Effective Parameters on Strength of Reinforced Clayey Sand

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***Abstract*-Soils and their related behavior has always been the subject of many studies. Recent researches show some interests in investigation of inclusion of randomly distributed fiber in soil. This study focuses on effect of fiber inclusion on the strength and other parameters of clayey sand composite material. The first part of this study is related to effective parameters on strength of the clayey sand composite with using natural fiber and plastic fiber with different fiber contents and length. UCS tests were carried out to investigate behavior of the composite under different condition. The fiber percentage varied from 0 % (for unreinforced samples) to 4% and fiber length varied from 8mm to 25mm. The fiber length and fiber content are found to play important roles in the strength of fiber reinforced composite. Furthermore it was observed that ductility of sample increased by fiber inclusion.**

Keywords- Component; UCS; Fiber; Strength

I. INTRODUCTION

Traditional ways of soil reinforcement involve the use of continuous planar inclusions (e.g. metallic strips, geogrids, geotexiles) in soil structures. The advances of these materials have usually been considered by an increase in their applications. The randomly short discrete fibers are easily added and mixed randomly with soil part, the same way as cement, lime or other additives. Some researches have been conducted on cement additive (Consoli et.al. 2009; Cai et.al 2006; Lorenzo and Bergado, 2004, Kaniraj et al. 2001) and can be used as a pattern of additive usage in soil. Fiber reinforced composite shows more ductility and smaller losses of peak strength i.e. compared to unreinforced material. Usage of fiber together with cement material can be useful as fiber inclusion helps composite to lose the brittle behavior gaining from being cemented. Therefore, application of fiber in soil composite is a practical solution in geotechnical engineering projects. On the other hand, due to the cost of engineering projects and also environmental issue related to the projects, natural fiber such as palm fiber is highly desirable as will be investigated in this paper. The main application of composite soil can be in embankment, sub-grade, sub-base, 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).

Working on different aspects of fiber inclusion in soils has been an interest all the time. Direct shear tests, unconfined compression tests and conventional triaxial compression tests have demonstrated that shear strength increases and post-peak strength reduces when discrete fibers are mixed with sandy soils (Al Refeai, 1991; Maher and Ho, 1994; Yetimoglu and Salbas, 2003; Tang et al., 2007, Chegenizadeh and Nikraz, 2011).

Fiber specifications including type, volume percentage, length, aspect ratio, modulus of elasticity, fiber orientation and also soil parameters have significant effects on the strength of composite samples. Moreover, fiber orientation has considerable influence on failure and strength (Jewell and Wroth, 1987; Micha1owski and Cermak, 2002; Gray and Ohashi (1983), Michlowski and Zhao (1999) and Zornberg (2002)).

However study on effects of fiber has been well investigated in sandy soil, research shortage is more considerable in clayey soil or mix of clay and sand. Therefore, more investigations on fiber inclusion in clayey composite are needed to be performed. As in practical engineering project, specifically geotechnical project strength has considerable effect on the design procedure; the first part of this study mainly focuses on changes in strength of composite clayey sand due to random plastic and natural fiber inclusion.

II. THEORETICAL BACKGROUND

Different approaches have been used so far to predict the behavior of reinforced soil. One of the most practical methods is Gray and Ohashi (1983) which investigate fiber inclusion in sandy soils with load transfer approach. This section focuses on these methods.

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 fibers placed at defined orientations. The shearing of soils is assumed to cause fiber distortion along the shear plane, thereby mobilising its tensile resistance (Figure 1). The fiber-induced tension was calculated from the extension of fibers assuming that fibers length, interface friction and confining pressure are large enough to prevent pullout failure. In this case, the fiber-induced tension can be expressed as a function of fiber modulus, interface friction, fiber diameter and thickness of the shear zone as follows:

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

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 fiber

d_f = equivalent diameter of single fiber

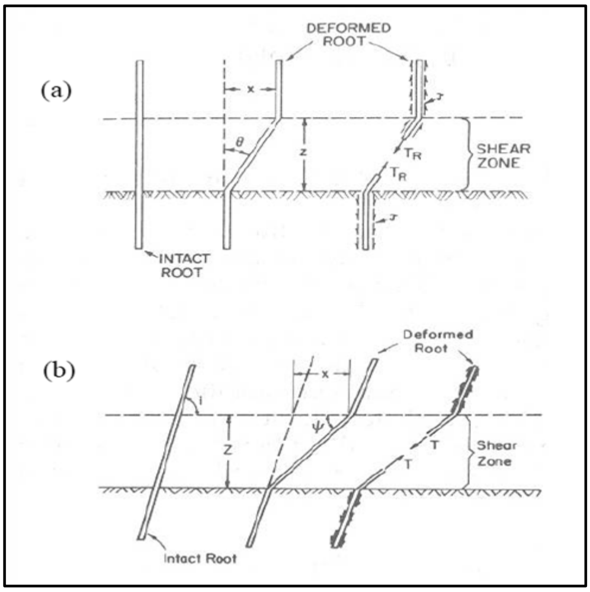

Fig. 1 Elastic fiber across the shear zone a) vertical fiber b) inclined fiber (Gray and Ohashi, 1983)

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

$$\Delta S = t(\sin\theta + \cos\theta \tan\emptyset) \quad (2)$$

Where:

θ= angle of distortion of fiber (Figure 13)

t= mobilized tensile strength defined as:

$$t = (\frac{A_f}{A})\sigma_t \quad (3)$$

Where:

A_f = area of fiber in shear

A= area of failure plane

Equitation (2) can be expressed when the fibers are oblique as follows:

$$\Delta S = \sigma_t' [(\sin(90-\psi) + \cos(90-\psi)\tan\emptyset)] \quad (4)$$

Where:

ψ= orientation angle of distorted fiber

$$\psi = \tan^{-1}[\frac{1}{\left(\frac{x}{z}\right)+(\tan\ i)^{-1}}] \quad (5)$$

Where:

i = initial orientation of fiber

The fiber-induced tension force in terms of the fiber extension is calculated by Equation (1), which is valid only for extensible fiber with a frictional surface. Commonly used polymeric fibers 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 fibers. 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) further developed the model presented by Gray and Ohashi (1983) to apply it to randomly-distributed fibers by incorporating statistical concepts.The average number of fibers *Ns*, intersecting the unit area of the shear plane was defined as:

$$N_s = \frac{2\chi}{\pi {d_f}^2} \quad (6)$$

χ= fiber content

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

$$\sigma_t = 2(\sigma_n \ \ tan\,\delta)\frac{l_f}{d_f}, \sigma_n < \sigma_{ncrit} \quad (7)$$

$$\sigma_t = 2(\sigma_{ncrit} \ \tan\delta)\frac{l_f}{d_f}, \sigma_n > \sigma_{ncrit} \quad (8)$$

σ_n = confining stress on fiber

δ= angle of skin friction

l_f =total length of fiber

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

The shear strength increase ΔS, induced by fiber presence was obtained by substituting Equations (8) into (2), as follows:

$$\Delta S = N_s\left(\frac{\pi {d_f}^2}{4}\right)[2(\sigma_n \ \tan\delta)\frac{l_f}{d_f}](\sin\theta + \cos\theta\tan\emptyset)(\zeta), \quad \sigma_n < \sigma_{ncrit} \quad (9)$$

$$\Delta S = N_s\left(\frac{\pi {d_f}^2}{4}\right)[2(\sigma_{ncrit} \ \tan\delta)\frac{l_f}{d_f}](\sin\theta + \cos\theta\tan\emptyset)(\zeta), \quad \sigma_n > \sigma_{ncrit} \quad (10)$$

ζ= coefficient depends on sand parameter

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

As the main previous studies are on sand, the current study in Curtin University considered new approach in using fibers types and materials to fully investigate the effects of fiber in clayey soils. As part of this research, the following section investigates clayey sand behaviour.

III. MATERIAL

Composite materials usually 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. As soils have relatively low tensile strength so that they are not able to transfer tensile forces through a foundation system. These forces can be transferred using geosynthetics materials - geogrids, geotextiles or geocomposites.

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

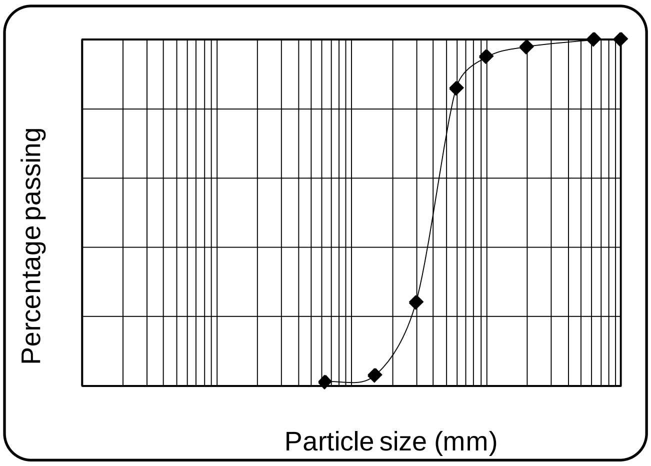

Fig. 1Sand particle distribution

B. Fiber Type

The natural fiber and plastic fiber has been used for this investigation. The natural fiber is available in Western Australia. This material can be easily found and prepared for industrial project. Being cost effective is the main advantage of this fiber. Figure 2 shows the natural used fiber. The second type of used fibers shown in Figure 3 was plastic fiber with great energy absorption capability. The main advantage of this plastic was its good interaction with soil part. The interlock forces were expected to be considerably higher than natural one due to skin friction. Therefore, the load transfer in case of plastic fiber was better than natural one.

Fig. 2 Natural fiber

Fig. 3 Plastic fiber

IV. TEST PROGRAM

A series of UCS tests have been conducted to verify effect of fiber content on strength of composite clayey sand.

A. Unconfined Compression Test Principle

The 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.

B. Equipment

- Unconfined compression testing machine (Triaxial Machine) as shown in Figure 4
- Specimen preparation equipment
- Sample extruder
- Balance

Fig. 4Triaxial machine

C. Sample Preparation

The samples were prepared by mixing clayey sand and four percentage of fiber. Specimen preparation method was the standard compaction method, which was used in an ongoing experimental research on fiber-reinforced clayey sand 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 by mixer because 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 contents (i.e. 0.6%, 1.5%, 4%) and different fiber lengths (aspect ratio) which were 8mm, 20mm and25mm.

V. 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 paid to preventing any moisture loose
5. The samples were put in triaxial base without any confinement pressure
6. According to ASTM, 1.27 mm/min was applied through the tests
7. The data were collected automatically
8. The stress-strain curve plot was used for modulus elasticity investigation

VI. RESULTS AND DISCUSSION

A series of UCS tests were conducted on fiber reinforced samples. Fiber parameters were changed during this study to evaluate the effect of each fiber parameter. (i.e. type, content and length). This section focuses on effect of each parameter.

A. *Effect of Fiber Type*

Two types of fiber were used in this research (i.e. plastic and natural). The results are presented in following figures. The results showed the difference in strength due to change in fiber material.

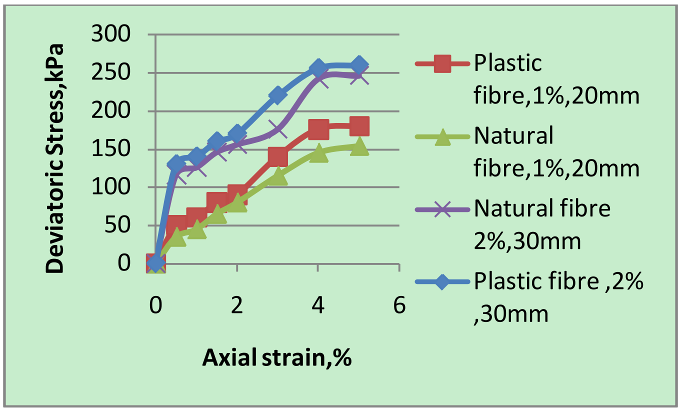

Fig. 5 Effect of fiber type on strength of clayey sand composite

The change in fiber material proved that the plastic fiber increased the strength of reinforced samples more than natural fiber. The main reasons can be considered as interlock forces between soil and fiber as the adhesion of soil part and fiber worked more proper than the natural one.

B. *Effect of Fiber Content*

The effect of fiber content was well investigated as the UCS tests were run for different fiber contents and constant length and type. The fiber length is kept at 8mm and plastic fiber is used for these tests. The Fig. 6 shows the effect of fiber content on strength of the samples.

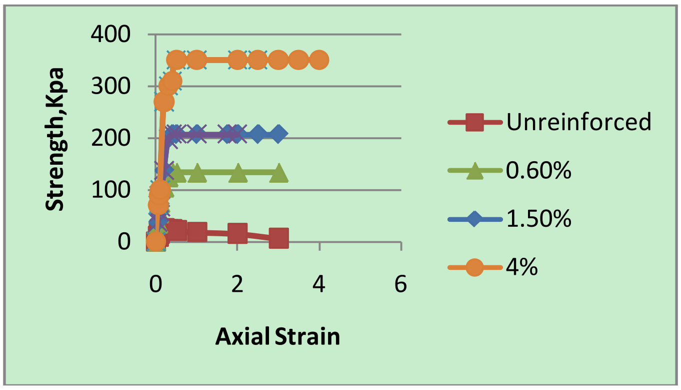

Fig. 6 Effect of fiber content on strength of clayey sand composite (at 8mm)

C. *Effect of Fiber Length*

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 is kept as plastic fiber and the fiber content as 0.6%. The Fig. 7 shows the effect of fiber content on strength of the samples.

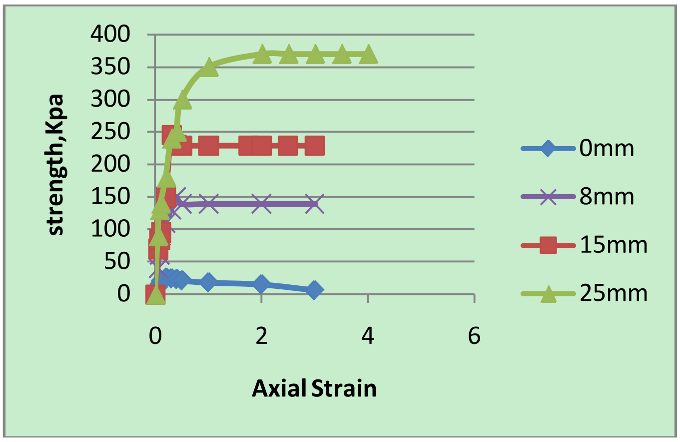

Fig. 7 Effect of fiber length on strength of clayey sand composite (at 0.6%)

VII. CONCLUSION

A series of UCS tests were conducted to examine the effect of fiber content, length and fiber type. The results showed that:

- These three parameters (i.e. fiber content, length and type) affected the performance and strength of composite clayey sand significantly.
- The tests proved that with the increase in fiber content, the strength increased considerably. The strength peak increased by six times in case of increasing in fiber content by four times.
- The results also proved that increasing in fiber length increased the strength of the composite. As an instance when fiber length increased from 8 mm to 25mm, the peak increased from 125 kpa to 340 kpa.
- During this research, the effects of fiber type (i.e. plastic fiber and natural fiber) were investigated. The results proved that increasing in strength of composite material was more considerable in case of plastic fiber compared to natural one. The main reason can be found as skin friction difference as the interlock forces for plastic fiber was more than natural one.

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