Effect of ceramic tiles dust on physical and engineering properties of tropical residual soil

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Abstract. Ceramic tile dust is a by-product from manufacturing plant or construction site which leads to the disposal or environmental issues. Previous research has identified the potential of ceramic tile dust in concrete and soil stabilisation. This research investigates on the potential application of ceramic tile dust for tropical residual soil stabilisation. Atterberg limits, compaction and unconfined compression tests were conducted on residual soil from Cheras, Malaysia with different ceramic tile dust contents (i.e., 0 %, 10 %, 20 %, 30%). The effect of ceramic tile dust percentage on plasticity index, compaction properties and unconfined compressive strength was discussed. It was found that the maximum dry density of the soil increased slightly until ceramic tile dust content of 20 %. However, the optimum moisture content and plasticity index were reduced with the addition of ceramic tile dust. The unconfined compressive strength was improved about 1.4 times for residual soil with 30 % of ceramic tile dust. In conclusion, ceramic tile dust is suitable to be recycled as a soil stabiliser as it could increase the maximum dry density and strength of the tropical residual soil.

1 Introduction

Soil stabilisation is defined as an alteration process that can improve the soil properties by using physical (e.g., compaction), chemical (e.g., cement, lime [1-3]), microbiological [4] or electrokinetic methods [5]. Recently, many researchers ventured into the possibility of using waste materials (e.g., steel dust [6], tyre chips [7], waste plastic crumb [8], ceramic tile waste [9] etc.) for soil stabilisation.

Ceramic waste (e.g., bricks, blocks, roof tiles, ceramic tiles, sanitary ware) can be generated from the construction site or manufacturing plants, either in pieces or powder forms. Al-Bared et al. [10] stated that approximately 30% of daily ceramic manufacturing are abandoned without undergoing the recycling process. Ceramic waste is somehow considered as problematic waste that could cause disposal issues and pollution to the environment. Nevertheless, some excellent properties (e.g., durability, hardness, cohesionless) of ceramic waste had created its recycling potential in the construction industry (e.g., concrete [11], soil stabilisation [9, 12-17].)

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Previous researchers [9, 12, 13] found that ceramic waste could reduce the plasticity index of soil and increase the maximum dry density and strength of the soil. However, the optimum moisture content of the soil was reduced with the addition of ceramic waste [9, 12, 13]. Moreover, the performance of ceramic waste on soil stabilisation varied with the particle sizes of ceramic waste and soil [9]. Most of the research focused on the application of ceramic tile waste on clay or sand [9, 12, 13, 16, 17]. Limited study was found on the application of ceramic tile waste on the soil with a mixture of sand and fines [14, 15].

Tropical residual soil is a product of weathering and decomposition of rocks at their original place. Tropical residual soils have different particle size distribution which is greatly dependent on the geographical location and grade of weathering [18]. They are mixtures of gravel, sand, and fines, which are normally classified as sandy silt, silty sand, or clayey sand. More than 80% of the land area in Peninsular Malaysia is covered by tropical residual soil [19]. Tropical residual soil is often found at the construction site in Malaysia. This research investigates the potential application of ceramic tile dust for tropical residual soil stabilisation.

2 Methodology

2.1 Materials

A tropical residual soil from Cheras, Malaysia was selected for this study. The soil was air-dried and crushed before the tests. Based on British Soil Classification System, it was classified as slightly silty sand (SP). **Fig. 1** shows the particle size distribution of the residual soil; it has a composition of 26 % of gravel, 72 % of sand, 2 % of fines. The liquid limit and plastic limit of the soil of 61 % and 34 %, respectively. Ceramic tile dust from a manufacturing plant was selected as the stabiliser. **Fig. 2** shows the particle size distribution of the ceramic tile dust. The ceramic tile dust had a particle size of less than 0.3 mm.

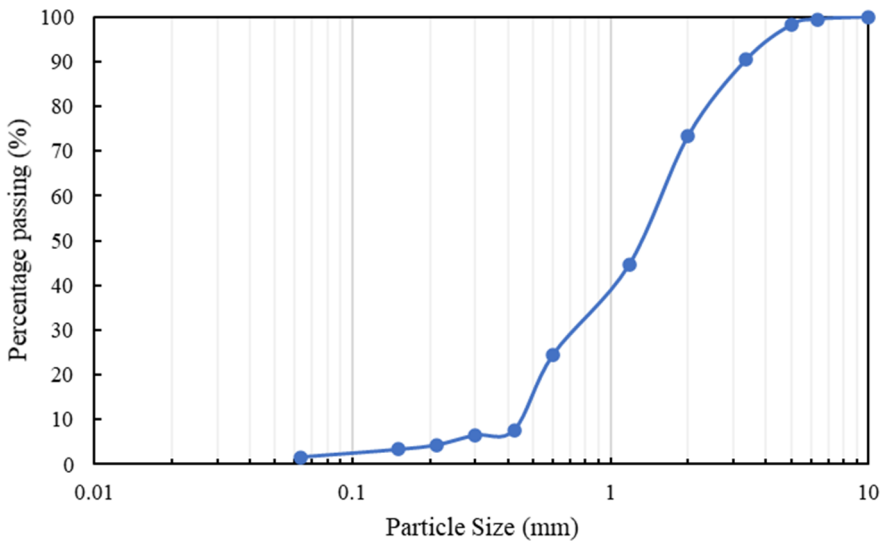

Fig. 1. Particle size distribution of the tropical residual soil.

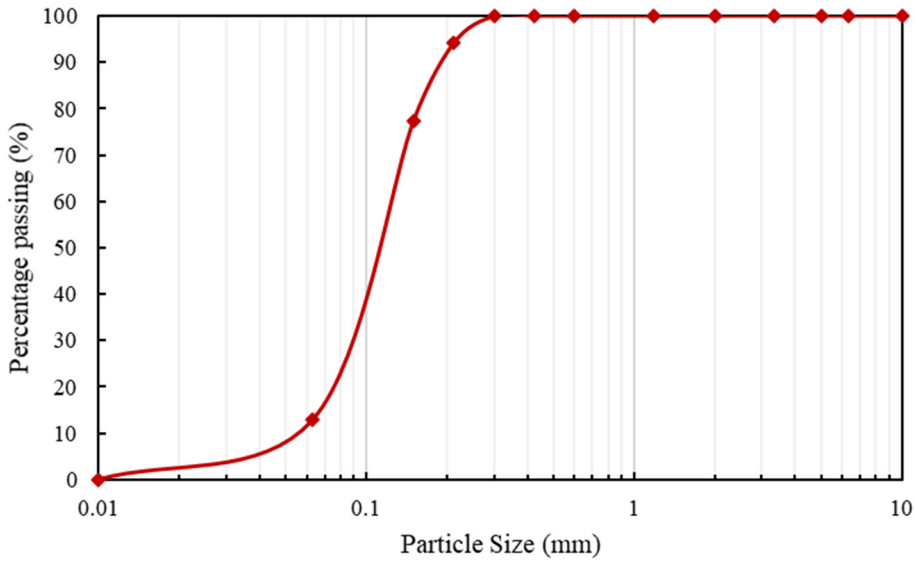

Fig. 2. Particle size distribution of the ceramic tile dust.

2.2 Laboratory tests

Laboratory tests were carried out on the selected soil with different ceramic tiles dust contents (i.e., 0 %, 10 %, 20 % and 30 %) to evaluate the effect of ceramic tile dust on physical and engineering properties of the residual soil.

The effects of ceramic tile dust on liquid limit, plastic limit and plasticity index of the soil were investigated by conducting cone penetrometer test as the liquid limit test and hand-rolling method as the plastic limit test. The air-dried tropical residual soil was sieved to pass 425µm sieve and mixed with ceramic tile dust based on the specified dry weight.

Standard Proctor compaction tests (i.e., 1-litre mould with 2.5 kg rammer) were conducted on both natural and stabilised specimens. The relationship between dry density and moisture content of residual soil with different ceramic dust contents was examined. Then, the optimum moisture content and maximum dry density were determined for each condition. The effect of ceramic tile dust on compaction curve, maximum dry density and optimum moisture content were investigated.

Unconfined compressive tests were conducted to investigate the effect of ceramic tile dust on strength of the residual soil. The specimens were prepared by compacting the mixture of the residual soil and dust to the pre-determined density, based on 95 percent dry density on the wetter side of the compaction curve. The specimens were tested on the same day of the specimen preparation. No curing effect was studied in this research.

All tests were conducted in accordance with BS1924 (1990) and BS1377 (1990).

3 Results and discussion

3.1 Atterberg limits

The effect of ceramic tile dust on liquid limit, plastic limit and plasticity index of tropical residual soil was investigated. **Fig. 3** shows the liquid limits and plastic limits of natural and ceramic tile dust stabilised soils. Both liquid and plastic limits decreased progressively with

the increase of ceramic tile dust content. When 30 % of ceramic tile dust was added to the soil, the liquid limit and plastic limit was reduced from 61 % to 41 % and 34 % to 26 %, respectively. The reduction of liquid limit due to the addition of ceramic tile dust was higher compared to the plastic limit. The plastic limit remained almost constant after adding 10% of ceramic tile dust but the liquid limit reduced continuously with dust added. The plasticity index reduced gradually with the increase of ceramic tile dust content. The plasticity index was about 1.8 times lesser when 30 % of ceramic tile dust was added.

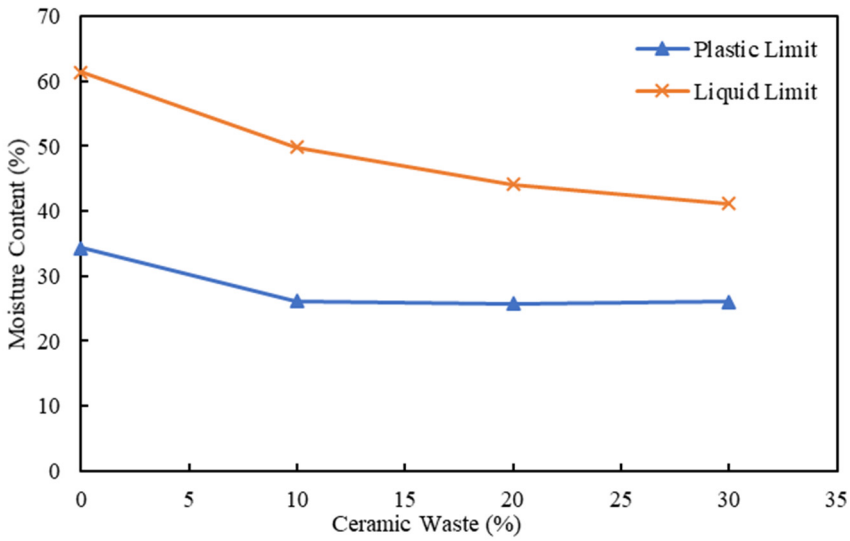

Fig. 3. Liquid limits and plastic limits of natural and ceramic tile dust stabilised soils.

3.2 Compaction properties

Compaction tests were conducted on residual soil mixed with 0 %, 5 %, 10 %, 20 % and 30 % of ceramic tile dust to investigate the effect of dust on the compaction properties of residual soil. The compaction curves are shown in **Fig. 4**. It was found that the compaction curve of ceramic tile dust stabilised soil was shifted to the left and had high curvature in which the range of optimum moisture content was reduced. The workability of the soil is slightly reduced. However, the maximum dry density increased with the addition of ceramic tile dust. With the increment of the maximum dry density, compaction at the site can be done more effectively as higher strength can be achieved with the high dry density.

Fig. 5 shows the effect of ceramic tile dust on the maximum dry density of residual soil. Higher maximum dry density was observed after the addition of ceramic tile dust. This might be due to the higher specific gravity of ceramic tile dust (i.e., 2.82) compared to residual soil which had a specific gravity about 2.6 [12, 13]. The maximum dry density of the original residual soil was 1788 kg/m^3. The maximum dry density increased with ceramic tile dust percentage until ceramic tile dust of 20 %. The highest increase was observed for the sample with 20 % of ceramic tile dust, in which the maximum dry density was increased to 1820 kg/m^3. However, the maximum dry density dropped slightly to 1812 kg/m^3 when 30 % of ceramic dust was added. This meant that the effect of ceramic tile on the maximum dry density was less significant after ceramic tile dust content of 20 %. Similar trend was also observed in clayey soil with about 15 % of sand [14].

Fig. 6 shows the effect of ceramic tile dust on the optimum moisture content of residual soil. The optimum moisture content of the residual soil was 15.1 %. The optimum moisture

content was reduced with the increment of ceramic tile dust until 20 % of dust was added, with the optimum moisture content of 13.9 %. However, the optimum moisture content increased slightly to 14.0 % when 30 % of ceramic dust was added. This meant that the effect of ceramic tile dust on the optimum moisture content was less significant when the dust content is more than 20 %. The reduction of optimum moisture content might be because of the replacement of the soil with ceramic tile dust which had less water attraction properties [12].

The addition of ceramic tile dust up to 20% successfully increased the maximum dry density and reduced the optimum moisture content of residual soil. However, the effects became less significant when the ceramic tile dust content is more than 20%.

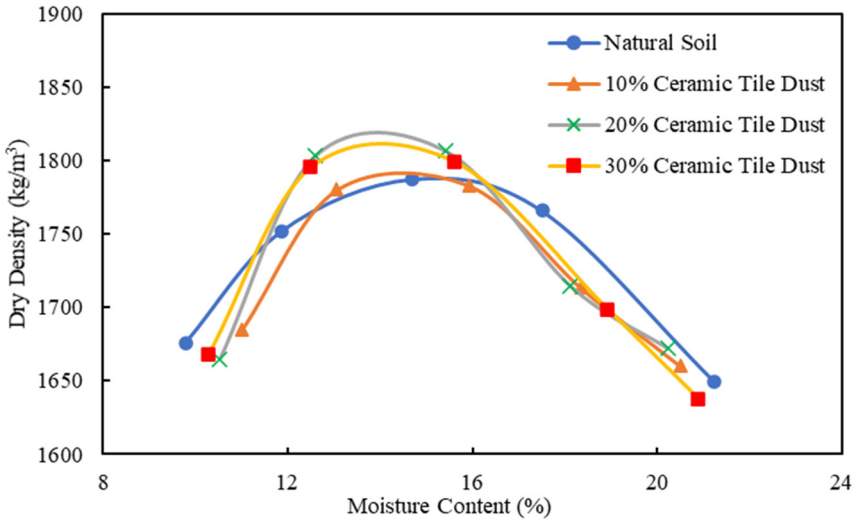

Fig. 4. Compaction curves of natural and ceramic tile dust stabilised soils.

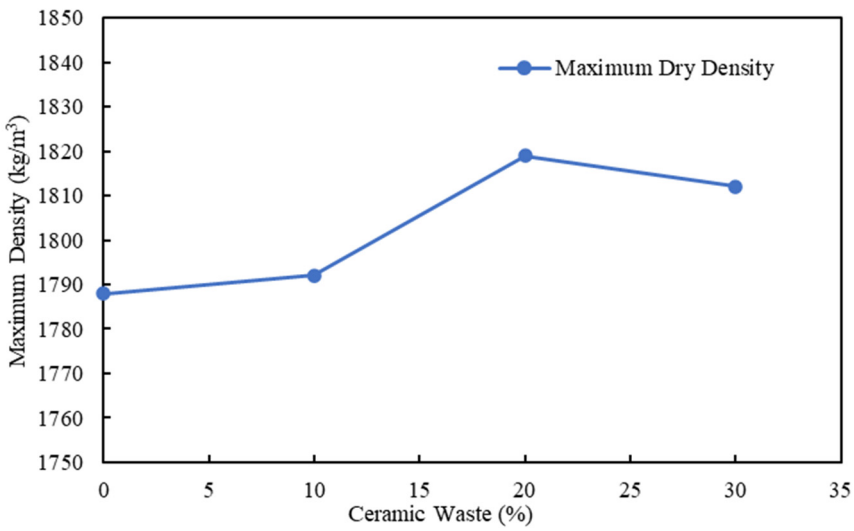

Fig. 5. Maximum dry densities of natural and ceramic tile dust stabilised soils.

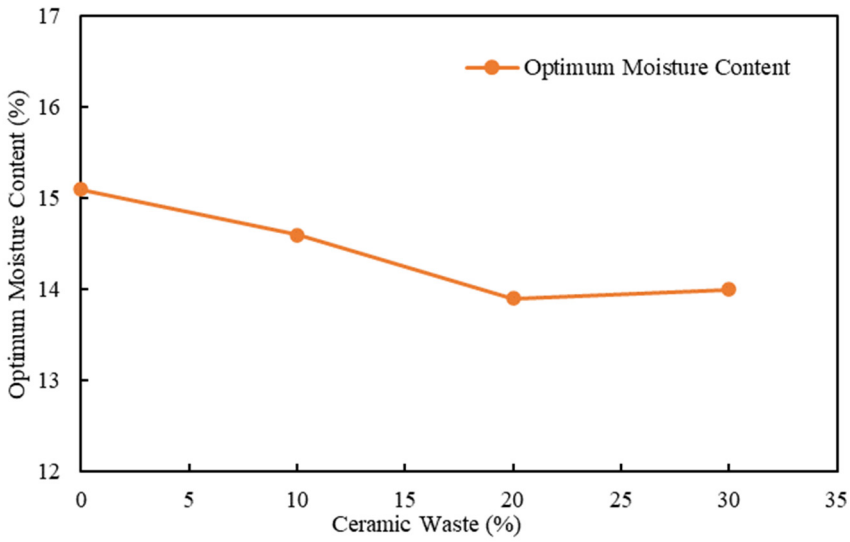

Fig. 6. Optimum moisture contents of natural and ceramic tile dust stabilised soils.

3.3 Strength properties

The dry density and moisture content of the specimens before the unconfined compression tests are shown in **Table 1.**

Table 1. Specimens' properties

	Dry Density (Mg/m^3)	Moisture Content (%)
Untreated Soil	1.72	14.9
10% Ceramic Dust + Soil	1.68	14.6
20% Ceramic Dust +Soil	1.73	13.6
30% Ceramic Dust + Soil	1.69	14.4

Fig. 7 shows the stress-strain curves for all the tested specimen from unconfined compression test results. The stress increased to a peak and reduced for all specimens. The peak stresses for all specimens were found at the strain of about 0.02. The initial stiffnesses of all specimens were almost similar.

Fig. 8. shows the effect of ceramic tile dust on the unconfined compressive strength of residual soil. The unconfined compressive strength of the tropical residual soil was 51 kPa. The unconfined compressive strength of the soil increased with the ceramic tile dust content. The unconfined compressive strength of sample with 30 % of ceramic tile dust was about 1.4 times of the unconfined compressive strength of natural residual soil. The increase of strength might be due to formation of new cementation compounds and the exchange of cations between the ceramic tile dust and fine contents of the residual soil. However, the increase of strength for residual soil with 30 % of ceramic tile dust was not as high as that obtained in soft clay (with about 60 % of fines) which was about 2.8 times of the untreated soil [9]. The fine content of the soil tested in this research is only about 2 %. The ceramic tile dust might act as the filler in the voids between the coarse particles in the residual soil.

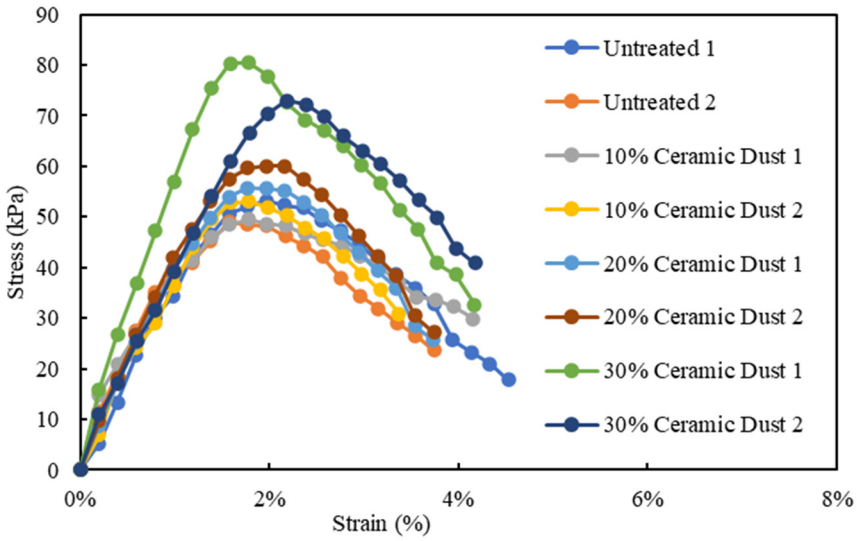

Fig. 7. Stress-strain curves of natural and ceramic tile dust stabilised soils from unconfined compression test.

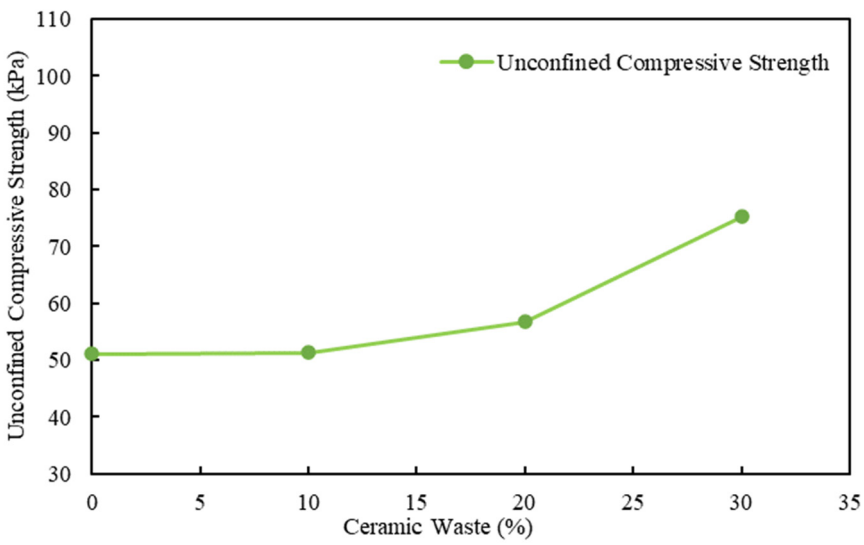

Fig. 8. Unconfined compressive strengths of natural and ceramic tile dust stabilised soils.

4 Conclusion

In conclusion, ceramic tile dust has potential to be recycled as a soil stabiliser. It successfully increased the maximum dry density and the unconfined compressive strength of tropical residual soil, which is a slightly silty sand. The maximum dry density was increased slightly from 1788 to 1820 kg/ m^3 until addition of ceramic tile dust of 20 %. The unconfined compressive strength was improved about 1.4 times for residual soil with 30 % of ceramic

tile dust. However, the optimum moisture content and plasticity index were reduced with addition of ceramic tile dust.

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