test first determines the maximum density achievable for the materials and uses this figure as a reference. Secondly, it tests the effects of moisture on soil density. The soil reference value is expressed as a percentage of density. These values are determined before any compaction takes place to develop the compaction specifications. Modified Proctor values are higher because they take into account higher densities needed for certain types of construction projects. Test methods are similar for both tests.

The standard method

A small soil sample is taken from the jobsite. A standard weight is dropped several times on the soil. The material weighed and then oven dried for 12 hours in order to evaluate water content

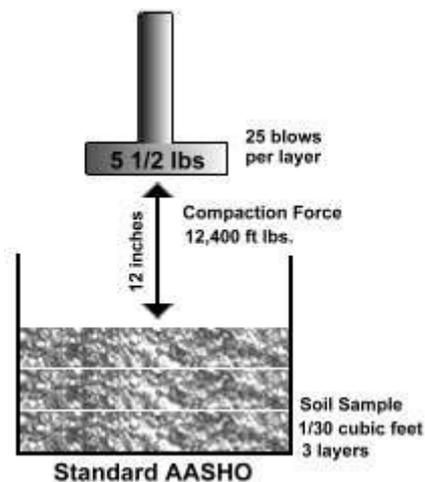


Fig. 1 Typical geometry of river levees

The modified method

This is similar to the Proctor Test except a hammer is used to compact material for greater impact. The test is normally preferred in testing materials for higher shearing strength.

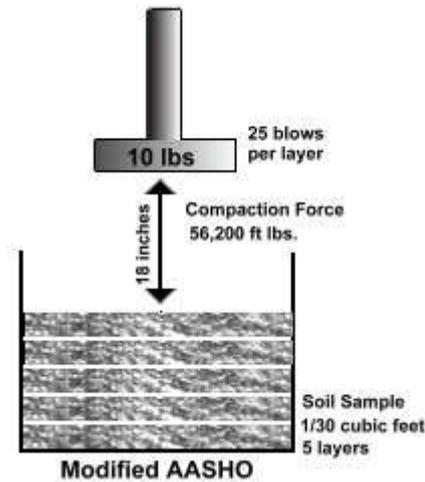


Fig. 2 Typical geometry of river levees

Sample preparation

The samples were prepared by mixing soil and two percentage of fibre. specimen preparation method adopted from the standard compaction method as described above, was used in an ongoing experimental research on fiber-reinforced clay at the University of Texas at Austin. The soils were initially oven-dried under a controlled temperature of 60 °C. The dry soils were then crushed using a hammer. A mixer was used to thoroughly mix the soils with water to reach the desired water content for compaction. The mixing of soil with fibers was conducted by hand rather than using the mixer because the mixer caused the fibers to tangle in previous trial. The fiber-soil mixture was stored in a covered container for 24 hours after mixing was completed. A split mold and a hammer were used to compact the specimen. Visual inspection showed that good uniformly distribution of fibers can be achieved using this specimen preparation procedure. Results of tests conducted using this procedure is not presented in this dissertation.

Equipments

1. Proctor mould with a detachable collar assembly and base plate.
2. Manual rammer weighing 2.5 kg and equipped to provide a height of drop to a free fall of 30 cm.
3. Sample Extruder.
4. A sensitive balance.
5. Straight edge.
6. Squeeze bottle
7. Mixing tools such as mixing pan, spoon, trowel, spatula etc.
8. Moisture cans.
9. Drying Oven

Test methodology and procedure

1. Obtain approximately 10 lb (4.5 kg) of air-dried soil in the mixing pan, break all the lumps so that it passes No. 4 sieve.

2. Add approximate amount of water to increase the moisture content by about 5%.
3. Determine the weight of empty proctor mould without the base plate and the collar. W1, (lb).
4. Fix the collar and base plate.
5. Place the first portion of the soil in the Proctor mould as explained in the class and compact the layer applying 25 blows.
6. Scratch the layer with a spatula forming a grid to ensure uniformity in distribution of compaction energy to the subsequent layer. Place the second layer, apply 25 blows, place the last portion and apply 25 blows.
7. The final layer should ensure that the compacted soil is just above the rim of the compaction mould when the collar is still attached.
8. Detach the collar carefully without disturbing the compacted soil inside the mould and using a straight edge trim the excess soil leveling to the mould.
9. Determine the weight of the mould with the moist soil W2, (lb). Extrude the sample and break it to collect the sample for water content determination preferably from the middle of the specimen.
10. Weigh an empty moisture can, W3, (g) and weigh again with the moist soil obtained from the extruded sample in step9, W4, (g). Keep this can in the oven for water content determination.
11. Break the rest of the compacted soil with hand (visually ensure that it passes US Sieve No.4). Add more water to increase the moisture content by 2%.
12. Repeat steps 4 to 11. During this process the weight W2 increases for some time with the increase in moisture and drops suddenly. Take two moisture increments after the weights starts reducing. Obtain at least 4 points to plot the dry unit weight, moisture content variation.
13. After 24 hrs recover the sample in the oven and determine the weight W5, (g).
14. Fill out the following table completely; Calculate rows 9 and 10, these two will give one point of the plot.

Notice that; The modified compaction procedure is similar to the above with a change in the compactive effort. The rammer used in the modified compaction is a 4.9 kg or 10 lb with a height of drop of 450mm or 18".

EQUATION TO BE USED

To derive the compaction curve, equation 1 was used to express variation of dry unit weight versus moisture content of samples.

$$\gamma_{dry} = \frac{\gamma_{wet}}{1 + \left(\frac{w}{100}\right)} \quad (1)$$

Where:

γ_{dry} = dry density

γ_{wet} = wet density

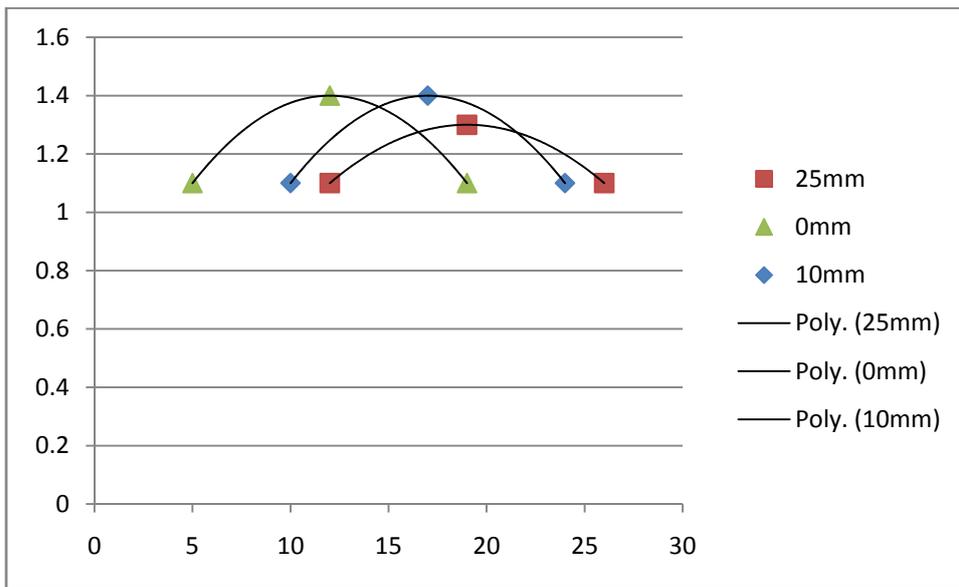
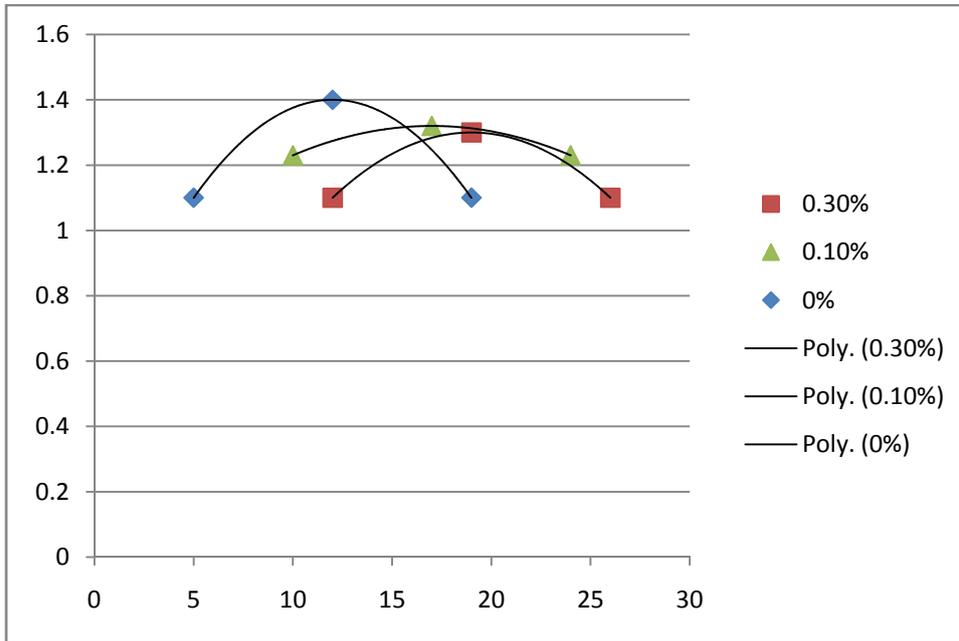
w = weight of water / weight of soil * 100

RESULTS AND DISCUSSIONS

The results of laboratory investigation are presented in this section. As the tests were designed systematically the effect of each fibre parameter can be observed in this study. The first engineering graph is related to effect of fibre dosage on compaction curve of composite soil. Respectively, second part is focused on effect of fibre length (aspect ratio) on soil composite compaction characteristics.

- a) Standard method results:

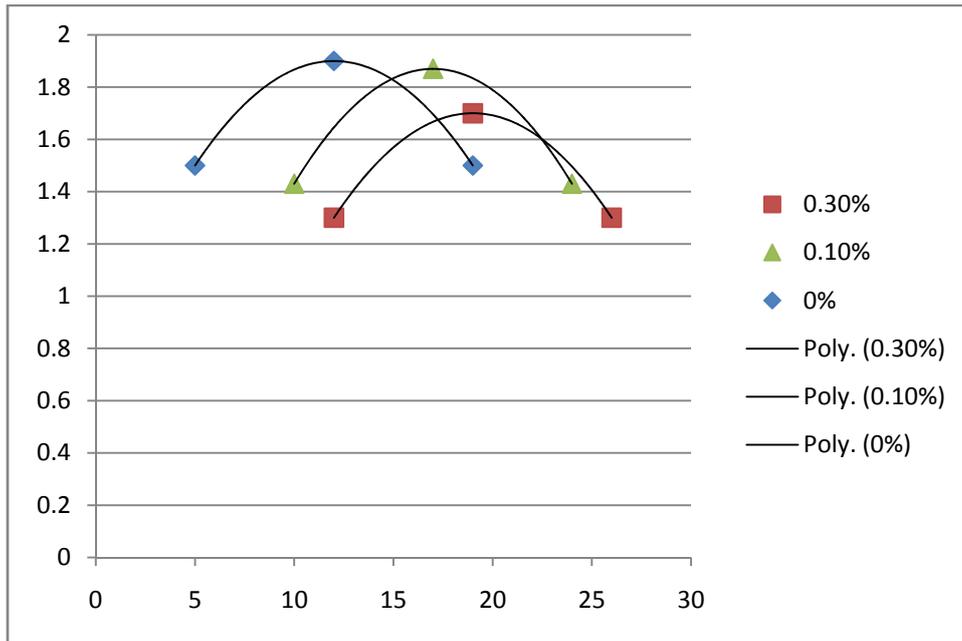
Effect of fibre percentage on compaction curve (fibre length 10 mm)



b) Modified method results

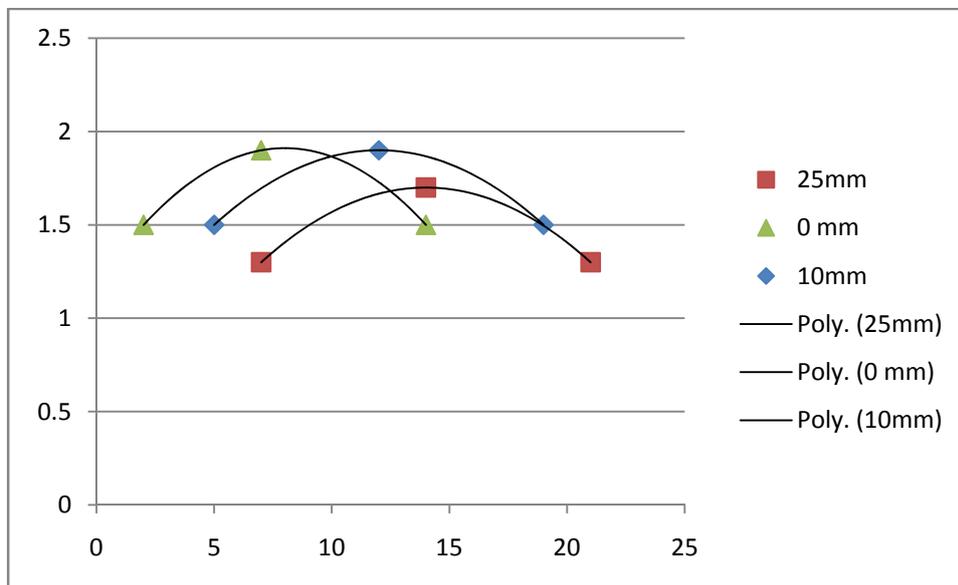
Effect of fibre percentage on compaction curve (fibre length 10 mm)

Analysing the results from laboratory investigation is presented in Figure 4. This graph proved that with increasing of fibre dosage maximum dry density was increased and optimum moisture content was decreased.



Effect of Fibre length (fibre percentage 0.3%)

To investigate the length (aspect ratio) of fibre influence in composite compaction curve in constant fibre content, which is 0.3% by dry weight of sample in this investigation, the length was changed from 10mm to 25 mm and results were derived in engineering graph as presented in figure 5.



CONCLUSION

Compaction tests were conducted on composite clay. This investigation proved that:

- Maximum dry density showed slight decrease due to induction of fibre
- Optimum Moisture Content (OMC) increase with increasing in fibre content
- Results showed good agreement with Modified Compaction Method as well
- Increasing in compaction effort causes increasing maximum dry density, this fact was observed for composite soil as well.
- Plastic fibre showed to be good material to be used in practical projects

ACKNOWLEDGEMENTS

The technical support from the Curtin University Laboratory is gratefully acknowledged.

REFERENCES

In the text, references should be quoted by the author followed by year of publication in parentheses. The list of references at the end of the main text should be arranged in alphabetical order. All references must be cited in the text. Examples are shown below:

Aboshi, H., Mizuno, Y., and Kuwabara, M. (1991) Present state of sand compaction pile in Japan in Deep Foundation Improvement: Design, Construction and Testing, ASTM STP 1089, M. I., Esrig and R.C., Bachus, West Conshohocken, Pa., pp. 32-46.

AlWahab, R.M. and Al Quirma, H.H., 1995, "Fibre Reinforced Cohesive Soils for Application in Compacted Earth Structures", *Proceedings of Geosynthetics '95*, IFAI, Vol. 2, Nashville, Tennessee, USA, March 1995, pp. 433-476.

Fletcher, C.S. and Humphries, W.K., 1991, "California Bearing Ratio Improvement of Remoulded Soils by the Addition of Polypropylene Fibre Reinforcement", *Transportation Research Record 1295*, Washington, DC, USA, pp. 80-86.

Gray, D.H. and Ohashi, H., 1983, "Mechanics of Fibre Reinforcement in Sand", *Journal of Geotechnical Engineering*, Vol. 109, No. 3, pp. 335-353.

IS:2720 (Part 8), 1983, "Method of Test for Soils: Part 8, Determination of Water Content -- Dry Density Relationship using Heavy Compaction", Indian Standards.

IS:2720 (Part 10), 1973, "Method of Test for Soils: Part 10, Determination of Unconfined Compressive Strength", Indian Standards.

KUMAR, KANAUJIA AND CHANDRA D Fibre-Reinforced Pond Ash and Silty Sand

518 GEOSYNTHETICS INTERNATIONAL S 1999, VOL. 6, NO. 6

IS:2720 (Part 13), 1986, "Method of Test for Soils: Part 13, Direct Shear Test", Indian Standards.

IS:2720 (Part 16), 1979, "Method of Test for Soils: Part 16, Laboratory Determination of CBR", Indian Standards.

Maher, M.H. and Gray, D.H., 1990, "Static Response of Sands Reinforced with Randomly Distributed Fibres", *Journal of Geotechnical Engineering*, Vol. 116, No. 11 pp. 1661-1667.

Maher, M.H. and Ho, Y.C., 1964, "Mechanical Properties of Kaolinite/Fibre Soil Composite", *Journal of Geotechnical Engineering*, Vol. 120, No. 8, pp. 1981-1993.

Nataraj, M.S. and McManis, K.L., 1997, "Strength and Deformation Properties of Soils Reinforced with Fibrillated Fibres", *Geosynthetics International*, Vol. 4, No. 1, pp. 65-79.

INVESTIGATION ON THE MODULUS OF ELASTICITY OF FIBRE REINFORCED SOIL

Amin Chegenizadeh¹ and Prof. Hamid Nikraz²

¹ PhD candidate, Department of Civil Engineering, Curtin University of Technology, Perth, Australia; Tel: +60-413165961; Fax: +61 8 9266 2681; Email: amin.chezenizadeh@postgrad.curtin.edu.au

² Prof. Hamid Nikraz, Head of the Department of Civil Engineering, Curtin University of Technology, Perth, Australia; Tel: +61 8 9266 7573; Fax: +61 8 9266 2681; Email: H.Nikraz@curtin.edu.au

Reinforced soil has been among the most effective soil modification materials. Its use has been expanded rapidly into civil engineering, geotechnical engineering and pavement engineering. Reinforcing subgrade in pavement systems has always been an issue. This study focuses on effect of fibre inclusion on the modulus of elasticity of subgrade material. Plastic fibre was used for this investigation. Fibre contents and aspect ratio have been changed during these tests. The fibre percentage varied from 0 % (for unreinforced samples) to 0.3%. Clay was used as sub grade material. Unconfined compression tests were carried out to investigate behaviour of the composite under different loading condition. The results showed that the modulus of elasticity of fibre reinforced composite has increased by fibre inclusion. The fibre length and fibre content found to play important rule on the modulus of elasticity of fibre.

INTRODUCTION

In conventional methods of reinforced soil construction, the inclusion of strips, fabrics, bars, grids etc are normally oriented in a preferred direction and are introduced sequentially in alternating layers. The development of these materials has been accompanied by an increase in the applications for which they are being used. The discrete fibers are simply added and mixed randomly with soil, much the same way as cement, lime or other additives. Fiber reinforced soil exhibits greater extensibility and small losses of peak strength i.e. greater ductility in the composite material as compared to unreinforced soil or soil reinforced with high modulus inclusions. Therefore, fiber-reinforced soil can be used as a soil-reinforcement technique with respect to embankment, subgrade, subbase, and other such problems. However, the data concerning the impact due to the addition of random discrete fibers on the characteristics of compacted native or virgin soils are limited, (Maher and Ho, 1993). Thus, there is a need for information on the effects of fibers on the properties of the pavement supporting layers. Ideally, the fibers themselves should be readily available, non-degradable and capable of being easily blended into the soils and compacted. The workability of fiber-reinforced materials implies that the fibers should be resistant to buckling and clumping.

MATERIAL

Composite materials consist of two parts. The first part is soil part which can be dealt as normal soil. The second part is reinforcement part which can be made up of any material which helps soil to have better performance.

Soil type

The soil type in this study was clay. The soil has been prepared with mixing sand and kaoline. The properties of kaoline clay are presented in table 1.

Table1. Clay properties

No.	Type	
1	Soil type	Clay
2	Liquid Limit	49
3	Plastic Limit	23
4	Pl. Index	26

Fibre type

The plastic fibre has been used for this investigation. The fibre properties are presented in table 2. The fibre is commercially available and is called fibre Meyco FIB SP 65 macro structural synthetic polypropylene fibre which generates a very high energy absorption rate when used in the matrix.



Fig. 1 Plastic fibre

Table2. fibre properties

No.	Type	
1	Material	polypropylene
2	Specific Gravity	0.92
3	Width	1.6825 mm

TEST PROGRAM

A series of unconfined compression tests have been conducted to verify effect of fibre content on elasticity modulus.

UNCONFINED COMPRESSION TEST PRINCIPLE

Aim of Unconfined Compression test is to obtain unconfined compressive strength of soil. This can be applied to fine grade and cohesive soil and will represent very fast response in practical condition as the test time is very quick in respect to confined one. This test is widely used for slope stability and embankment dam applications.

EQUIPMENT

- Unconfined compression testing machine (Triaxial Machine)
- Specimen preparation equipment
- Sample extruder
- fibre
- Balance



Fig. 2 Triaxial machine

Sample preparation

The samples were prepared by mixing soil and two percentage of fibre. specimen preparation method adopted from the standard compaction method, was used in an ongoing experimental research on fiber-reinforced clay at Curtin University . The soils were initially oven-dried under a controlled temperature of 60 °C. The dry soils were then crushed using a hammer. A mixer was used to thoroughly mix the soils with water to reach the desired water content for compaction. The mixing of soil with fibers was conducted by hand rather than using the mixer because the mixer caused the fibers to tangle in previous trial. The fiber-soil mixture was stored in a covered container for 24 hours after mixing was completed. A split mold and a hammer were used to compact the specimen. The specimens were prepared in different fibre content and length (aspect ratio).

Test Procedure

- The specimens were prepared in the laboratory with 90% compaction effort, special care was taken during this process
- The size of samples were checked to be suitable for the test purpose
- The samples were put for 24 hours in geotxtile and packed
- Special attention was applied for preventing any moisture loose
- The samples were put in triaxial base without any confinement pressure
- According to ASTM 1.27 mm/min were applied through the tests
- The data was collected automatically
- The stress-strain curve plot used for modulus elasticity investigation

Results and discussion

The unconfined compression tests were conducted in order to determine the modulus of elasticity (E-value). It was calculated based on the initial tangent of the stress-strain curve. The tests were conducted on cylindrical specimen of 60 mm diameter and 170 mm height.

Table 2 provides values of elastic modulus of soil with and without fiber reinforcement. The maximum E-value of clayey soil was 12250 kPa obtained at the aspect ratio of 50 and fiber content 2.25 percent. It was observed that initial readings of stresses of reinforced soil decreases whereas failure stress and corresponding strain increase with increase in the percentage of fiber and aspect ratio.

Table 2 E-Values (kPa) for Reinforced and Unreinforced Soils

Fibre length(mm)	Fiber content %	E value
-----	0.00	5500
10	0.5	6100
	1	8010
	2	9260
	3.0	10100
20	0.5	7500
	1	8740
	2	10000
	3.0	10750
25	0.5	9000
	1	10023
	2	11548
	3.0	12816

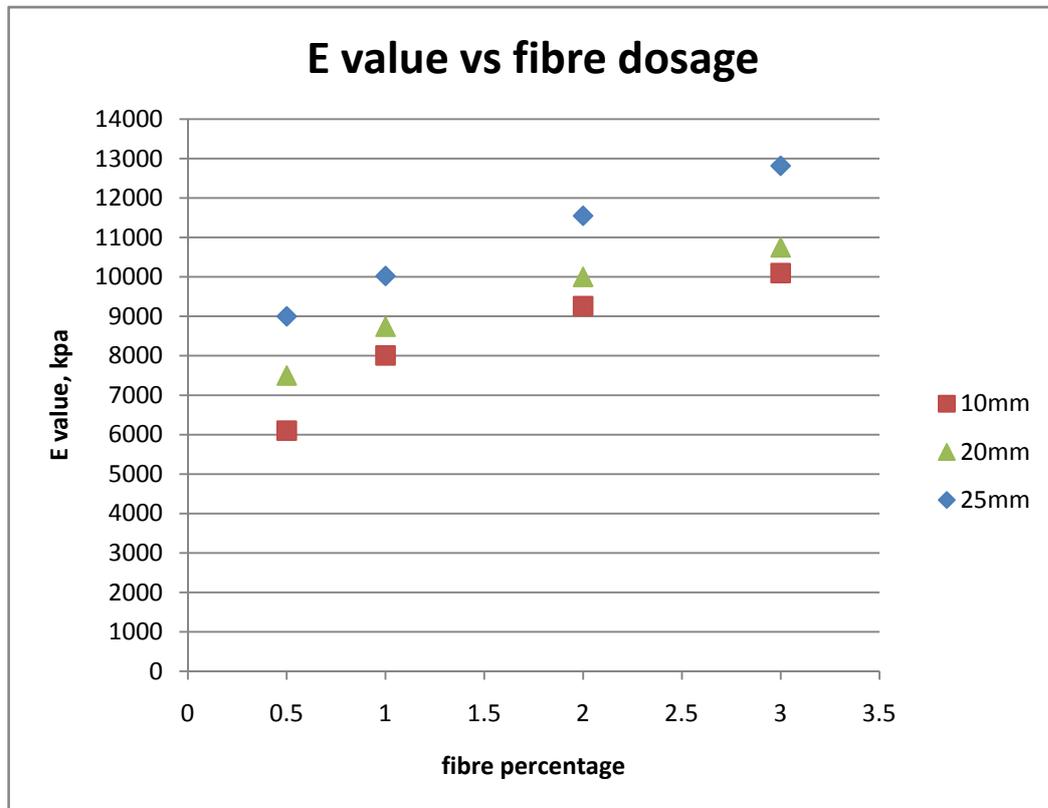


Fig. 3 Effect of fibre percentage and length on modulus of elasticity

Conclusions

- Increasing in fibre percentage increased modulus of elasticity
- Increasing in fibre aspect ratio increased modulus of elasticity
- During the test, it was observed that ductility behaviour of reinforced clay increased because of fibre inclusion.
- Short and randomly Fibre inclusion showed to be reliable in industry projects.

ACKNOWLEDGEMENTS

Authors would like to thank Curtin laboratory staff for their kind assistance.

REFERENCES

- Lorenzo, G. A. and BERGADO, D. T. (2004). Fundamental parameters of cement-admixed clay – New approach. *Journal of Geotechnical and Geoenvironmental Engineering*, Vol. 130, No. 10, pp. 1-9.
- Michalowski, R. L., Cermak, J. (2002), “Strength anisotropy of fiber-reinforced sand.” *Computers and Geotechnics*, Vol. 29, No. 4, pp. 279-299.

Maher, M. H., Ho, Y. C. (1994), "Mechanical-properties of kaolinite fiber soil composite." *J. of Geotech. Engrg, ASCE*, Vol. 120, No. 8, pp. 1381-1393.

Nataraj, M. S., Mcmanis, K. L. (1997), "Strength and deformation properties of soils reinforced with fibrillated fibers." *Geosynthetics Int.*, Vol. 4, No. 1, pp. 65-79.

Ziegler, S., Leshchinsky, D., Ling, H. I., and Perry, E. B. (1998), "Effect of short polymeric fibers on crack development in clays." *Soils and Foundations*, Vol. 38, No. 1, pp. 247-253.

Aboshi, H., Mizuno, Y., and Kuwabara, M. (1991) Present state of sand compaction pile in Japan in Deep Foundation Improvement: Design, Construction and Testing, ASTM STP 1089, M. I., Esrig and R.C., Bachus, West Conshohocken, Pa., pp. 32-46.

Effect of clay layer thickness on desiccation and cracking

Amin Chegenizadeh

PhD candidate, Department of Civil Engineering, Curtin University of Technology, Perth, Australia; Tel: +61-413165961; Fax: +61 8 9266 2681; Email: amin.chegenizadeh@postgrad.curtin.edu.au

Prof. Hamid Nikraz

Head of the Department of Civil Engineering, Curtin University of

Technology, Perth, Australia; Tel: +61 8 9266 7573; Fax: +61 8 9266 2681; Email: H.Nikraz@curtin.edu.au

ABSTRACT: Clay materials are usually part of geotechnical projects such as slopes, embankment dams and landfills. Crack problem in clayey soil is one of the most destructive phenomenon as can affect the stability and efficiency of geotechnical projects. Thermal, mechanical and volume changes which lead to stress in soil can be cause of cracking. A series of desiccation tests were carried out to investigate effect of thickness of clay layer in crack pattern. Circular container selected with 150 mm diameter. Soil thickness was changed during the tests (i.e. 10mm, 15mm, and 30mm). Kaolin clay was used as soil part. The container material selected as metal. The results from the tests proved that thickness of soil is a significant parameter in desiccation tests and with increasing in thickness crack pattern is moved to orthogonal manner. During the tests also effect of fibre inclusion observed and showed that fibre inclusion had significant effect on crack density of the sample.

KEYWORDS: Desiccation; clayey soil; cracking, fibre

1 INTRODUCTION

In conventional application of reinforcement in soil, the inclusion of tire, bars, grids etc are usually in a preferred orientation. The advances of these materials have usually been considered by an increase in their applications. The randomly discrete fibers are easily added and mixed randomly with soil part, the same way as cement, lime or other additives. Some researches have been done on cement additive (Consoli et.al. 2009; Cai et.al 2006; Lorenzo and Bergado, 2004) and can be used as a pattern of additive usage in soil. Fibre reinforced composite shows more ductility and small losses of peak strength i.e. in compared to unreinforced material. Therefore, fiber-reinforced soil composite is a practical solution in civil engineering projects. The main application of composite soil can be in embankment, subgrade, subbase, and slope stability problems. However, the data concerning the effects of fiber inclusion on the characteristics of compacted native or virgin soils are limited, (Maher and Ho, 1993). This shortage is more considerable in pavement engineering and landfill systems in terms of crack control. Limited attempts have been made to control clay cracking by fibre reinforcement (Allan and Kuckacka, 1995; Al Wahab and El-Kedrah, 1995; Ziegler et al., 1998). Miller and Rifai (2004) studied the effects of fibre reinforcement on the development of desiccation

cracking in compacted clay samples. Therefore, the significance this study is to evaluate the effect of fibre inclusion on crack propagation in clayey soil. The application of controlling crack cause significant improvement in land fill systems and pavement engineering as cracking which lead these systems to be failed in the real civil projects.

2 MATERIAL

Composite soils consist of two parts. The first part is soil part which can be dealt as normal soil. The second part is reinforcement part which can be made up of any material which helps soil to have better performance.

2.1 Soil Type

The soil type in this study was kaolin clay. The properties of clay are presented in table 1. This type of kaolin clay is widely used in industrial project and research activities in Western Australia.

Table 1. Clay properties

No.	Size (cm)	
1	Soil type	Clay
2	Liquid Limit	49
3	Plastic Limit	23
4	Pl. Index	26

2.2 Fiber Type

The plastic fiber has been used for this investigation. Figure 1 shows the used fiber. The used fiber has good potential to absorb energy and good adhesion with soil particle.



Figure. 1 Plastic fiber

3 TEST PROGRAM

Test program in this study includes a series of cracking test were conducted to investigate the effect of thickness of sample and fibre inclusion on cracking phenomenon.

3.1 Main Equipments

- Metal container and glass container for cracking test
- Electrical light for cracking test
- Balance for cracking test

Figure 2 shows the metal container which was used to run the crack test.



Figure 2. Metal Container used for cracking test

4 SAMPLE PREPARATION FOR CRACK TEST

The soil was passed through a 4mm sieve in order to obtain a consistent mixture once water had been added. The cured soil would be sealed in a couple of plastic bags to prevent moisture loss. When placing soil at 45% moisture content into containers, they were continuously tapped to surface any trapped air bubbles in the soil. Cling wrap was used to smoothen the surface of each sample as well as provide a cover to prevent moisture loss when allowing the soil to settle over night. The surface of the sample was a circle with 150mm and thickness was 10mm, 15 mm and 30mm.

5 TEST METHODOLOGY AND PROCEDURE

5.1 Cracking test

To run the cracking test following steps were taken:

- Putting soil into container
- Making sure that moisture content is as what required (i.e. 45%)
- Setting up the height of light faced to sample precisely on 1m
- Using digital camera to record image of soil specimen every hour
- Extracting of images to analysis of crack pattern
- Crack Intensity Factor is considered as ratio of crack area to total surface of sample.

The figure 3 shows the sketch of experimental set-up which used to run the cracking tests. As previously mentioned the flood light used to run cracking test. The soil in metal container is directly faced to flood light.

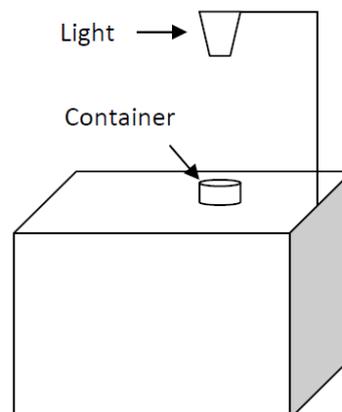


Figure sketch

6 RESULTS AND DISCUSSIONS

In this section the results of cracking tests are presented.

6.1 Cracking test on clay without fibre

The results from cracking test for different thickness proved that with increasing in soil thickness the pattern moved to orthogonal behavior. Figure 4 shows the sample with 10 mm.

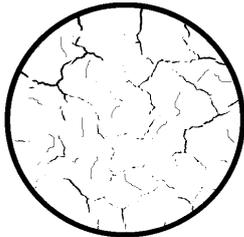


Figure 4. The crack propagation with 10mm thick

Figure 5 shows the crack pattern for 15mm thickness.

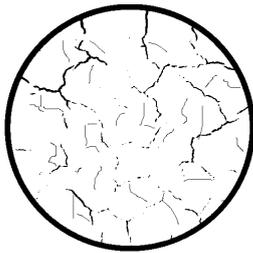


Figure 5. The crack propagation with 15mm thick

Figure 6 shows the crack pattern for 30mm thickness.

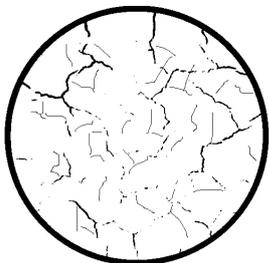


Figure 6. The crack propagation with 30mm thick

6.2 Effect of fibre in cracking test

A series of cracking tests were conducted and following results obtained. Table 2 shows the crack density with different fibre content and length.

Crack density factor was computed based on image processing and obtaining the ratio of crack to total surface area. Crack Intensity Factor (CIF) is the ratio of the crack area to total area of the sample surface.

Table 2. Crack density versus fibre content

No.	Fibre	CIF
1	No fibre	5.28
2	1%	3.7
3	2%	1.2

Figure 7, 8 and 9 show the images from different fibre contents. The results proved that with increasing in fibre content and length crack density decreased rapidly.

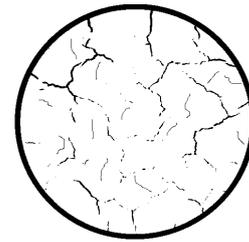


Figure 7. The crack propagation without fibre

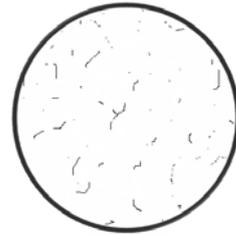


Figure 8. The crack propagation pattern with 1% fibre with 25mm length

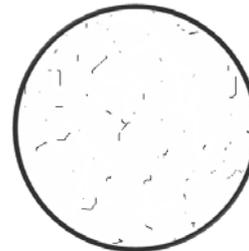


Figure 9. The crack propagation pattern with 2% fibre with 25mm length

The results from cracking test proved that increasing in fibre content and fibre length decreased the Crack Intensity Factor (CIF). Therefore, fibre inclusion is good solution to solve the cracking problem of clayey soil.

7 CONCLUSION

A series of cracking on cylindrical clayey soil with 150 mm diameter and 10 mm, 15mm and 30 mm

thickness, were conducted and following results obtained:

- 1-Using fibre caused huge decrease in crack intensity factor
- 2-Increasing in fibre length and content directly decreased the crack
- 3-Image processing proved that can be used as useful tool in further crack analysis
- 4-Image analysis proved that with increasing in soil thickness the crack pattern moved to orthogonal shape.

ACKNOWLEDGEMENTS

The technical support from the Curtin University Laboratory is gratefully acknowledged.

REFERENCES

- [1] Akbulut, S., Arasan, S. and Kalkan, E.(2007),Modification of clayey soils using scrap tire rubber and synthetic fibers, *Journal of Applied Clay Science* 38,23-32.
- [2] Allan, M. L., Kukacka, L. E. (1995) "Permeability of microcracked fibre-reinforced containment barriers." *Waste Management*, Vol. 15, No. 2, pp. 171-177.
- [3] Al Refeai, T.O. (1991) .Behaviour of granular soils reinforced with discrete randomly oriented inclusions, *Journal of Geotextiles and Geomembranes*, 10, pp. 319–333.
- [4] Cai, Y., Shi, B., Charles, W.W. Ng. & Tang, C. , (2006),,Effect of polypropylene fiber and lime admixture on engineering properties of clayey soil, *Engineering Geology* 87, 230– 240.
- [5] Consoli, N.C., Vendruscolo, M.A., Fonini, A. and Dalla Rosa, F. (2009),,Fiber reinforcement effects on sand considering a wide cementation range, *Geotextiles and Geomembranes* 27, pp. 196–203.
- [6] Dvorak, G.K. and Bahei-El-Din, Y.A., (1982) ,Plasticity analysis of fibrous composites, *Journal of Applied Mechanics* 49, , pp. 327–335.
- [7] Freitag, D.R. , (1986) ,Soil randomly reinforced with fibers, *Journal of Geotechnical Engineering ASCE* 112 (8) , pp. 823–826.
- [8] Gray, D. and Al-Rafeai, T. O. , (1986),Behavior of fabric versus fiber reinforced sand,. *Journal of Geo-technical Engineering*, vol. 112, no. 8 ,pp. 804-820.
- [9] Gray, D. H. and Ohashi, H. , (1983) ,Mechanics of fiber reinforcement in sand,. *Journal of Geotechnical and Geo-environmental Engineering*, ASCE, vol. 109, no. 3, pp. 335-353.
- [10] Lorenzo, G. A. and Bergado, D. T. , (2004). Fundamental parameters of cement-admixed clay – New approach,. *Journal of Geotechnical and Geo-environmental Engineering*, Vol. 130, No. 10, , pp. 1-9.
- [11] Kaniraj, S. R. and Havanagi, V. G , (2001) .,Behavior of cement-stabilization fiber-reinforced fly ash-soil mixtures. *Journal of Geotechnical and Geo-environmental Engineering*, vol. 127, no. 7, ,pp. 574-584.
- [12] Maher, M. H., Ho, Y. C., (1994), ,Mechanical-properties of kaolinite fiber soil composite,. *J. of Geotech. Engrg. ASCE*, Vol. 120, No. 8, pp. 1381-1393.
- [13] Nataraj, M. S., Mcmanis, K. L., (1997), Strength and deformation properties of soils reinforced with fibrillated fibers., *Geosynthetics Int.*, Vol. 4, No. 1, pp. 65-79.
- [14] Sivakumar Babu, G.L., Vasudevan, A.K. and Haldar, S. (2008) Numerical simulation of fiber-reinforced sand behaviour, *Geotextiles and Geomembranes* 26, pp. 181–188.
- [15] Waldron, L. J., ,(1977),Shear resistance of root-permeated homogeneous and stratified soil., *Soil Society. Of American Journal*41. (5), pp. 843–849.
- [16] Yetimoglu, T. and Salbas, O.,A (2003) study on shear strength of sands reinforced with randomly distributed discrete fibers, *Geotextiles and Geomembranes* 21, (2), pp. 103–110.
- [17] Ziegler, S., Leshchinsky, D., Ling, H. I., and Perry, E. B., (1998),,Effect of short polymeric fibers on crack development in clays. *Soils and Foundations*, *J of Applied clay science*,Vol. 38, No. 1, pp. 247-253.

- [18] Zornberg, J. G., Cabral, A. R. and Viratjandr, C. , (2004) Behavior of tire shred-sand mixtures, *Canadian Geotechnical Journal* 41 (2) , pp. 227–241.
- [19] Zornberg, J. G. , (2002),discrete framework for limit equilibrium analysis of fiber-reinforcement, *Geotechnique Journal* 52 (8) , pp. 227–241.
- [20] H. Nahlawi and J.K. Kodikara, (2006) , Laboratory experiments on desiccation cracking of thin soil layers *Geotechnical and Geological Engineering* 24: 1641–1664

Investigation on Shrinkage behaviour of kaolin clay

Amin Chegenizadeh

PhD candidate, Department of Civil Engineering, Curtin University of Technology, Perth, Australia; Tel: +61-413165961; Fax: +61 8 9266 2681; Email: amin.chegenizadeh@postgrad.curtin.edu.au

Prof. Hamid Nikraz

Head of the Department of Civil Engineering, Curtin University of

Technology, Perth, Australia; Tel: +61 8 9266 7573; Fax: +61 8 9266 2681; Email: H.Nikraz@curtin.edu.au

ABSTRACT: As evaporation prevails, soils lose water and shrink upon desiccation, which lead to formation of desiccation cracks. The cracking of desiccated clay soils is problematic to many civil structures hence an adequate understanding of the desiccation cracking process is of great significance. To build this understanding, knowledge of how crack forms, their position, orientation and connectivity in space are necessary. This paper aims to investigate shrinkage problem deeply. A series of shrinkage test were conducted. The container dimensions were 50mm X50mm X 50mm. the soil was selected as kaolin clay. Different initial moisture content of 45% and 40% considered. The results proved that water content decreased as desiccation rate increased. The engineering graph of change in water content versus time and shrinkage strain versus change in water content was plotted for each test. The desiccation curves shows similar behaviour for different initial moisture content as finally reached the balance with local climate.

KEYWORDS: Desiccation; clayey soil; cracking

1 INTRODUCTION

Compacted clay is commonly used in embankment dam cores, low permeable barriers in waste landfills, canal sections, foundations and roadways. Areas that are susceptible to damage from expansive soils are those that have large surface deposits of clay and climates characterised by alternating periods of rainfall and drought. Expansive soil is a term used by geotechnical engineers for soils that expand or contract depending on the amount of water that is present. In a research on reactive clayey soil, Nahlawi (2004) found out that the economical aspect of this problem can be significant in Australia. This view was reviewed by Dudal and Eswaran (1988). Soil shrinkage is problematic around the world and poses risks of damage to light buildings, road pavements and clay liners used for waste containment in landfills. Soil shrinkage and shrinkage cracks are caused by a decreasing in soil moisture content through either evaporation from the soil surface in dry climates, lowering of the groundwater table, or desiccation of soil by trees during humid climates. In a study on shrinking and swelling of soils, Holtz and Kovacks (1981) found that as water content decreases, capillary stress in the void spaces enhances due to the increased surface tension. This increased surface tension tends to pull adjacent soil particles closer together resulting in an overall soil volume

decrease. The key factors effecting the shrinkage potential of a soil can be evaluated in three different groups, the *soil characteristics* that influence the basic nature of the internal force field, the *environmental factors* that influence the changes that may occur in the internal force system, and the *state of stress* (Kudikarra, 2005, Nelson and Miller, 1992).

In conventional application of reinforcement in soil, the inclusion of tire, bars, grids etc are usually in a preferred orientation. The advances of these materials have usually been considered by an increase in their applications. The randomly discrete fibers are easily added and mixed randomly with soil part, the same way as cement, lime or other additives. Some researches have been done on cement additive (Consoli et.al. 2009; Cai et.al 2006; Lorenzo and Bergado, 2004) and can be used as a pattern of additive usage in soil. Fibre reinforced composite shows more ductility and small losses of peak strength i.e. in compared to unreinforced material. Therefore, fiber-reinforced soil composite is a practical solution in civil engineering projects. The main application of composite soil can be in embankment, subgrade, subbase, and slope stability problems. However, the data concerning the effects of fiber inclusion on the characteristics of compacted native or virgin soils are limited, (Maher and Ho, 1993). This shortage is more considerable in pavement engineering and landfill systems in terms of crack control. Limited

attempts have been made to control clay cracking by fibre reinforcement (Allan and Kukacka, 1995; Al Wahab and El-Kedrah, 1995; Ziegler et al., 1998). Miller and Rifai (2004) studied the effects of fibre reinforcement on the development of desiccation cracking in compacted clay samples. Therefore, the significance this study is to evaluate the effect of fibre inclusion on shrinkage behavior of clayey soil. The application of controlling crack cause significant improvement in land fill systems and pavement engineering as cracking which lead these systems to be failed in the real civil projects.

2 MATERIAL

Composite soils consist of two parts. The first part is soil part which can be dealt as normal soil. The second part is reinforcement part which can be made up of any material which helps soil to have better performance.

2.1 Soil Type

The soil type in this study was kaolin clay. The properties of clay are presented in table 1. This type of kaolin clay is widely used in industrial project and research activities in Western Australia.

Table 1. Clay properties

No.	Size (cm)	
1	Soil type	Clay
2	Liquid Limit	49
3	Plastic Limit	23
4	Pl. Index	26

2.2 Fiber Type

The plastic fiber has been used for this investigation. Figure1 shows the used fiber. The used fiber has good potential to absorb energy and good adhesion with soil particle.



Figure. 1 Plastic fiber

3 TEST PROGRAM

Test program in this study includes a series of shrinkage test were conducted to investigate the effect of fibre inclusion on shrinkage phenomenon.

3.1 Main Equipments

- Metal container for shrinkage test
- Balance

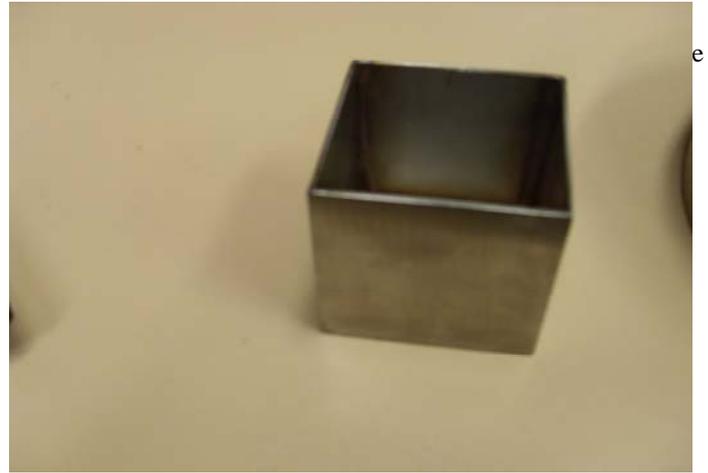


Figure 2. Metal Container used for shrinkage test

4 SAMPLE PREPARATION FOR SHRINKAGE TEST

Isotropic shrinkage tests were conducted on clay samples. This rather contemporary method involved compacting soil into small moulds to produce blocks of soil compacted to a specific density (Nahlawi et al., 2006). Compacting soil at specific moisture content to a specific density may be ideal when trying to model landfill conditions. The aim of this test is to determine the shrinkage strain of compacted clay as time elapses with different starting moisture content and sizes, and generate desiccation curves. Accordingly, this will determine what size sample(s) will be good for carrying out further testing. Specimens were compacted at 40% moisture content and 40% moisture content. Ideally we would want to compare slurry clay to compacted clay for this test however, since the dry density is unknown for moisture content beyond 45%, a comparison of clay at 45% and 40% was carried out. Moreover to an unknown dry density, slurry state clay would not hold its shape once the moulds are removed. Shrinkage tests were undertaken in a constant temperature room in the civil engineering laboratories. 50 mm x 50mm x 50 mm size blocks clay, were left to dry under similar environmental conditions. Their weight and shrink-

age were recorded over time. The following section will explain in detail the experimental procedures.

5 TEST METHODOLOGY AND PROCEDURE

5.1 General steps

Once the soil had been compacted into the moulds, ‘cling wrap’ was used to wrap the sample to prevent moisture loss. Water was then sprayed, and soil was put in sealable plastic bags to cure overnight. Approximately a day later the soil specimens were isolated from the moulds. Firstly the lid of each mould was carefully removed, and excess soil was cut with a wire. Once the entire soil was exposed, metal tacks were positioned in the centre of each face of the block using glue as a reference point for measuring shrinkage in two dimensions with a calliper. The soil blocks were then put on a metal rack in a constant temperature room where the soil was to undergo drying at a constant temperature of 24°C and relative humidity of 40%. The degree of shrinkage and weight of each sample were recorded each day until the samples reached equilibrium with the local climate or cracked. Same procedure was applied with putting fibre inside the clayey soil and effect of fibre also investigated on shrinkage behaviour. The fibre length was selected as 10 mm and fibre content varied during the tests. (i.e. 1% , 2% and 3%)

5.2 Shrinkage analysis

Desiccation curves were plotted by weighing the soil specimens over time to determine the water loss.(Kudikara ,2005) The change in water content in each sample was determined by applying Equation 1, where w_i is the initial water content and w_t is the water content at the specific desiccation time.

$$W = W_i - W_t \quad (1)$$

Shrinkage strain also recorded as ratio of changing in length to initial length.

6 RESULTS AND DISCUSSIONS

Desiccation curves were plotted for each soil sample to identify the desiccation rate. The graph plotted for 40% and 45% moisture content.

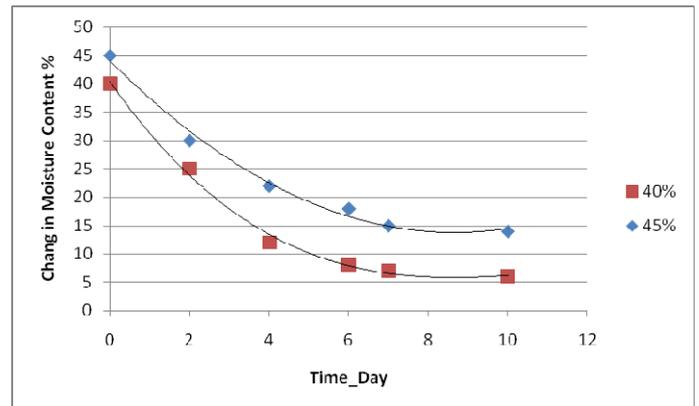


Figure. 3 Changing in moisture content in shrinkage test

The degree of shrinkage was calculated in all 3 directions with a calliper on each specimen and an average shrinkage strain was recorded. The graph of the drying process and strain evolution of soil samples were derived as indicated in Figure 4. The shrinkage strain versus change in moisture content, Δw was plotted in figure 4.

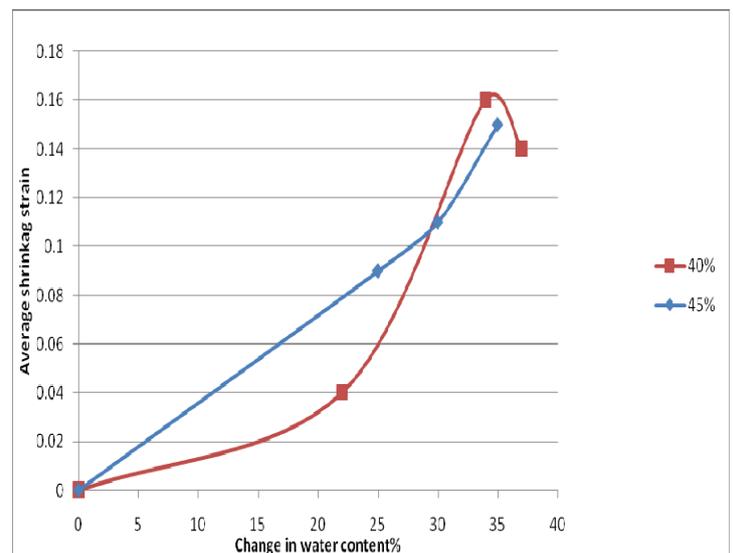


Figure. 4 Changing in moisture content in shrinkage test

6.1 Effect of fibre inclusion

A series of shrinkage tests was conducted to find out the effect of fibre inclusion on linear shrinkage behaviour. Figure 5 shows the effect of fibre content which changed from 1% to 3%. The results proved that with increasing in fibre content linear shrinkage was reduced.

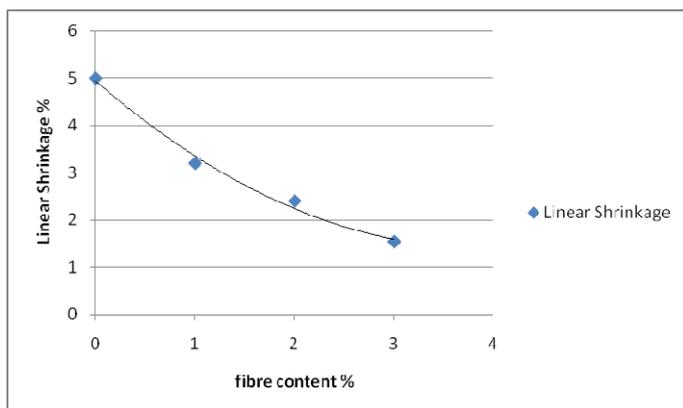


Figure. 5 Effect of fibre content in shrinkage test

7 CONCLUSION

A series of shrinkage test on a block sample of clayey soil was conducted and following results obtained:

- Kaolin clay experiences shrinkage in all directions, and shrinkage of the clay layer was followed by cracking due to desiccation.
- Using fibre caused huge decrease in crack intensity factor
- Increasing in fiber content directly decreased the linear shrinkage.

ACKNOWLEDGEMENTS

The technical support from the Curtin University Laboratory is gratefully acknowledged.

REFERENCES

- [1] Akbulut, S., Arasan, S. and Kalkan, E.(2007),Modification of clayey soils using scrap tire rubber and synthetic fibers, *Journal of Applied Clay Science* 38,23-32.
- [2] Allan, M. L., Kukacka, L. E. (1995) "Permeability of microcracked fibre-reinforced containment barriers." *Waste Management*, Vol. 15, No. 2, pp. 171-177.
- [3] Al Refeai, T.O. (1991) .Behaviour of granular soils reinforced with discrete randomly oriented inclusions, *Journal of Geotextiles and Geomembranes*, 10, pp. 319–333.
- [4] Cai, Y., Shi, B., Charles, W.W. Ng. & Tang, C. , (2006),Effect of polypropylene fiber and lime admixture on engineering properties of clayey soil, *Engineering Geology* 87, 230– 240.
- [5] Consoli, N.C., Vendruscolo, M.A., Fonini, A. and Dalla Rosa, F. (2009),Fiber reinforcement effects on sand considering a wide cementation range, *Geotextiles and Geomembranes* 27, pp. 196–203.
- [6] Dvorak, G.K. and Bahei-El-Din, Y.A., (1982) ,Plasticity analysis of fibrous composites, *Journal of Applied Mechanics* 49, , pp. 327–335.
- [7] Freitag, D.R. , (1986) ,Soil randomly reinforced with fibers, *Journal of Geotechnical Engineering ASCE* 112 (8) ,pp. 823–826.
- [8] Gray, D. and Al-Rafeai, T. O. , (1986),Behavior of fabric versus fiber reinforced sand,. *Journal of Geo-technical Engineering*, vol. 112, no. 8 ,pp. 804-820.
- [9] Gray, D. H. and Ohashi, H. , (1983) ,Mechanics of fiber reinforcement in sand,. *Journal of Geotechnical and Geo-environmental Engineering*, ASCE, vol. 109, no. 3, pp. 335-353.

- [10] Lorenzo, G. A. and Bergado, D. T. , (2004). Fundamental parameters of cement-admixed clay – New approach,. *Journal of Geotechnical and Geoenvironmental Engineering*, Vol. 130, No. 10, , pp. 1-9.
- [11] Kaniraj, S. R. and Havanagi, V. G , ,(2001). ,Behavior of cement-stabilization fiber-reinforced fly ash-soil mixtures. *Journal of Geotechnical and Geo-environmental Engineering*, vol. 127, no. 7, ,pp. 574-584.
- [12] Maher, M. H., Ho, Y. C., (1994), ,Mechanical-properties of kaolinite fiber soil composite,. *J. of Geotech. Engrg, ASCE*, Vol. 120, No. 8, pp. 1381-1393.
- [13] Nataraj, M. S., Mcmanis, K. L., (1997), Strength and deformation properties of soils reinforced with fibrillated fibers,. *Geosynthetics Int.*, Vol. 4, No. 1, pp. 65-79.
- [14] Sivakumar Babu, G.L., Vasudevan, A.K. and Haldar, S. (2008) Numerical simulation of fiber-reinforced sand behaviour, *Geotextiles and Geomembranes* 26, pp. 181–188.
- [15] Waldron, L. J. , (1977),Shear resistance of root-permeated homogeneous and stratified soil,. *Soil Society. Of American Journal*41. (5), pp. 843–849.
- [16] Yetimoglu, T. and Salbas, O.,A (2003) study on shear strength of sands reinforced with randomly distributed discrete fibers, *Geotextiles and Geomembranes* 21, (2), pp. 103–110.
- [17] Ziegler, S., Leshchinsky, D., Ling, H. I., and Perry, E. B., (1998),Effect of short polymeric fibers on crack development in clays. *Soils and Foundations*, *J of Applied clay science*,Vol. 38, No. 1, pp. 247-253.
- [18] Zornberg, J. G., Cabral, A. R. and Viratjandr, C. , (2004) Behavior of tire shred-sand mixtures, *Canadian Geotechnical Journal* 41 (2), ,pp. 227–241.
- [19] Zornberg, J. G. , (2002),discrete framework for limit equilibrium analysis of fiber-reinforcement, *Geotechnique Journal* 52 (8), , pp. 227–241.
- [20] H. Nahlawi and J.K. Kodikara, (2006) , Laboratory experiments on desiccation cracking of thin soil layers *Geotechnical and Geological Engineering* 24: 1641–1664