Geotechnical Characteristics of Soil Stabilised with Waste Steel Dust for Soil Improvement Works

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Abstract. This paper reports on the research carried out onto a kind of waste material from the medication supply industry viz, the waste steel dust. This research focuses on the potential of the waste steel dust as soil stabiliser agent based on strength improvement. Soil stabilisation is conducted to enhance the geotechnical characteristics of the problematic soil, such as marine clay soil. The engineering properties of the marine clay soil has been determined such as particle size distribution, particle density and plasticity of the soil. The soil sample was mixed and compacted with different amount of the waste steel dust i.e. 5%, 10% and 15% for compaction and strength test. Dry weight technique was used to prepare these samples. Standard Proctor Test has been executed to determine the Optimum Moisture Content (OMC) and Maximum Dry Density (MDD) of the stabilised soil sample. Meanwhile, Unconsolidated Undrained Triaxial Test (UUT) has been done to obtain the undrained cohesion, \( c_u \) of the stabilised soil. Findings from this study shows that additional of waste steel dust in the marine clay soil is unbeneficial, because as the content of the waste steel dust increased, the value OMC increased and both of MDD and decreased. Therefore, the waste steel dust alone incapable to become a soil stabiliser agent. However, based on the comparison with previous study, it is found out that the presence of activated agent could potentially increase the performance of the waste steel dust as soil stabilizer. Significant findings from this study would contribute additional literature knowledge related to soil improvement works using waste material.

1. Introduction

The definition of soft soil is given by soil with large fraction of fine particles such as silty and clayey soils, have high moisture content, loose sand deposits and located under the water table. Marine clay is other type of soft soil that originates from oceanic bed and is formed under shallow coastal saline water condition and tend to have high percentage of organic content. This type of soil cannot be used as foundation due to its poor engineering properties such as low in strength and permeability, excessive settlement, high compressibility, and swelling behaviour [1]. Furthermore, marine clay is not suitable as pavement or support because it will experience a volumetric change when heavy load is applied [2].

Soil stabilization is a well-known method to treat problematic soil to improve the geotechnical properties of the soil. Soil stabilization refers to the process of changing soil properties to improve strength and durability. There are many techniques for soil stabilization such as compaction, dewatering and putting additives as stabiliser to the soil. Soil stabilization techniques can be carried out through chemical, mechanical or biological methods. Among these three techniques, chemical methods were found to be the easiest, cheapest and reliable in enhancing the strength of soil. Various type of materials has been proved of being able to enhance the shear strength of soil by past researchers. The mechanical
behaviour of soil is improved by the pozzolanic reaction that occurs in between the stabilising agents with the presence of siliceous or a combination of siliceous and aluminous material react with calcium hydroxide \( \text{Ca(OH)}_2 \) to provide cementitious properties.

Soil stabilization is an on-going research where nowadays this technique reuses the waste material in order to reuse the waste as part of the efforts to ensure the sustainable development goal can be reached. Some of studies conducted on different soil stabilization techniques by using waste materials includes coir fiber [3], coconut fiber [4], fly ash [5], ground granulated blast furnace [6], and rice husk ash [7] etc. In this study, the waste produced from the medication supply industry, i.e. the waste steel dust has been investigated for the capacity as soil stabilization agent. The waste steel dust is categorized as SW104 by the Department of Environmental Malaysia, which consist of dust, slag, dross, or ash containing arsenic, mercury, lead, cadmium, chromium, nickel, copper, vanadium, beryllium, antimony, tellurium, thallium or selenium. This paper describes the results and effects of utilizing waste steel dust on the compaction and strength characteristics of marine clay soil retrieved from the northern region of Peninsular Malaysia.

2. Methodology

2.1. Sample collection

2.1.1. Marine Clay Soil
The soil sample was collected at a construction site in Seberang Jaya, Penang (5.3987° N, 100.3982° E). The sample was obtained from 7 meter depth using a boring machine. Index test was performed to determine the soil’s physical properties such as natural moisture content, particle size distribution, compaction characteristics, plasticity and specific gravity.

2.1.2. Waste Steel Dust
The waste steel dust used in this study was obtained from Abbott Medical Device Division (Previously Known As St. Jude Medical Operations Sdn Bhd). It is currently a manufacturing company that produces medical devices located at Bayan Lepas, Penang. The waste produced by this production is categorized by the Department of Environment (DOE) as SW104 group which consist of dust, slag, dross, or ash containing arsenic, mercury, lead, cadmium, chromium, nickel, copper, vanadium, beryllium, antimony, tellurium, thallium or selenium. About 85% of the waste consist of fine material passed through 150μm. The chemical properties of the waste dust is shown in Table 1.

| Parameter               | Unit | Result   |
|-------------------------|------|----------|
| Aluminum (as Al)        | mg/kg| 19       |
| Vanadium (as V)         | mg/kg| 2        |
| Arsenic (as As)         | mg/kg| ND(<5)   |
| Mercury (as Hg)         | mg/kg| ND(<5)   |
| Lead (as Pb)            | mg/kg| ND(<5)   |
| Cadmium (as Cd)         | mg/kg| ND(<0.5) |
| Chromium (as Cr)        | mg/kg| ND(<1)   |
| Nickel (as Ni)          | mg/kg| ND(<1)   |
| Copper (as Cu)          | mg/kg| ND(<1)   |
| Beryllium (as Be)       | mg/kg| ND(<0.1) |
| Antimony (as Sb)        | mg/kg| ND(<5)   |
| Tellurium (as Te)       | mg/kg| ND(<10)  |
| Thallium (as Tl)        | mg/kg| ND(<5)   |
| Selenium (as Se)        | mg/kg| ND(<10)  |

Note: ND (<MDL) denotes not detected for the value obtained is less than the Method Detection Limit (MDL) stated.
2.2. Soil Index Test

2.2.1. Natural moisture content
The soil sample was oven dried for 24 hours to obtain the percentage of water in the soil sample. Natural water content goes by the weight ratio of water over the weight of the solid in given soil mass. The percentage is used in expressing this ratio, as it is based on BS 1377: Part 2:1990:3.2.

2.2.2. Particle Size Distribution Test & Hydrometer test
Sieve analysis test is carried out to determine the amount and distribution of the particle size of the soil. The test is conducted by using sieve sizes; 2mm, 1.18mm, 0.6mm, 0.425mm, 0.3mm, 0.212mm, 0.15mm and 0.063mm based on BS 1377: Part 2:1990:9.2. for the particle size smaller than 0.063 mm, a 100g of soil sample were used for the hydrometer test.

2.2.3. Atterberg limit
Cone penetration test was done to determine the liquid limit, meanwhile the plastic limit is measured as the gravimetric water value, at which a soil sample can be manually rolled into a 3.2 mm diameter thread without splitting. The value of plastic limit and liquid limit will determine its Plasticity Index (PI), as a mean of classifying the cohesive soil.

2.2.4. Particle density test
This test was done by using three density bottles to obtain average result of specific gravity. The sample placed in the density bottle was placed in desiccator for 24 hours to remove entrapped air in the density bottle. After the required weigh of density bottle with soil sample have been obtained, the specific gravity of soil was obtained by calculated the mass of divided by mass of waster displaced by soil.

2.3. Compaction test
Compaction test was carried out to find the compaction characteristics i.e. Maximum Dry Density (MDD) and Optimum Moisture Content (OMC). This test use 2.5kg rammer and drop by height of 300mm. The sample was divided into three layers and was blow at 27 times each layer. The value of compaction moisture content is obtained from every type of sample. The passing soil was used for the hydrometer testing and the retained soil sample were oven dried to be used in sieve analysis test.

2.4. Preparation of sample
The soil sample was prepared for the strength test by mixing with pure water and varies percentage of the waste steel dust i.e. 5%, 10% and 15%. Table 2 shows the summary of sample prepared for the main experimental works. The percentages of waste steel dust used in this study based on previous study carried out on steel slag [8].

| No. | Type of Sample                  | % waste steel dust | Number of Sample | Compaction Test | UUT |
|-----|---------------------------------|--------------------|------------------|----------------|-----|
| 1.  | 100% soil (Control sample)      | 0                  | 1                | 1              |     |
| 2.  | Soil + waste steel dust         | 5                  | 1                | 1              |     |
| 3.  | Soil + waste steel dust         | 10                 | 1                | 1              |     |
| 4.  | Soil + waste steel dust         | 15                 | 1                | 1              |     |

2.5. Unconsolidated Undrained test (UUT)
In this type of triaxial test, both undrained and unconsolidated conditions were maintained. The size of mould used is 76 mm height and 39 mm diameter. The axial deviator stress is applied consecutively along the axial direction until it fails which this stress brings shear stress to the soil sample. The strain rate used was 1 mm/min. Mohr’s envelope developed after gaining the average undrained shear strength to obtain undrained cohesion intercept and angle of shearing resistance ($c_u$ and $\phi_u$ respectively).
3. Result and discussion

3.1. Physical properties of soil sample

Based on the soil index test conducted, the soil sample is classified as the soil is classified as Slightly Sandy Clay of Intermediate Plasticity (CI) based on British Soil Classification System (BSCS). Details of the soil index properties shown in Table 3.

| Soil Properties                     | Test Values |
|-------------------------------------|-------------|
| Colour                              | Dark Grey   |
| Natural Moisture Content (%)        | 103.06      |
| Specific gravity of soil            | 2.5         |
| Particle size distribution:         |             |
| a. Gravel (%)                       | 0           |
| b. Sand (%)                         | 12.53       |
| c. Silt (%)                         | 43.62       |
| d. Clay (%)                         | 43.85       |
| Liquid Limit, LL (%)                | 41.99       |
| Plastic Limit, PL (%)               | 23.14       |
| Plasticity Index, IP (%)            | 18.85       |
| Classification of soil              | CI          |

3.2. Compaction test

The plot of compaction curves where dry density against moisture content of the soil samples mixed with 5%, 10% and 15% of waste steel dust are shown in Figure 1. The summary of the value of OMC and MDD obtained from the compaction test is shown in Table 4.

![Compaction curves](image)

**Figure 1.** Compaction curves of the soil samples

Generally, the value of OMC is higher and MDD is lower as the quantity of waste steel dust increases. The possible reason for the reduction of the density was due to small specific gravity possess by the steel dust. Similar behaviour was observed on fly ash and cockle shell powder [9]. The high-water content separates the high-density soil particles from each other and thus decreases the maximum dry density.
Table 4. Optimum moisture content and maximum dry density of soil samples

| Soil Sample         | Optimum Moisture Content OMC (%) | Maximum Dry Density MDD (Mg/m³) |
|---------------------|----------------------------------|---------------------------------|
| Control Sample      | 19.73                            | 1.748                           |
| 5% waste steel dust | 20.22                            | 1.741                           |
| 10% waste steel dust| 20.50                            | 1.730                           |
| 15% waste steel dust| 22.30                            | 1.720                           |

3.3. Unconsolidated undrained test

3.3.1. Stress-strain curve.

Based on the UU test, the axial stress versus strain curves are plotted as shown in Figure 2, 3, 4 and 5 for different percentages of waste steel dust. Three different confining pressures were applied during the test series which are 50 kPa, 100kPa and 150kPa.

Generally, as the confining pressure rises, the axial stress increases until it reaches its ultimate failure at a constant value called residual strength. The stress-strain curve of all soil samples behaves similarly.
in which a non-linear pattern of the soft soil can be observed. The factors that differentiate the stress-strain behaviours of soil influenced by soil composition, soil structure, state, loading condition etc.

3.3.2. Undrained shear strength (Su) of treated marine clay soil.

Based on the magnitude of stress at failure obtained from the UU test, the undrained shear strength (Su) of the soil can be determined. The maximum stress from the stress-strain curves are identified as the stress at failure or also known as the major principle stress, $\sigma_1$. Meanwhile, the pre-determined confining pressure is termed as the minor principle stress, $\sigma_3$. Based on the value of major and minor principle stresses, the Mohr’s circle can be drawn for all the test series that has been carried out. For each series of test, three Mohr’s circle was plotted. Eventually, from the Mohr’s circle, the magnitude of undrained shear strength can be analysed. The undrained shear strength is determined from the interception of the tangent line of the three Mohr’s circle to the vertical axis of the plot shear stress versus normal stress.

In unconsolidated undrained test, theoretically all the Mohr’s circle will have the same radius, therefore the tangent line will be truly horizontal, giving a zero value to the friction angle. However, in this experimental works, the tangent line may not be truly horizontal, and the friction angle may not be zero due to random errors. Random errors were due to inconsistency of the respective samples that was not fully saturated during sample preparation. The magnitude of undrained shear strength for the soil sample mixed with different percentage of waste steel dust is shown in Table 5.

| Soil Sample                  | Undrained Shear Strength (Su) kPa | Friction angle, $\phi$ |
|-----------------------------|-----------------------------------|------------------------|
| Control Sample              | 80                                | 7.5                    |
| 5% waste steel dust         | 61.25                             | 0.0                    |
| 10% waste steel dust        | 46.25                             | 4.0                    |
| 15% waste steel dust        | 27.20                             | 0.0                    |

The magnitude of undrained shear strength reduced as the amount of waste steel dust added to the soil increased. Factors affecting the change in undrained shear strength are grain size distribute, clay minerology, initial water content, dry density, depth of soil, plasticity etc. [10]. At first, the presence of fine material allowed the voids to be filled between the coarse particles while providing more cohesive bonding without affecting the friction surface between the soil particles. As more fine materials added, it began separating the soil particles and thus acted as a lubricant [12]. Consequently, the friction angle decreased, thus reducing the shear strength. In this study, the added waste steel dust acting as lubricants, which could explain on the reasons why the strength of soil reduced as more waste steel dust added to the soil sample. Based on the observations on compaction and strength characteristics, it is noted that the waste steel dust is not eligible as soil stabilizer.

The lack in waste steel dust could possibly be enhanced by combining it with activated agent that could improve chances of the waste steel dust as soil stabilizer. For examples, Sodium Lignosulfonate could enhance the performance of steel slag to increase the strength of the soil samples [13]. This is due to the stabilizer act as additives meanwhile the activated agent binds and attract both soil and additives without decreasing the cohesion of soil thus increase in strength. Lime could also be used as a good activated agent, such as mixed of lime and fly ash will increase the soil strength [14].

4. Conclusion

The engineering properties of the soil sample collected from the study area are classified as slightly sandy CLAY of Intermediate Plasticity. The effect of adding the waste steel dust cause the Optimum Moisture Content (OMC) increases, the Maximum Dry Density (MDD) decreases and the Undrained Shear Strength decreases. Based on the observations on compaction and strength characteristics, it is noted that the waste steel dust is not eligible as soil stabilizer. The lack in waste steel dust could possibly be enhanced by combining it with activated agent that could improve chances of the waste steel dust as soil stabilizer.
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