The Effectiveness of Demolished Tile Material for Soil Improvement: A Review

E Hillary¹,*, F Pakir¹,², N A A Aziz¹ and A Madun¹,²

¹ Faculty of Civil Engineering and Built Environment, Universiti Tun Hussein Onn Malaysia, Batu Pahat, Johor, Malaysia  
² Research Centre for Soft Soil (RECESS)  
*Corresponding author: ernyzaeza@gmail.com

Abstract. Recently, many researchers have reported the effects of non-traditional additives, on soils geotechnical properties and proven these additives are extensively used to solve the problematic soil. However, there is a lack of publications on the fundamental microstructural behaviour of non-traditional additives treated clay soil soils and their influence on the engineering behaviour. Therefore, this paper focused on determining the improvement mechanism for stabilization and the performance of clay soil mixed with two types of additives: traditional and non-traditional additives, namely cement and Demolished Tile Waste (DTM). A microstructural study pH analysis had been conducted and reviewed to elucidate the stabilization mechanism. It also includes an unconfined compressive test, oedometer consolidation test and compaction test used to assess the stabilized soil’s engineering properties. The laboratory tests showed the effectiveness of the additive on stabilizing the soft clay by using DTM. The microstructural tests results indicated the formation of new mineral products in the mixtures, identified as sodium aluminosilicate hydrate (NASH) and calcium silicate hydrate (C₅H) for soils treated with DTM. In the nutshell, at an early period the selected additive had expected to increase the strength of soft soil. Thus, the application combination stabilizer helps to reduce cost for the geotechnical project.

1. Introduction
In the geotechnical field, the major problem faced in construction is soil characteristics such as soft soil, impacting any construction’s increment to have a huge settlement value. Soft soils are classified as problematic soils that are always associated with weak performance when loaded [1]. A settlement is one the critical issue which often occurs in road construction due to the impact of the poor soft soil as an embankment base. Settlement may occur if the highway is built on less stable lands and has a low bearing capacity, particularly clay soil. Clay soil is a type of soil that needs to be treated and improved before highway construction is undertaken.

There are various methods to solve issues associated with soft soil such as compaction, vibration, jet grouting, lightweight material or mixing the soil with any stronger materials to solve the problem. One of the innovative soil improvements that have been used widely nowadays is by chemical additives. However, different technique is required to produce the best idea to replace existing chemical soil improvement methods and produce better new material than previous research.

The soil stabilization by using chemical method categorized into two, which is traditional and non-traditional. Traditional additives are chemical stabilization method discussed in previous research from all the basic fundamental to details mechanisms and performances. Traditional stabilizers include...
cement, lime, fly ash and bituminous materials. Besides, the other category, non-traditional is any chemical additives that rarely have been used in the industry. Generally, granite tile ash, biopolymer, lignin, resin, enzyme, acid and ion are included as a type of non-traditional additives [2]. Non-traditional stabilizers are marketed in liquid and powder form by several companies [3]. According to [2], the variety of non-traditional stabilizers especially for liquid and powder form are becoming trendy due to their relatively short curing period, low cost and ease of application.

2. Clay Soil Behaviour
In any civil engineering construction, the most consideration required to be taken is to identify and investigate soil type. The reason is that nowadays, the increment of the failure due to soil failure has known widely. Soft clay soil is one of the problematic soils covering considerable parts of the earth including many coastal regions and low-land where frequently encountered in construction industry. Some of the strength problems and major behavioural associated with soft soils are excessive settlements, low strength, high plasticity, swelling, erodibility, high compressibility and sensitivity to environmental conditions [4]. Besides, clay soil also is a low very bearing capacity which is one of the problematic soils found in the development industry project [5].

Clay soil is occupying surficial areas and widely available; however, it is well known to be complicated and hard to deal with, especially as a foundation for various overhead structures. Hence, the soil needs to be improved with a stronger stabilizer for better performance under various loads. Also, as a modern-day trend nowadays, the development and reclamation of oceanic areas are drastically increase. One of the motives for developing marine structures is various, and they range from land scarcity to aesthetic requirements. Land scarcity in that mature and crowded area is one of the issues faced by Nusajaya, Johor Bahru in Malaysia for the expansion of the new development projects and existing civil structures. Despite, the aesthetic perception and the limited land aspect of the setting, the development of oceanic areas has dominated the Straits of Johor, which divides Malaysia from Singapore. The physical characteristics of the study area’s clay soil, are summarized and presented in Table 1 [6]. The physical characteristics are also including Malaysia and Singapore area.

| Physical Characteristics | Malaysia                  | Singapore                  |
|-------------------------|---------------------------|----------------------------|
| Lithology               | Fine grains (majority of silt and clay) |                           |
| Mineralogy              | Montmorillonite, kaolinite, illite | Kaolinite, smectite, illite |
| Color                   | blackish dark grey        |                           |
| Density, ρ (g/cm³)      | 2.70 – 2.80               | NA                        |
| Permeability, k (10⁻⁹ m/s) | 1.77 – 2.00               | NA                        |
| Plasticity Index, PI (%)| 19 -77                    | 40 – 60                   |

3. Demolished Tile Material
Granite tile ash can be found in demolished tile material (DTM). Granite tile ash is one of the huge wastes from cutting and grinding processes production. Construction sites and manufacturing factories are the main sources of granite tile ash production. Demolished Tile Material (DTM) is among huge wastage that seems to have a serious increment that needs a bundle of ideas for an early stage of environment protection. Since the waste of the DTM among the huge production which is ranked sixth, just after the concrete wastage, it is really important to reduce the waste, including its uses as soil improvement. DTM is among the popular wastes production in any construction industry around Malaysia.

3.1. Granite Tile Waste
The construction industry and manufacture factories produce a huge number of wastes from cutting and grinding processes. From these processes granite tile waste can be obtained. Granite tile waste is a fine particle, but the total accumulative from many projects and production contributes to a huge
amount of waste that finally can harm the environment if there is no early stage to handle it. Moreover, granite tile is considered a construction and demolition waste. This waste is obtained due to the transportation of the materials and inefficient handling as well as the inconsistency of the tile sizes that were really required a solution [7]. According to [8], the idea produced is to identify the granite tile dust performance to stabilize the soft clay. Granite tile dust also can be found in demolished tile material (DTM). This type of waste claims effectiveness as an environmentally friendly, green solution, and cost-effective for marine clay [8]. The non-biodegradable fine powder was obtained inside the granite tile waste that was presented in a dumped slurry.

Besides, granite tile waste is almost similar to granite fines. The materials are the same, but they might be-have slightly differently in terms of particle sizes. The particle sizes of it influence the effectiveness of granite waste for soil stabilization. Granite’s fines waste can be obtained through the polishing or cutting process of granite slabs in powder form. Then, the powder mixed up together with water will be stored inside the tanks [9]. Jigani granite industrial area, Bangalore, was the area where granite fines waste sources were taken [9]. Besides, from the study, the granite fines contained 44.47%, 51.03%, and 4.5% for sand-size particles, silt size particles and clay size particles respectively. The specific gravity of granite fines waste was 2.46. Figure 1 shows the grain size distribution curve.

![Figure 1. Grain size distribution curve of granite fines [9].](image)

Furthermore, fine granite waste is also identified as a large contribution to environmental pollutions. The granite fines disposal was one of India’s major issues [9]. The reason is that, the researchers were found that granite fines will affect the occurrences of health hazards, and at the same time, these wastes will also shorten the lifetime of the landfill.

3.2. Ceramic Tile Waste for marine Clay Treatment
Ceramic Tile Waste (CTW) is included as a type of material that used in the construction area. [10] identified that CTW had a low content of calcium with high alkali content. CTW was included as one of the alkaline-activated cement types. Due to this purpose, an alkaline aluminosilicate, N-A-S-H gel or product reaction as a three-dimensional structure influences durability and mechanical strength [11]; [12]. This alkaline aluminosilicate, N-A-S-H gel or the product’s reaction are different from calcium-silicate-hydrate and C-S-H gel that can be found from the OPC hydration [13]. However, a C-(A)-S-H gel can be formed by combining this gel with a small amount of aluminium.

3.3. Roof Tile Waste for marine Clay Treatment
In geotechnical engineering construction, and demolished wastes (CDW) and other waste materials incorporating cementitious materials and aggregates are widely used as a soil improvement purposes, including slope protections and foundation support. CDW acts as an aggregate in soil stabilization. Besides nowadays, roof tile waste (RT) in any development is widely applied. RT will be used for concrete production and manufacture of different building types such as ceramic blocks and bricks; an example can be referred from the previous study conducted by [14]. However, RT was also
implemented in some applications as a soil aggregate agent. RT will not be mixed up together with cement, since RT used as a soil aggregating agent [15].

4. Effect of tile waste additive on UCS limits of Soil

UCS is a mechanical test used to identify the strength of both treated and untreated clay soil when treated with different types of waste additives. Strength test data often are used to provide a baseline comparison between treated and untreated wastes. Demolished Tile Material (DTM) was used as filler. Based on previous research, [8] stated that less than 10% of DTM is unsuitable for improving the soil due to the less filler effect obtained. However, even though less than 10% is unsuitable for improving soil quality, they were identified that the optimum percentage was at 5% with 28 days of curing time with a very low increment [8]. Based on [16], the modification process was affected the strength development after 7 days was less significant. However, the process of stabilization could be related to the increment in strength of the treated soils rapidly at 28 days curing period.

Furthermore, the improvement in strength of the soil influenced of the roof tiles that are used in the construction industry. From the previous study, researchers [15] identify the effectiveness of soil-tile mixtures with cement addition toward the UCS. This research also stated that when the cement content increases, the strength is also increasing. When the RT amount increases, the strength is also decreasing along the increment RT made instead of adding additional strength to the ground. Furthermore, the additional of 9% cement and 5% (Figure 2 (a)) RT showed the strength of soil was 3523 kPa; while with the same content of cement mixed with 15% RT (Figure 2 (b)), 2580 kPa strength of soil was obtained. Lastly, with the same value of cement content, which is 9% mixed up with 30% of RT resulted that the strength value was slightly decreased with 2400 kPa (Figure 2 (c)). All of these results were referred from the previous study by [15]. The strength was slightly decreased with the increment of roof tile mixed up with the constant amount of cement from the study. On the other hand, [14] stated that RT also could be used as an aggregate because it was identified that RT aggregate could be as an internal water reservoir in order to increase the pore structure of concrete with a high-volume, 40% replacement of Class-F of wastes and to improve the compressive strength of the soil.

![Figure 2](image-url). Influence of cement content (a) 5%, (b) 15% and (c) 30% RT on the UCS samples. C denotes the cement content [15].
According to the previous study conducted by [17], they found that a stainless steel plunger was used by extruding each of the UCS samples inside it. The UCS tests were conducted for both sizes of Recycled Blended Tiles (RBT), which is 0.063 mm and 0.15 mm. Figure 3 shows the results of 0.063 mm particle size of RBT for treated marine clay. According to the graph, the strength of treated marine clay increases along with curing time increment. Evidently, from all mixed design of RBT size 0.063 mm, the highest strength achieved was 20% of RBT mixed up in marine clay. The highest value of mix design was 40% of RBT, but for this percent of mix design, marine clay’s strength only shows a slight increment. In a nut of a shell, the optimum percentage of 0.063 sizes of RBT was 20%.

![Figure 3. 0.063 mm RBT of UCS results for treated marine clay [17].](image)

Also, as for UCS results for 15% of RBT particles size, the optimum strength is different. This data was analysed by [17] and shown in Figure 4. From the graph, the optimum percentage of RBT was 30% after an overall comparison. The strength of the marine clay was increase corresponded with the increment of the curing time. Besides, for the highest percentage, 40% of 0.15mm RBT showed a slight increment from 0 day to 28 days of curing time. The graph presented that in 28 day curing time, the increment for both 10% and 40% had a very less different in strength. It means the 10% value of RBT almost has the same strength with, 40% of RBT. Lastly, for comparison purposes, Figure 3, which is for a particle size of 0.063 mm of RBT has a larger strength during 28 days of curing with 218 kPa UCS. Comparing with the 0.15 mm of RBT particle size, the highest value of UCS strength is only 190kPa.

![Figure 4. 0.15 mm RBT treated marine clay of UCS results [17].](image)
5. Effect of chemical additive on compaction parameters of the soil

The compaction test is an important test to identify a Maximum Dry Density (MDD) and Optimum Moisture Content (OMC). MDD and OMC for both untreated and treated can be determined. All of the samples preparation, must be done to avoid influences of these variables at the strength of stabilization soil, by controlling the bulk density and moisture content [18]. Based on the previous research [8] the relationship between MMD and OMC versus the percentage of DTM was shown in Figure 5. Besides, previous researchers [17] stated that the higher portion of DTM content affected the increment of MDD of the treated marine clay while the OMC value was decreased. A reduction of the value of water holding capacity in marine clay by an additional DTM is one of the reasons for the decrement in OMC value.

Moreover, [17] reported that the standard compaction tests were conducted for both untreated and treated marine clay, with different percentages divided into two different sizes of Recycled Blended Tile (RBT) which is 0.063 and 0.15. The mix design of RBT used in this study was 10%, 20%, 30% and 40%.

![Figure 5: Compaction parameters of marine clay treated with 0.15 mm DTM.](image-url)
Figure 6: MDD and OMC of marine clay treated with 0.063 and 0.15 mm RBT [1].

The result of MDD and OMC versus the different percentages of RBT are shown in Figure 6. The results show that when both 0.063 mm and 0.15 mm sizes of RBT increase, MDD and OMC’s value also increases. The other coarse particles with the decrement of OMC will influence the reduction of water holding capacity in marine clay. The higher MDD values influence by the larger size of RBT. Thus, improved compatibility in marine clay is related to RBT’s particle size used for soil stabilization.

6. Effect of chemical additive on pH of the soil
The pH value of marine clay is an important parameter to identify its strength and for improvement purposes. The BS 1377: Part 3, the samples and tests in [8] were respectively prepared and tested. This study was has investigated the effect of pH value to support the rapid strength decrement’s causes after the additional of DTM amount inside the marine clay. The graph shown in Figure 7 shows the results of pH for both treated and untreated marine clay soil with different percentages of DTM that were mixed up inside the marine clay. Based on the graph, the pH values were increased along with the increment of DTM percentages. Therefore, the reduction in strength was obtained due to the low H⁺ ion concentration [19]. The reading of pH value was 8.33, which is categorize as a slightly alkaline. The pH value reading is different from all different mix designs. From the graph in Figure 7 for 20% of the DTM mix design, the pH value shown an increment from 2.88 to 3.40. According to these results, the acidic environment will result in the reduction of strength in marine clay. The concrete reason is that it can explain the causes of strength reduction and the condition of the current climate in Malaysia and chemical compositions off acid rain. The acidic rain fall into the ground as a wet deposition consisted of SO₂ and NOx type of chemical [8]. Commonly, an infiltration of rainfall is high and its corresponding is also remarkably high, especially in Malaysia. Ca2+, Na+, K+, and Mg2+ are types of soil cations. These cations will be removed from the marine clay’s top surface due to the climate condition occurs. Then, if the cations were removed the soil will become more acidic. The reason is that the Al and Fe oxides concentration are also experienced a high increment inside the soil. Hence, the soil elements or particles will produce a strong bonding because they will rich with Al3+ and Fe3+. The surrounding marine clay used for testing should be identified; then the marine clay will be easily determined as an alkaline or acidic. Moreover, very high (high alkalinity) or very low (high acidity) soil pH accelerates the breakdown of soil particles and metals [3]. The pH values collected will be widely affected by the identification of the strength of marine clay soil [20]. The low pH value reading, also considered an acidic, will influence the reduction in strength of the marine clay [21]. Normally, the residual soils’ pH usually is in the rate of 4.5 to 6.0 [22].
7. Conclusions
In conclusion, it could be summarized that soil stabilization is one way to improve the engineering properties of soil, which may reduce the soil's weakness. Some researchers have concentrated their studies on the macrostructural such as plasticity, strength, and compressibility characteristics of the treated soil with non-traditional additives. However, a clear lack of understanding regarding the correlation between macrostructural and microstructural assessment of clay soil mixed with these non-traditional stabilizers is apparent in the literature. In this study, an effort was made to recognize the responsible mechanisms to enhance these additives mixed with the clay soils.

8. References

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