Strength Development of Marine Clay Treated by Demolished Concrete Materials with Morphological Identifications

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Abstract Construction and demolition (C&D) waste nowadays increasing years by years, which eventually leads to environmental and financial problems. Hence, it is suggested to recycle the concrete materials obtained from demolished building activities for geotechnical engineering applications. This study focuses on recycling the demolished concrete materials (DCM) to stabilize the Nusajaya marine clay. In this research, unconfined compressive strength (UCS) test was performed on DCM treated marine clay at 5%, 10%, and 15% and different range of curing time, 7 days, 28 days, 60 days and 90 days respectively. In additions, microstructure analysis, such as EDX, FESEM and XRD has been done in order to verify the optimum results as obtained from UCS test. The result obtained shows the strength of DCM-treated marine clay increase from 87.9kPa to 403.6kPa in 60days curing period with 15% of DCM content. EDX analysis shows the increment of Ca2+ elements meaning the cementitious agent of treated marine clay increase, hence increase the strength of soil itself. Plus, FESEM image portrays the flaky pores of the untreated marine clay, reduce because more needle-like structure of DCM contents filled up the pores particularly at 15% of DCM content. In conclusion, DCM acts as stabilizers optimally within 7-28 days curing time at 15% of DCM content.

1. Introduction

The number of construction developments increase due to the increase in demand for houses and major building, especially in Malaysia. This is attributable to the increasing of Malaysian population as well as towards of Vision 2020 achievement. While the human is too busy fulfilling the needs and pursuing visions, the effects of those rapid developments of ecosystem often being neglected [1]. As mentioned by the Board of Engineering, it has been reported that illegal dumping cases which include construction and demolition waste shown high increment from 3 cases in 2001 up to 31 cases in 2005 [2]. Not only that, statistics from Hong Kong proved that landfills need to cover 13844 tons of waste daily in 2012 and also 5.05 million ton per year.[3][4]

Marine clay could be found abundantly around the coastal and offshore areas and also beneath the ocean bed [5][6]. According to [7] most of the construction activities recently happens to be built on the clayey soil as a matter of sub grade and sub base. However, in many cases, clayey soil considers as
problematic soil alike soft clays, musk, organic deposits and loose sand because they exhibit weak engineering properties [8] and portrays an inadequate sub grade performance which eventually may result in premature structural failure [9][10]. Other than that, marine clay is also known as weak soil due to its unstable properties such as low bearing capacity, high compressibility, soft and would swell when wetted and shrink easily when water is dissipated from it [11]. Thus, soil stabilizations are one of the best methods to improve the engineering properties of clay itself [12] and its mainly done with a purpose to modify the soil engineering properties such as to improve strength, the bearing capacity and their durability property of that particular weak soil [13]. As mentioned by [14], in some cases by a method of stabilization and soil compaction the strength of the subgrade is increased upon by mixing appropriate additives.

In conjunction with concrete and masonry constitute more than 50% of waste generated [14], reutilising this waste into fine particulate matter promotes dual benefits of saving landfill quota while at the same time reduce the usage of natural raw material for new construction activity [15]. This study, then focuses more on utilizing fine particles of demolished concrete materials to observe their stabilizing effects on Nusajaya marine clay.

2. Materials and testing programme
The main materials used for this study are natural marine clay and demolished concrete material which then will be added with different percentages; 5%,10%,15% of the soil. Each of the samples are then being cured for 7, 28 and 60 days.

2.1. Marine clay
The marine clay is obtained in the construction area of Nusajaya, Johor Bharu as shown in Figure 1. It was collected from a 2-3m depth. The clay obtained, was greenish black in colour and undesirable smell. The 2 mm marine clay used for test was air dried before any test has taken place. The fresh and original marine clay deposited on the site is taken to the Geotechnical Laboratory of Universiti Teknologi Malaysia for further experimental works. Table 1 summarizes the properties of Marine clay used in this study while Table 2 provides the chemical elements of marine clay according to [16].

![Image of marine clay at Nusajaya](image-url)
Table 1. Summary of marine clay properties

| Marine clay properties       | Value     |
|-----------------------------|-----------|
| Natural water content       | 50.99     |
| Specific gravity            | 2.083     |
| Free swell index            | 50%       |
| Liquid limit                | 47.05%    |
| Plastic limit               | 23.14%    |
| MDD                         | 1530 kg/m³|
| Optimum moisture content    | 24%       |

Table 2. Summary of chemical elements forming Marine Clay (After Mohd Yunus et al., 2014)

| Chemical elements | Amount(%) |
|-------------------|-----------|
| Al                | 13.67     |
| Si                | 21.91     |
| K                 | 2.02      |
| Ti                | 2.06      |
| Fe                | 5.11      |
| Mg                | 0.78      |

2.2 The demolished concrete materials
Grade 30 demolished concrete blocks as shown in Figure 2 are collected from the disposal site of Structural Laboratory, Faculty of Civil Engineering, Universiti Teknologi Malaysia. The demolished concrete is then being crushed and sieve up to 63µm to mix efficiently with the soil.

Figure 2. Grade 30 demolished concrete in cubes formed is used
2.3 Specimen Preparation
Soil samples which here refers to marine clay were sieved through 2 mm mesh sieve in order to prepare samples for UCS. Distilled water was used during sample preparation. All samples were prepared using 95% of the maximum dry density (MDD) from dry side and the corresponding optimum moisture (OMC) content in order to treat the samples before failure. The volume of the mold at which the samples were compacted and the MDD was used as reference during sample preparation. The predetermined values of DCM were measured to the dry mass of marine clay. Marine clay and DCM were mixed thoroughly and then distilled water was added and mixed until homogeneity was achieved. The mixing period did not exceed 5 minutes to minimise loss in water content. The mix designs of DCM were 5, 10, and 15% at which three UCS samples were prepared for each percentage to avoid errors during the test. The mixture of marine clay and tiles was compacted inside the mould (76 mm height and 38 mm diameter) using the hydraulic jack machine. A stainless steel plunger was used to extrude the samples from the mould. Samples were trimmed to remove the extra soil and wrapped with several layers of cling film in order to preserve the water content. Samples were placed inside air tight plastic containers and stored for curing inside a controlled humidity chamber. The humidity chamber temperature was 27 ± 2°C and the humidity was 97% ± 2%. Samples were cured for 7, 14 and 28 days before testing.

Microstructural tests such as Energy Dispersive X-Ray (EDX), X-ray Diffraction (XRD), and Field-Emission Scanning Electron Microscope (FESEM) test were done to support the result as obtained from UCS test as well as to identify any possible chemical reactions happened. EDX is an analytical technique used for the elemental analysis or chemical characterisation for both treated and untreated marine clay which in this study to identify any cementitious agents presence. In addition to compound verification, X-Ray Diffraction (XRD) is then further analyses the sample in order to determine the chemical elements presence in marine clay and DCM with specific strain, preferred orientation, or even crystallographic structure by using 2theta intensity. Lastly, FESEM helps to visualise very fines topographic details and changes for treated marine clay after 60 days curing time at desire magnifications.

3.0 Results and discussion
The results show the shear strength of both untreated and treated marine clay after 7, 28, and 60 days curing period with different percentage of DCM. The resulted is then supported by the microstructure analysis through SEM, EDX, and XRD.

3.1 Unconfined compressive strength
Effect of compressive strength of marine clay treated with DCM is determined based on different curing periods and various additions of DCM contents. Table 3 summarizes the value of compressive strength for both treated and untreated marine clays at 5%, 10% and 15% of DCM contents after selected curing periods.

| Percentage of DCM (%) | Curing Period(days) |
|-----------------------|---------------------|
|                       | 0       | 7       | 28      | 60      |
| 0                     | 87.9    | 87.9    | 87.9    | 87.9    |
| 5                     | 153.6   | 163.0   | 188.3   | 292.1   |
| 10                    | 173.4   | 210.0   | 320.6   | 327.8   |
| 15                    | 217.7   | 249.4   | 352.2   | 403.6   |
The results of the UCS tests carried out on DCM-treated marine clay at different curing periods are shown in Figure 3. It can be seen that strength increase with addition of demolished concrete materials with a maximum value of 403.6 kPa in 60 days of curing time. Figure 3 shows that the shear strength of all the treated specimens increased significantly compared to the strength of untreated Marine clay which in agreement with previous study [13]. Basically, strength increased with higher curing periods. It was found that, DCM can provide initial strength gained, where strength increase from 87.9 kPa to 153.6 with addition of 5% DCM contents immediately (i.e. 0 day) after mixing with marine clay. However, the slight increased in shear strength is observed at 7 curing days as compared to 0 day. At 28 days, only specimen treated with 5% DCM shows insignificant strength gained, while for 10% and 15%, the significant increased in strength is remarkable. Strength was increased from 320.6 kPa to 352.2 kPa. Investigation on strength development was continue at higher curing period of 60 days. Based on the result, it was found that, slight increased in strength of specimens treated with 10% and 15% strength as compared to 28 curing days.

The strength of treated marine clay gained due to the the frictional interaction between soil and DCM which correlation to the facts that waste materials consisting cementitious agent, particularly demolished concrete material act as an effective stabiliser for marine clay soil [17]. DCM obviously shows that it can be a great stabiliser to the marine clay even at only 5% DCM content added to the clay. Then, the cementitious agent present in the recycled concrete is well reacted with the clay itself as more curing time allocated [18].

Furthermore, it could be perceived that the strength of treated marine clay increase significantly as compared to untreated marine clay with the highest value of 403.6 kPa in 60 days. [19], quoted that the improvement of soil properties stabilized with demolished concrete could be due to it having the same reaction as lime or cement. As there is cement in concrete, this could be deemed possible. The increment of soil strength with increasing addition of cement is due to the hydration reaction of cement water which is the drying of soil-cement mix and the formation of cementitious product [18].

Based on the graph, at 15% DCM content increase from 28 day to 60 day eventually portrays highest strength compared to other curing period. Yet, according to [20] concrete has better cementitious agent as compared to other materials like aggregate and marble tiles. However, a little difference on strength increment is due to the a slight difference of DCM content. There is no significant increase might due to the only 5% of DCM being added to each of the samples. This is because DCM less distributed into the
marine clay which then resulting in poor workability as the air void in marine clay is not fully covered by the DCM content. This even common to other stabilisation process where the strength development required more cement additives to enhance more compressive strength as discussed by [21]. Thus, the DCM content approximately works at its best with the 10%, 20%, 30% of DCM content.

Effect of DCM content on shear strength of marine clay at different curing period is shown in Figure 4. There is a huge difference between untreated marine clay to 5% treated day at 60 days curing time. It shows that, at 60 day the reaction between DCM and marine clay getting better and helps in improving the marine clay strength even at 5%, as compared to other curing time. Other than that, the graph also illustrated there is slightly difference between 5% DCM content and 10%DCM content for each curing period, which means, DCM acts more when more DCM contents is added. Therefore, it can be conclude here, the untreated marine clay at Nusajaya posses about 88 kPa and become higher up to 403 kPa after 60 days curing time.

**Figure 4.** Effect of curing period on DCM content

**Figure 5.** Strength gained at different curing period
The experimental result plotted in Figure 5 shows the strength gained from 0-7, 7-28 and 28-60 day, at different percentage of DCM. The graph obviously shows, the strength gained gradually especially at 5% from 0 to 60 day curing time. This literally defines that the DCM reacts better on marine clay from time to time. 10% of strength gained try to imposed only a DCM still not binds friendly and closely with marine clay as it appears only a bit strength gained. However, the confidence rise as more strength regained with 15% of DCM content. Hence, this result correlant as [22], mentioned, additives reacts greater when more supplementary additives (which in this case is DCM) being added to the natural soil.

3.2 Microstructural Analysis

Microstructure analysis were carried out on untreated marine clay, DCM, 5%, 10% and 15% of treated marine clay at 60 days. Samples were chosen to test at 60 days as the highest strength for each addition of DCM contents was recorded at longer curing periods which is at day 60.

![Figure 6. FESEM images of Nusajaya marine clay at different magnification a) 20,000 magnification b) 15,000 magnification](image)

Figure 6 shows the microstructure of marine clay at different magnification. Marine clay structure appears to be flaky and have pores as could be seen in figure (a). While in figure (b) shows that the structure of the marine clay could be seen arranged as a book-like structure. The image appears as stated by [23] which soft soils like clay gives better soil structure due to presence of high organic content. Figure 7 shows the microstructure of demolished concrete material (DCM) with different magnification. The DCM structure shown in figure (a) and (b) is more of a needle-like shape with a few clumps.
Figure 7. FESEM images of Demolished Concrete Material (DCM) at different magnification (a) 20,000 magnification (b) 30,000 magnification.

In Figure 8, with 5% DCM content shows that DCM is filling up the pore spaces in between the marine clay structure. But there are still pore spaces in between as there are not enough stabilizer content mixed well. Research done by [24], cement tend to fill up the pore spaces in between the soil structure thus increasing its stability. Other than that, the flakiness of marine clay structure could still be clearly seen in this figure.

Figure 8. FESEM photography of marine clay stabilized with 5% DCM at 60 days.

Figure 9(a) shows that DCM is filling the pore spaces in the marine clay structure, thus making it denser and become more stable structure. At 10% DCM, it clearly appears there is a significant difference as compared to 5% addition of DCM. The pore spaces are now filled with hydration products. Moreover, figure 9(b), clearly shows an increase in DCM needle-like structure filling up the pore spaces. This is verify that significant strength increase happened at 10% DCM addition as compared to 5%. At 10%, it could be observed that the marine clay structure shows a reduction in terms of quantity. This is might due to the reaction of soil, water and cementation agent. [25] stated that stabilization of soil begins when mixing the soil with water and a stabilizer. On the other note, with the
presence of water and cementation agent the soil becomes a modified soil.

(a)  
(b)  

*Figure 9. Soil structure of marine clay treated with 10% at 60 days curing time at a magnification of  a)20 000x b) of 30 000x*

Figure 10 shows that the pore spaces are filled with 15% DCM content. With the addition of 15% DCM, it could be observed that the flakiness of soil structure could no longer be seen. Moreover the needle-like structure of DCM could be found abundantly in figure 10(b) as compared to 10(a). With increasing percentage of DCM used, the more cementation product present in the soil structure, hence improve the strength.

(a)  
(b)  

*Figure 10. Soil structure of marine clay treated with 15% at 60 days curing time at magnification of a)20000x b) 30000x*

Table 4 shows the result from EDX analysis which the main element that consist in both marine clay and DCM itself. According to [26], the cementation compounds are Ca, Mg, Al, and Fe. The adsorption/desorption primarily depends on valence element. The lowest cations are easily removal or replaced cation in soil particle [27]. Based on the EDX result, it could be observed that Si percentage decrease with increasing DCM percentages. While Ca percentage is increasing with the increment of stabilizer content. During ion exchange reaction of the soil with cementitious additive, cation of soil is replaced by cation of additive (Ca) and the thickness of double diffused layer is reduced. Hence, the
replacement of cations results in an increase in workability and strength of soil-additive mixture [28]

Table 4. EDX analysis shows the chemical elements presence in marine clay and DCM after 60 days curing period

| Element | DCM content added (%) |
|---------|-----------------------|
|         | 0         | 5         | 10        | 15        |
| Si      | 19.40     | 17.9      | 15.7      | 8.4       |
| Al      | 14.0      | 11.6      | 10.0      | 4.9       |
| Ca      | -         | 1.4       | 2.6       | 8.3       |
| Fe      | 0.3       | 1.7       | 0.7       | 0.8       |
| Mg      | 0.6       | 0.6       | 0.7       | 0.4       |

According to the XRD analysis as shown in Figure 11, the Nusajaya marine clay contain mineral quartz, illite, montmorillonite, and kaolinite. High content of kaolinite and illite may control the characteristic of Nusajaya marine clay. DCM contain minerals such as quartz, portlandite, cristobalite and calcite. Immediate reaction of treated marine clay by 5% DCM shows reduction of kaolinite and illite. Moreover, there are presents of ettringite in the mix. This is due to the result of hydration reaction. [29], mentioned that in the presents of calcium sulfate, there would be ettringite as an additional product of hydration.

![Figure 11. Comparison of XRD results for 60 days at different percentage of DCM](image)

4.0 Conclusion
In this study, the effect of demolished concrete materials on marine clay has been determined. The comparison was made between treated and untreated marine clay at different percentages of DCM content and at different curing periods. Based on the obtained result and analysis performed the following conclusions can be drawn:

- The higher the amount of DCM content, the higher the strength of treated marine clay. A compressive strength increase from 87.9 kPa to 153.6 kPa after 5% DCM content being added.
- The unconfined compressive strength of treated marine clay is then increased with addition of DCM.
The highest value of UCS is 403.6 kPa in 60 days with the addition of 15% DCM. But the highest strength increase for marine clay could be observed at 10% DCM addition at 28 days.

- Maximal strength gained is within the period of 7-28 days. While within the period of 28-60 days, the increment of strength starts to reduce.
- Based on FESEM, the DCM filled in between the pore clay spaces. With the increasing DCM addition, it could be observed that the flakiness of the clay material has decreased, but the needle-like structure of DCM increase. This concludes that by filling the pore, DCM helps in stabilised the soil cause the strength to be increased.
- EDX result obtained portrays the presence of Ca$^{2+}$ elements increase as the percentage of DCM increase. Ca$^{2+}$ elements proved that presence of cementitious agent from DCM cause to increase the soil strength.

Meanwhile, XRD result shows a reduction of chemical compound for marine clay which are kaolinite and illite. Calcium aluminium hydrate (CAH) exists as new chemical compound after treating with DCM. Thus, it can be concluded that DCM act as stabiliser due to the possible chemical reactions occur such as pozzolonic reaction in which cause the well development of soil strength optimally within 7-28 days.

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