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Application of wood to sand-slag and its effect on soil strength

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Abstract

In certain situations, sand is required to have extra shear strength to provide more safety, stability and support for structures. Shear strength in sand arises from friction and resistance between particles. The most common means of increasing the shear strength of sand is the cementation method. Another practice is using an additive such as slag. Some studies show that wood has also been used to improve soil strength, mostly for soft and expansive soil. However, there is limited information available on sand. Therefore, the purpose of this research is to determine whether the shear strength of a sand-slag mixture is affected by the addition of wood. Baldvis sand, a locally sourced material, was used in the experiment because it has been widely used in construction and geotechnical projects in Western Australia. The shear strength of the sand-slag-wood material was determined using an automated direct shear testing machine. There were a number of variations in test conditions, including as the amount of wood introduced into the sand-slag, the percentage of slag in the sand, the gaps between the wood, and wood orientation. The results showed that the shear strength of the sand-slag mixture tended to be enhanced by the presence of wood. The sand-slag mixture containing wood seemed to be stronger than the sand-slag without wood or the pure sand. The position of the wood also contributed to the improvement in shear strength. Placing the wood vertical to the shear direction resulted in greater strength than when the wood was positioned horizontally. From these results, it can be concluded that wood is another potential means of enhancing the shear strength of sand-slag mixture. The quantity of wood and the way it is arranged, such as distance and direction, may result in different levels of improvement to the shear strength of the sand-slag.

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1. Introduction

Soil plays an important role as a construction material, especially as the basic foundation. Soil material is complex and varies from one location to another. There are conditions where the stability of soil in the field is not suitable for construction and structural projects, thus it is necessary to improve soil stability in order to meet the technical requirements needed. Soil stabilization is a method used to alter or improve the properties of the soil.

Shear stress or shear strength of the soil is a very important factor in reviewing the stability of the soil. Shear strength is mainly influenced by two soil shear strength parameters, namely the cohesion and friction angle [1]. Soil shear strength is important in analyzing the stability of a slope and analysis of the subgrade bearing capacity of the foundation. Therefore, soil strength analysis and careful design are required to avoid structural failure arising from the collapse of the soil structure and prevent the undermining of the basic foundation of the structure built upon it [1].

There has been an increase in the use of chemicals (chemical additives) for land improvement, such as cement, lime, slag and fly ash, due to the ease of use of these materials [2, 3 and 4]. Portland composite cement (PCC) is especially popular due to its availability on the market and the relative ease with which it can be used in the field. However, a very high shear strength indicates that soil stabilized with cement tends to be brittle and has a low tensile strength [5]. This means the soil is less satisfactory for use as construction material which needs to be strong but ductile. In the meantime, the addition of wood has been found to improve the tensile strength of soil [6].

Since this research is focused on Western Australia, the sand used for the tests is one that is widely used across Western Australia. The shear strength properties of sand that has already been chemically stabilized by the use of slag will be tested with the addition of timber as a reinforcement. This paper is part of a large project at Curtin University and there could be a possible application into the current projects in Curtin University [10 and 11]. In particular, this study aims to test the effect on soil shear strength of adding wood to sand containing various percentages of slag. The benefit of this study is to determine whether the addition of wood to slag-stabilized sand is a viable alternative for improving soil shear strength. Moreover, the application of wood may be a more sustainable solution for soil stabilization.

2. Materials

The mixture consists of two major materials which are discussed in the following sections. This experiment used Baldvis sand which is widely employed for construction and structural projects in Western Australia. Baldvis sand is a quartz sand coming from the Baldvis area (50 km south of Perth), and is classified as poorly graded, with a specific gravity of 2.65.

2.1. Slag

Slag is an additive which is widely used in structural engineering. The addition of slag to soil is a recent interest of the researchers [3, 5]. The slag used in this experiment is ground granulated blast furnace slag (GGBS), and was obtained from BGC Cement, Western Australia. GGSB contains chemical compounds including CaO, SiO₂, Al₂O₃, and MgO [7]. The characteristics of GGSB are shown in Table 1 and Table 2 respectively [7].

Table 1. Chemical content of GGSB [7]

Calcium oxide (<i>CaO</i>)	Silica (<i>Amorphous CaO</i>)	Aluminium oxide (<i>Al₂O₃</i>)	Sulphur (<i>S</i>)
30–50%	35–40%	5–< 5%	15%

Table 2 Physical properties of GGBS [7]

Colour	Bulk density: loose (<i>tonnes/m³</i>)	Bulk Density: vibrated (<i>tonnes/m³</i>)	Relative density	Surface Area
Off-white powder	1.0–1.1	1.2–1.3	2.85–2.95	400–600 m ² /kg

2.2. Wood

The wood employed in this experiment was aspen timber. Since the experiment only needed a small quantity of wood, and considering the limited length of wood that can be accommodated by the small direct shear machine, it was decided to use the wood from ‘Redheads’ matches. The wood was prepared by removing the tip of the matches which contain the chemical mixture that forms the heads. The initial moisture content of the wood was 12% with a specific gravity of 0.36 [8].

Table 3 Properties of aspen timber [8]

Moisture content	Specific gravity	Modulus of rupture (kPa)	Modulus of elasticity (<i>e</i>) (MPa)	Shear parallel to grain (kPa)
12	0.36	37,000	7,700	5,000

2.3. Experimental procedure

The direct shear test was used to obtain the failure stresses for each composite and the failure data was then used to calculate cohesion and friction angle. Direct shear tests series were conducted to examine the shear strength of the sand composite, starting with the pure sand specimen, progressing to the sand containing various percentages of slag, and finally to the sand-slag mixture with added wood. The percentages of slag introduced to the sand specimens were 1%, 2% and 3%. The direct shear test was run based on AS 1289.6.1.1-1998 [9]. Prior to shear testing, the sample was loaded into and compacted in a 60mm x 60mm shear box layer by layer according to its dry density. The sample then was saturated by filling the shear box with distilled water. A specific normal stress was applied to let the sample consolidate properly. Three normal stresses of 50, 150 and 250 kPa were applied in each series of tests for all samples.

3. Results and discussion

The direct shear test result for the pure sand is shown in Fig. 1. The normal loads applied were 50, 150, and 250 kPa and the maximum shear stresses for each normal stress applied were 35.87, 98.86 and 172.36 kPa at failure respectively. The friction angle of sand (θ) was 34.3°. This test was then followed by experiments to determine the optimal quantity of wood to add to the sample and the most effective direction in which to place it. Preliminary tests suggested that placing the wood vertical to the shear direction had greater influence on the shear strength.

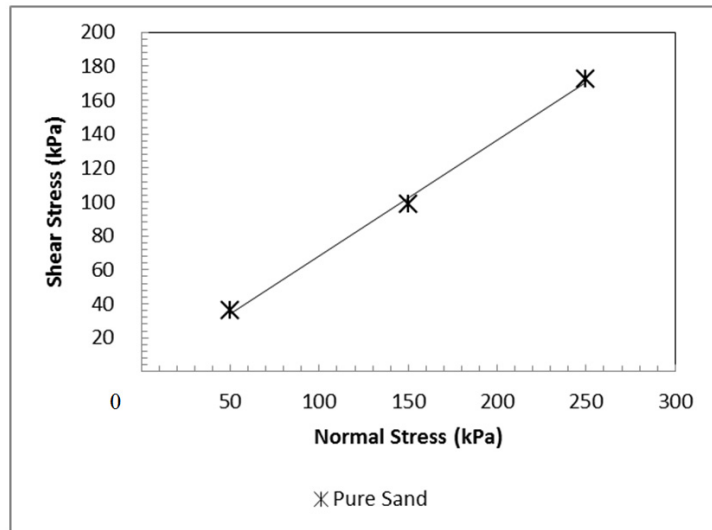


Fig. 1. Shear stress with various normal stresses of pure sand

Slag was then added to the mixture to form a sand-slag mixture, and the same procedure was carried out to examine the shear strength effect after addition of slag to the sand. The same series of normal stresses (50, 150 and 250 kPa) were applied to the sand-slag mixture. Fig. 2 illustrates that the 1% slag sample had the lowest maximum shear stress of all the sand-slag samples, achieving a maximum shear stress of 36.4 kPa under 50 kPa of normal stress, 98.6 kPa under 150 kPa of normal stress and 174.192 kPa under 250 kPa of normal stress. The maximum shear stresses resulting from application of all three normal stresses were obtained for the sand sample containing 3% slag. The sand with 1% slag produced a friction angle (θ) of 34.6° , while the sand containing 2% and 3% slag gave 34.9° and 35.1° friction angles respectively. The slag was expected to react as a chemical additive, bonding the sand particles and increasing the sand strength when fully hydrated and cured. However, in this experiment, we tried to examine the shear performance of the sand-slag without considering the curing time. It appears that the slag had not fully reacted as a chemical additive but only functioned as a finer particle addition to the sand.

Fig. 3 represents the results attained from applying 50 kPa of normal stress to the three samples with a slag content of 1%, 2% and 3% by weight, with wood added. The sample with a 3% slag content had the highest shear stress compared to the others, going into almost a slightly inclined phase towards the end of the test. It was decided to continue the trend and increase the rate of shear stress until reaching a maximum of 62.2 kPa. This sample also showed the highest initial gradient compared to the other samples. The maximum shear stresses for sand containing 1% and 2% slag under 50 kPa of normal stress were 54.8 and 56.03 kPa respectively.

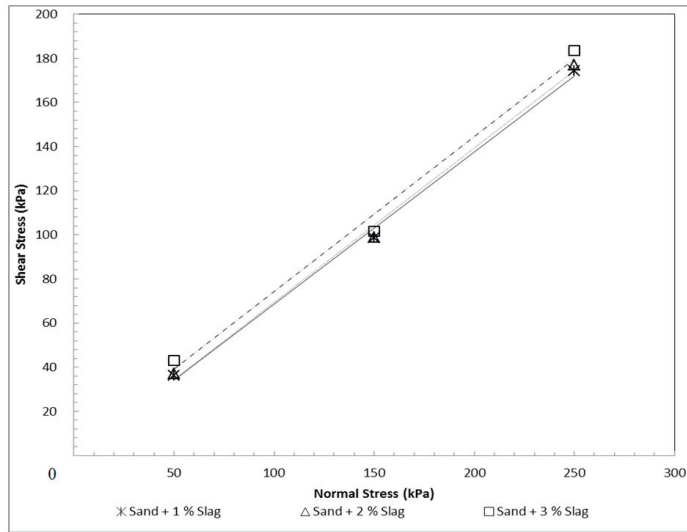


Fig. 2. Shear stress of sand-slag mixture under different normal stresses

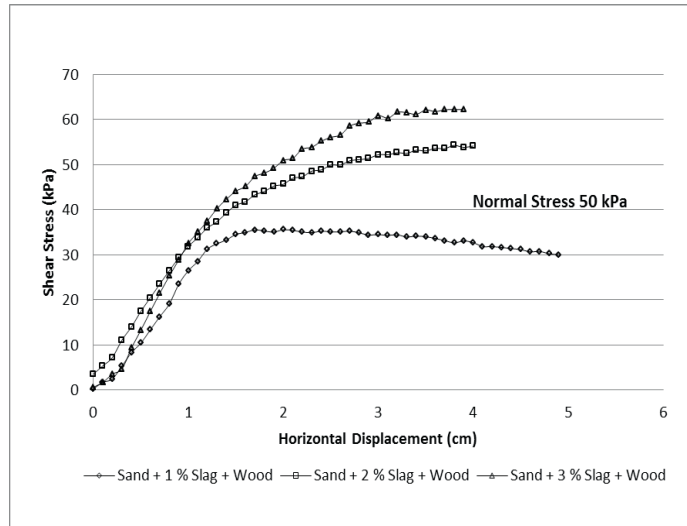


Fig. 3. Shear stress-horizontal displacement of sand with different percentages of slag and wood under 50 kPa of normal stress

As can be seen in Fig. 4, the sand-slag mixture sample that achieved the greatest maximum shear stress when wood was introduced to the sample was the one containing the highest percentage of slag (3%). The sand-slag mixture with 3% of slag produced a shear stress of 62.3 kPa at a normal stress of 50 kPa, 134.57 kPa at a normal stress of 150 kPa, and 221.9 kPa at a normal stress of 250 kPa. The friction angle of each sand-slag mixture also increased when wood was present in the mixture. The friction angles of sand containing 1%, 2% and 3% slag and added wood were 35.06°, 37.71° and 38.59° respectively.

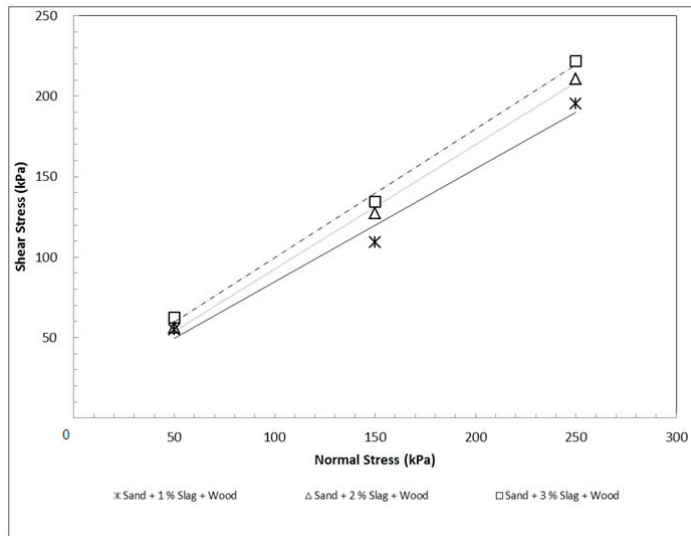


Fig. 4. Shear stress of sand mixtures with different percentages of slag and added wood under various normal stresses

Fig. 5 illustrates that the 3% slag content sample with added wood had the greatest maximum shear stress of the tested samples. With the application of 50 kPa of normal stress, the introduction of wood to the sand-slag mixture can increase the shear strength by 52.7%, 56.2% and 73.6% respectively for sand containing 1%, 2% and 3% slag and added wood. Under 150 kPa of normal stress, the percentage increase in shear strength of introducing wood to the mixture ranged from about 10.4% to 36.1%. The contribution of added wood to the shear strength performance of the sand-slag mixtures under 250 kPa of normal stress extended to about 13%–28% improvement for every mixture. According to Fig. 5, the introduction of wood into the sand-slag mixture improves the shear strength of the mixture for each percentage of slag content and under the application of every level of normal stress.

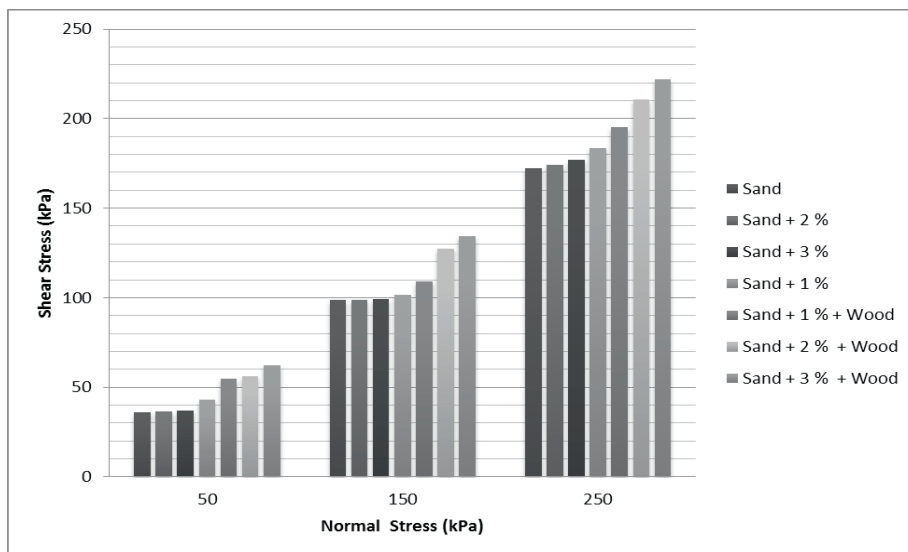


Fig. 5. The comparison of shear stress for sand-slag mixtures with and without wood under different normal stresses

4. Conclusion

A series of direct shear tests were applied to sand-slag and wood mixtures. The percentages of slag added to the sand were 1%, 2% and 3%, and the results showed good potential for the application of wood or slag. Based on the preliminary tests, the amount of wood introduced to the sample was calculated as a percentage based on the top surface area of wood and sand sample. The wood was then placed in a position vertical to the shear direction, as this configuration seemed to provide the optimum result. In this experiment, by adding wood into sand-slag mixtures, the shear strength of the mixtures increase significantly. Wood appears to improve the shear strength performance of sand-slag mixture by various degrees, from 10.4% to about 73.6%, when normal stresses of 50 kPa, 150 kPa and 250 kPa are applied. The greatest improvement in shear strength occurred when 50 kPa of normal stress was applied to the mixture. The highest shear strength was seen in the sand mixture containing 3% slag under all normal stresses applied.

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References

- [1] M. Budhu, Earth fissure formation from the mechanics of groundwater pumping, *Int. J. Geomech.* 11(1) (2010) 1–11.
- [2] O. Azadegan, M.J. Yaghoubi, Gh.R. Pourebrahim, A laboratory study of the behavior of the lime/cement slurry and compacted un-reinforced piles, *Electron. J. Geotech. Eng.* 16 (2011) 375–386.
- [3] M.L. Allan, L.E. Kukacka, Blast furnace slag-modified grouts for in situ stabilization of chromium-contaminated soil, *Waste Manage.* 15(3), (1995), 193–202.
- [4] E.O. Tastan, T.B. Edil, C.H. Benson, and A.H. Aydilek, Stabilization of organic soils with fly ash, *J. Geotech. Geoenviron.* 137(9) (2011) 819–833.
- [5] Y. Yi, M. Liska, A. Al-Tabbaa, Properties of two model soils stabilized with different blends and contents of GGBS, MgO, Lime, and PC, *J. Mater. Civ. Eng.* 26(2) (2014) 267–274.
- [6] J. Prabakar, R.S Sridhar, Effect of random inclusion of sisal fibre on strength behaviour of soil, *Constr. Build. Mater.* 16(2) (2002) 123–131.
- [7] Ecocem, I.L. History of the use of GGBS, Ecocem Ireland Ltd., viewed 16 February 2014, <http://www.ecocem.ie/technical/ggbs/history.htm>.
- [8] D.E.Kretschmann, Wood Handbook, Chapter 05: Mechanical Properties of Wood, General Technical Report FPL-GTR-190, U.S. Department of Agriculture, Forest Service, Forest Products Laboratory, Madison, WI, 2010, pp. 5-1 – 5-46.
- [9] Standards Australia, Methods of Testing Soils for Engineering Purposes — Soil strength and consolidation tests — Determination of the shear strength of a soil — Direct shear test using a shear box (AS 1289.6.1.1-1998), (1998). Viewed 4 February 2014, Standards Online Premium database (Sai Global).
- [10] M.A. Budihardjo, A. Chegenizadeh, H. Nikraz, Land subsidence: The presence of well and clay layer in aquifer, *Aust. J. Basic & Appl. Sci.* (in press).
- [11] M.A. Budihardjo, A. Chegenizadeh and H. Nikraz, Prediction of heavy metal contamination from landfill: Lead and chromium, *Aust. J. Basic & Appl. Sci.* (in press).