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Enhancing the compressive strength of landfill soil using cement and bagasse ash

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Abstract. The stabilisation of contaminated soil with cement and agricultural waste is a widely applied method which contributes to the sustainability of the environment. Soil may be stabilised to increase strength and durability or to prevent erosion and other geotechnical failure. This study was carried out to evaluate the compressive strength of ex-landfill soil when cement and bagasse ash (BA) are added to it. Different proportions of cement (5%, 10%, 15% and 20%) was added to sample weights without BA. On the other hand, the cement in a different batch of sample weights was replaced by 2.5%, 5%, 7.5% and 10% of BA. All samples were allowed to harden and were cured at room temperature for 7, 14 and 28 days respectively. The strength of the contaminated soil was assessed using an unconfined compressive strength test (UCS). The laboratory tests also included the index properties of soil, cement and bagasse ash in raw form. The results indicated that the samples with cement achieved the highest compressive strength measuring 4.39 MPa. However, this study revealed that the use of bagasse ash produced low quality products with a reduction in strength. For example, when 5% of cement was replaced with 5% ash, the compressive strength decreased by about 54% from 0.72 MPa to 0.33 MPa. Similarly, the compressive strength of each sample after a curing period of 28 days was higher compared to samples cured for 7 and 14 days respectively. This is proved that a longer curing period is needed to increase the compressive strength of the samples.

1. Introduction

One of the most basic elements which make up our ecosystem is soil. It is necessary for the survival of mankind as well as the development of civilisations [1-2]. Unfortunately, soil is also extremely susceptible to contamination. John *et al.* [3] defines land contamination as areas with high concentrations (above normal background level) of substance which may have been left behind by previous land use. The contamination of soil, especially by heavy metals, may threaten the environment and human health. That is why there is a dire need to seek efficient and cost-effective solutions to curb soil contamination [4].

Soil contamination is mainly caused by industrial activities which generate waste and contaminants which seep into soil through direct disposal, emissions and other pathways [5]. Furthermore, past land use, human activities and the proximity to pollution sources may also have a negative impact on soil. Soil contamination can be caused by substances such as pesticides, fertilizers and other amendments to soil [6-7]. One of the important properties that is affected by contaminants is compressive strength which is vital for soil to withstand axial forces. The compressive strength of soil is important in nearly all geotechnical engineering designs because it is used for obtaining an estimate of the soil strength.

Similarly, unconfined compressive strength (UCS) is often used to provide a baseline comparison between unstable and stabilised wastes. In general, unstable waste materials are unable to provide good shear strength. Nevertheless, soil strength may increase significantly if it is stabilised using certain materials such as concrete [8-9]. This study aims to evaluate the compressive strength of contaminated soil mixed with cement and bagasse ash material.

2. Materials and methods

2.1. Collection of soil samples

The contaminated soil samples were collected at the Bukit Bakri Landfill Site (BBLS), Muar, Johor. The top of the soil to a depth of 1 meter was removed in order to avoid taking the humus, waste and plant roots. Then, the soil was placed in polystyrene containers. After that, the soil samples were taken to the laboratory to be dried in the oven at 105°C for 24 hours. After being dried for 24 hours, the soil was crushed using a rubber hammer before being decimated into 2 mm in size using a grinder machine. The soil which passes the 2 mm sieve was stored in polyethylene plastic. Figure 1 shows the soil sample collection site at BBLS, Muar, Johor.

Figure 1. Soil sample collection site at BBLS, Muar, Johor.

2.2. Cement and Bagasse Ash (BA)

Cement was used as the primary binder reagent in the stabilisation/solidification (S/S) method. The type of cement that was used in this study was Ordinary Portland Cement (OPC) type 1. Normally, when soft soil is mixed with cement, it can stabilise the soil because cement and water react to form cementitious calcium silicate and aluminate hydrates, which bind the soil particles together [2]. Sugarcane bagasse ash, a type of agricultural waste, was chosen to be incorporated with Ordinary Portland Cement (OPC) in the S/S technique. Tajudin et. al. [10] stated that sugarcane bagasse ash is known as a mineral additive in cementitious materials. Besides that, sugarcane bagasse ash can also reduce the remediation cost normally incurred by cement usage as it is relatively cheap. Sugarcane bagasse ash is also environmentally friendly [11]. The raw form of sugarcane bagasse was dried under the sun and burnt until a grayish-black ash was obtained. These materials are considered as uncontrolled burned bagasse because it is burnt under uncontrolled temperature. The bagasse ash (BA) was further burnt under a controlled temperature at 650° C for one hour. This burning process brought down the carbon content by at least 4.9% [11]. After cooling, the ash was grounded using grinder machines until a particle size of 90 µm was obtained.

2.3. Production of soil samples
In this study, the percentage of cement was partially replaced with bagasse ash (BA) as an additive to the soil. A study conducted by Ahmaruzzaman, [12] indicated that 5% to 20% cement content was the optimal percentage for the formation of cementitious product with clay. Another study by Voglar & Lestan [13] stated that 5% and 20% of ordinary Portland cement (by weight to soil) showed good results in the treatment of heavy metals using the S/S method. The weight of each sample was measured to avoid any material waste whereas the quantity of each component was calculated through its percentage in the sample according to Table 1. Sample batches were triplicated for 3 hydration durations namely 7, 14 and 28 days respectively. The sample were mixed in bulk to obtain relative homogeneity prior to packing and storage. The water to cement ratio used in this research has been determined from the optimum moisture content (OMC) obtained from the compaction test which ranged from 0.20 to 0.40 (w/c) depending on the quantity of bagasse ash (BA) added. Next, the raw material was mixed in using a small mixer to ensure the homogeneity of the S/S sample. Later on, a split mould was used to make S/S samples measuring 38 mm in diameter and 76 mm in height. The mixture was compacted in 4 layers using a custom-made hand compacting tool where 50 blows were applied to each layer [14]. The extruded samples were carefully wrapped and kept for 7, 14 and 28 days before the tests were carried out on them. The mix design of the S/S samples are shown in table 1.

Table 1. Mix design of S/S samples.

No.	Mixing Type	Sample Name	Label	Percentage of Binder (%)		
				Soil	OPC	BA
1.	Soil only (control)	Soil	A	100	0	0
2.	Cement only	soil + 5% cement	B	95	5	0
3.		soil + 10% cement	C	90	10	0
4.		soil + 15% cement	D	85	15	0
5.		soil + 20% cement	E	80	20	0
6.	Cement with BA	soil + 2.5% cement + 2.5% BA	F	95	2.5	2.5
7.		soil + 5% cement + 5% BA	G	90	5	5
8.		soil + 7.5% cement + 7.5% BA	H	85	7.5	7.5
9.		soil + 10% cement + 10% BA	I	80	10	10
10.	BA only	soil + 5% BA	J	95	0	5

2.4. Soil properties
Laboratory tests were conducted to determine the index properties of the natural ex-landfill soil in accordance to BS 1377. Figure 2 shows the particle size distribution curve of ex-landfill soil determined based on dry sieving and a hydrometer test. The index properties of ex-landfill soil are summarised in table 2.

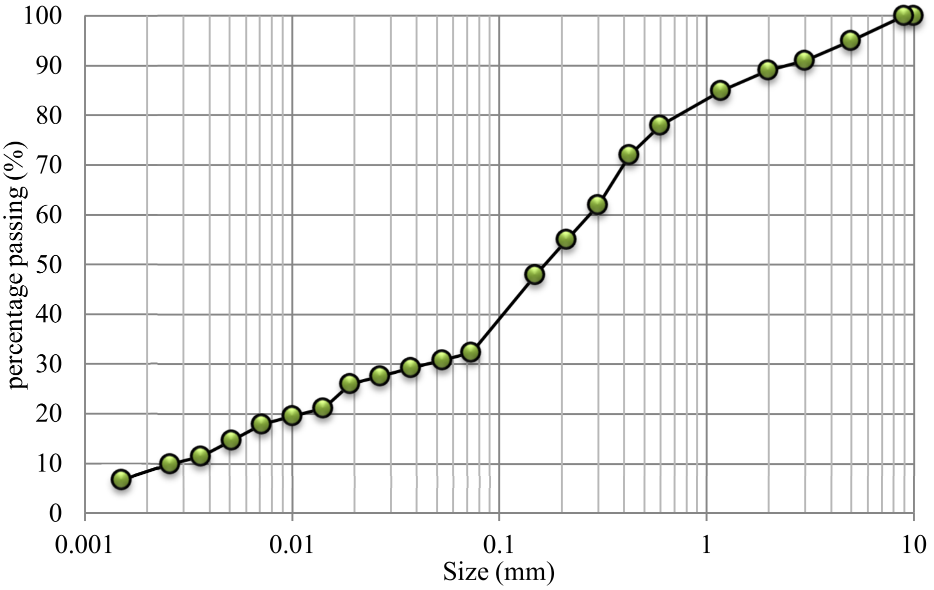

Figure 2. Particle size distribution of ex-landfill soil.

Table 2. Index properties of ex-landfill soil.

Properties	Result
Moisture Content (%)	24.25
Particle Size analysis (%)	
Gravel (4.75 – 75mm)	4.0
Sand (4.75-0.075mm)	63.5
Silt & Clay (<0.075)	32.5
Atterberg Limit (%)	
Liquid limit	47.15
Plastic limit	21.31
Plasticity index (%)	25.84
Linear Shrinkage (%)	21.4
Specific Gravity	2.49
Maximum Dry Density (g/cm^3)	1.60
Optimum Moisture content (%)	18.90
Loss of Ignition (%)	7.33
Soil type	MH
Degree of plasticity	Low plasticity

2.5. Unconfined compressive strength test

The mixture was casted into cylindrical specimen (D = 38 mm, H = 76 mm) moulds of five layers, where each layer was compacted with 50 blows each. A further 7, 14 and 28 days were allowed for curing and the solidified samples were air dried in a cabinet under controlled conditions (temperature 25±2 ◦C, humidity > 80%) before the test was carried out. The UCS test was carried out using the Geocomp LoadTrac II system available in RECESS at UTHM. The test was conducted according to BS1377-7:1990. The samples were placed in a loading device and subjected to the uniaxial compression test (UCT) at a constant strain at of 1% per minute.

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3. Results and discussion

3.1. Effect on compressive strength

Compressive strength is an important factor because it determines the load that can be applied to soil [15]. For example, according to U.S. EPA, if materials are disposed of at landfills, they will have a minimum compressive strength of 0.35 MPa which is the minimum strength required for soil to bear heavy equipment that will be used to cut and fill the surface of the area.

Unconfined compression test results showed an increase in strength with the addition of cement and also the addition of ash mixed with cement as shown in figure 3. In addition, the figure also shows that there were 4 types of samples measuring less than 1.0 MPa beginning with soil sample G which consisted of 5% cement + 5% ash. However, the weakest sample was sample A which consisted of soil alone with a compressive strength of less than 0.35 MPa. This may be due to high organic carbon content (2.9%) and a low level of calcium content in the ash (<15%) as well as a relatively low density of 1.3 g/cm^3. This is a pozzolanic characteristic where it does not harden or solidify very slowly on its own but increases the strength of the material if it is mixed with cement or lime [7,14].

As expected, the samples with cement were found to achieve the highest compressive strength measuring 4 MPa. The figure shows that ash does not affect the strength of the samples significantly. For example, a soil sample mixed with 5% cement and 5% ash has an average strength of 0.63 MPa compared to the samples which were mixed with 10% of cement alone which achieved compressive strength up to 1.78 MPa. However, small quantities of alkaline mixture do not affect compressive strength. Soil samples mixed with 2.5% cement and 2.5% ash cement have an average compressive strength of 0.40 MPa while soil samples which were mixed with 5% cement only achieved an average compressive strength of 1.40 MPa. This has been proven through research conducted by Cordeiro *et al.* [14] who obtained a compressive strength ranging between 2 to 10 MPa for soil stabilised and solidified with cement after a dry curing period of 28 days depending on the type of binder used.

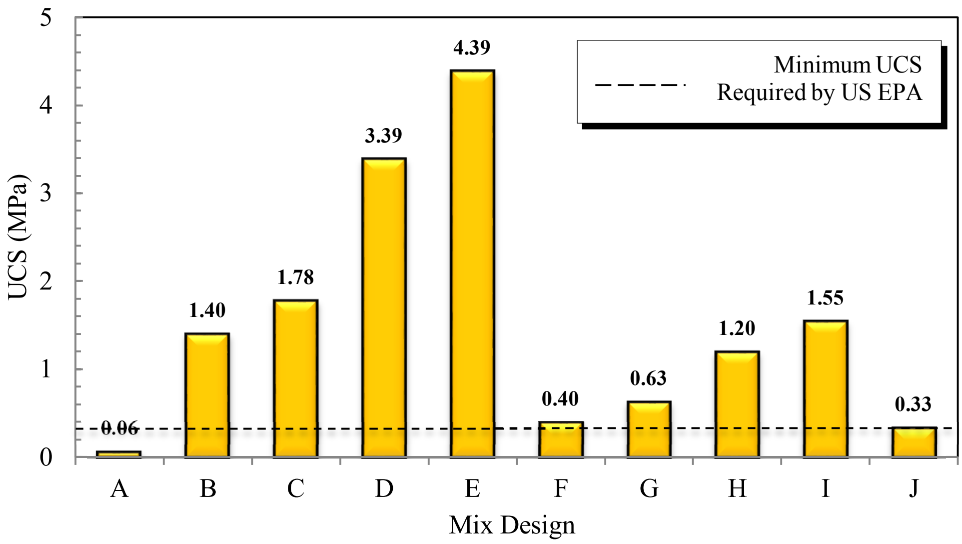

Figure 3. Compressive strength of stabilised samples.

3.2. Effect of UCS on curing period

The effect of UCS on curing time is important to measure whether the treated soil gains the expected strength in a specified period. In this study, soil samples were prepared in several mix ratios and cured for a period of 7, 14 and 28 days respectively. Based on the results obtained, the compressive strength of the soil sample for all the mix ratios increases with the curing period. Figure 4 shows the changes in compressive strength for different curing periods. Soil sample E (20% OPC) has the highest compressive strength which is 4.39 MPa after a curing period of 28 days. Based on results obtained, it can be concluded that the increase in the number of curing days will also result in the increase of compressive strength.

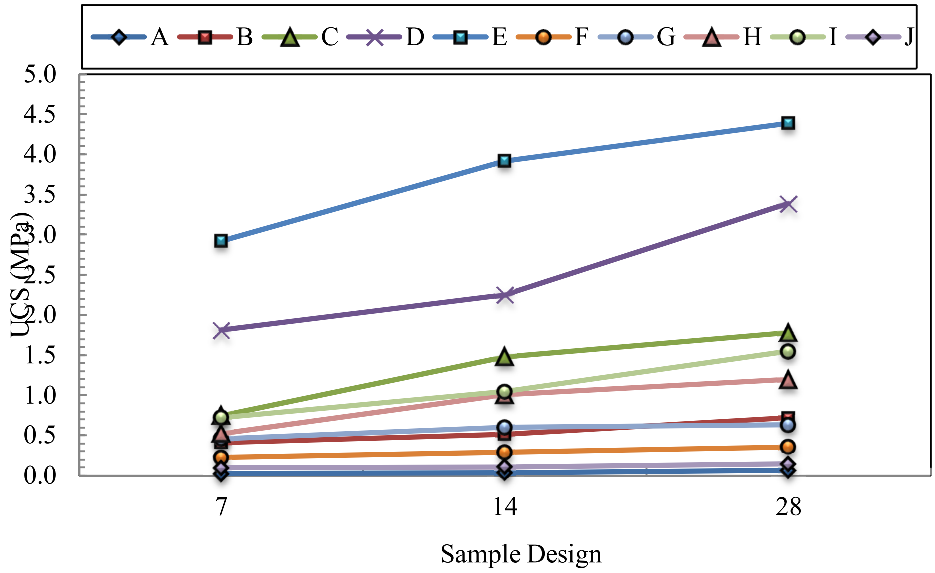

Figure 4. The variation in compressive strength for different curing periods.

In addition, the figure also shows that the compressive strength value for each sample after a curing period of 28 days was higher compared to samples cured for a period of 7 days and 14 days respectively. This may be caused by the formation of C-S-H (calcium silicate hydrate) which contributes to strength development in the S/S method [16]. However, the formation of C-S-H only occurs when the samples go through a certain period of hydration which allows water molecules to penetrate into the pores of cementitious products.

4. Conclusion

The findings revealed that highlight the stabilised soil by with cement and bagasse ash are successful on improve the compressive strength of samples. The samples containing cement alone show highest value in terms of compressive strength compared to samples containing cement with bagasse ash. However, even these two groups of samples (cement alone and cement with bagasse ash) were contradictory in terms of value. The samples containing bagasse ash still exceeded the minimum landfill disposal limit stated by US EPA of 0.35MPa after a curing period of 28 days. Thus, this implies that the two most important factors in strength development are cement content and curing period. On the other hand, the water/cement ratio is considered to be a secondary factor compared to matrix constituents [17]. This was concurred by a study by Basha *et al.* [18] where it was found that the compressive strength of cement structures is influenced by the quality of pore structures which depend on the type and quantity of constituents (cement hydration products and admixtures).

5. References

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