Ceramic Dust Based Binder for Sustainable Stabilisation of Low Flood-Plain Soil

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Abstract. The main objective of this study is to investigate the potential use of ceramic dust, by-products from manufacturing industry as a binder in the stabilisation of Laterite Soil. Laboratory investigation involving fabrication of soil cylinders of laterite soil stabilised with 100% CD and combination of CD with traditional binder Lime and PC at 50:50 ratio at 10%, 20% and 30% stabiliser dosage. The compacted cylinders were cured for 7, 28, 60 and 180 days prior for testing. The results from this study illustrated that all key parameters of compressive strength, durability and linear expansion were within the acceptable engineering standard of soil stabilisation. When using blended binders, it further enhances the engineering properties of stabilised material. From the environmental and sustainability, this cementitious technology anticipated that this new innovative stabiliser can be used in low flood-plain soil to mitigate the effect of flooding.

1. Introduction
The most serious problems in the field of foundation engineering are the changes of water content of some clay soils. These changes may cause undesirable movement of structures particularly for road pavements and building foundations. Since decades, soil engineers have been reported the problems correlated with low-load bearing soils. Thus, in order to produce an improved soil material which has the desired engineering properties, it is essential for the soil to gone thorough alteration of their engineering properties. Either by doing the alteration by mechanical or chemical, this process is called as soil stabilisation. The purpose of soil stabilisation not only limited to enhance the load-bearing of the soil capacity but also improve shear strength, permeability, enhance soil resistance to the weathering process and traffic usage to meet specific engineering projects requirement.

The treatment of these low load-bearing capacity soils is not always easy or economical especially dealing with soft subgrade soil is one of most major problems moreover, with the presence of water due to flood disaster will tremedously affect the nature and stability of this soils that significantly contribute to the changeable behavior of its condition [1]. In order to cater this issue, there is a need for soils alteration to improve the engineering properties. The conventional methods such as removing the soil and change for remediation is costly and unsustainable. The best way is to use locally available materials through sustainable cementitious technology with are more sustainable [2]-[5].

Although the conventional soil stabilisation using lime and/or cement is well established, there is also a need of alternative cementitious technologies which are more sustainable, environmentally friendly economical and relatively cheap or free. At present, searching for the best stabiliser to overcome problems occur by the soft soils are becoming the main concern. Instead of using chemical product,
utilising the industrial waste by-products may offer more economical alternatives for a wide range application of soil stabilisation [1]. There are various industrial by-products that being utilised for stabilisation of soils such Copper slag [6]-[8], Tile Waste [9], Steel Slag [10], Saw Dust Ash [11], Foundry Sand Waste [8] are some of the prominent waste materials which has been successfully utilised for soil stabilisation. This paper aims to investigate on the innovative soil stabilisation approach utilising industrial wastes Ceramic Dust as based for binders for the application on the low-flood plain.

2. Materials and Methodology
Laterite Clay was used as the target material for the investigation. It was taken from a construction site in Shah Alam, Selangor. The soil is known to have high content of secondary oxides of iron or aluminum or both. Additionally, it is nearly of bases and primary silicates, but it may contain large amount of quartz and kaolinite. The mineralogical studies by Arinze (2015) showed that LC contains Iron Oxide minerals such as goethite (HFeO\(_2\)); lepidocrocite (FeO[OH]) and hematite (Fe\(_2\)O\(_3\)).

| Table 1. Some Common Properties of Laterite Soil (LS) |
|-----------------------------------------------|
| **Material** | Moisture Content (%) | Liquid Limit (%) | Plastic Limit (%) | Plasticity Index (%) | Max. Dry Density (Mg/m³) | Compressive Strength (kN/m²) |
| Laterite Soil | 6.41 | 41.4 | 23.5 | 17.5 | 1.66 | 220-623 |

2.1 Stabilisers
Ceramic Dust (CD) was used as main stabiliser supplied by Guocera Tile Industries Sdn. Bhd. in the form of sludge. It was then dried at room temperature and crushed into powder form. Portland Cement (PC) were manufactured by YTL Cement Sdn. Bhd., Malaysia and Lime was supplied by MCB Industry Sdn. Bhd. Table 2. Shows some oxide composition of material used in this investigation

| Table 2. Oxide composition of Target material and stabilisers |
|-----------------|-----------------|-----------------|-----------------|-----------------|
| Oxides          | LS              | CD              | Lime            | PC              |
| SiO\(_2\)       | 26.51           | 45.26           | 0.9            | 9.67           |
| Al\(_2\)O\(_3\)  | 33.26           | 18.32           | 0.15           | 4.70           |
| Fe\(_2\)O\(_3\)  | 21.56           | 13.7            | 25.97          | 25.29          |
| CaO             | 0.3             | 8.36            | 69.09          | 49.38          |
| MgO             | 1.13            | 5.59            | 0.46           | 4.21           |
| CaCO\(_3\)      | -               | 56.77           | 2.20           | -              |

2.2 Mix Compositions
LS were stabilised using 100% CD as binder and the combination of CD with traditional stabiliser Lime and PC (CD:Lime and CD:PC) 50:50 ratio at 10%, 20% and 30% stabiliser dosage. The mix design composition and mix code are presented in Table 3.

| Table 3. Mix Design Composition |
|--------------------------------|
| Target Material | Mix Code | Stabiliser | Ratio (%) | Dosage (%) |
|-----------------|----------|------------|-----------|------------|
| 2 |
2.3 Methodology

Soil cylinder of 50mm diameter and 100mm in height were fabricated from dried LS mixed with the different stabilisers as illustrated in Table 4. All cylinder sample were fabricate based on formula; $T + sT + W(T+sT) = 380g$. Where $T =$ Target Soil, $s =$ Stabiliser, $W =$ Water. The blended dry materials comprising of LS, CD with Lime or PC were mixed thoroughly prior to adding pre-determined moisture contents based on a proctor compaction test as accordance to BS 1377 to establish the Optimum Moisture Content (OMC) and Maximum Dry Density (MDD) of the material. After mixing these materials were placed in a steel mould fitted with a collar then subjected to a static compression using a hydraulic compacter. The cylinder was then extruded using hydraulic jack. The cylindrical specimens were wrapped with cling film and placed in plastic containers for 7, 28, 60 and 180 curing period. Three cylindrical specimens per mix composition were subjected to Unconfined Compressive Strength (UCS) test as compliance with BS 1377-7:1990. One cylinder sample was set-up in a Perspex container for linear expansion test. For durability Index test, two cylindrical specimens were weighted before completely soaked in water for 4-days to investigate the effect of flash flooding. This was followed by another UCS test and the strength values compared with baseline values obtain from UCS test conducted on the un-soaked specimen equivalent as a percentage for durability index (DI) using formula:

$$DI = \frac{UCS \text{ value for soaked specimen (S)}}{UCS \text{ value for unsoaked specimen (US)}} \times 100$$

(1)

UCS test were performed using CBR Test machine with capacity of 30kN with dynamic mode 200 points per second (Figure 1)

![Figure 1. Apparatus for Linear Expansion and UCS Test](image)

3. Results and Discussion

3.1 Control System LS+100% CD

Figure 2 (a), (b) and (c) shows the UCS, Durability Index (DI) and Linear Expansion (Lexp) test of LS+100% CD only as control system. It is clearly shown that stabilised LCD did not perform in both strength development, durability index and imbibe sufficient of water through linear expansion. Increasing the stabiliser dosage from 10% to 30% marginally increase the UCS with prolong curing period to 180 days. Durability Index is also recorded below 10% and Linear expansion were about 2.2% all stabiliser dosage used. This is hypotheses as because there is insufficient lime to produce significant
amounts of cementing reaction products allows for modification, with little or no stabilisation during the curing process.

3.2. Unconfined Compressive Strength (UCS)

Figure 3(a) and (b) illustrate the UCS for LS stabilised with CD combined with Lime (LCDL) and CD combined with PC (LCDP) at (50:50) ratio respectively. Both systems using identical stabiliser dosage of 10%, 20% and 30%. Generally for both systems, strength developed tremendously as stabiliser dosage and curing period increased. Early strength of 7 days curing for LCDL was lower at about 1000 kN/m² for all stabiliser dosage compared to LCDP, which recorded about 2236 kN/m² for 30% stabiliser dosage. The strength developed dramatically along all curing period especially at 180 days of curing. At prolonged curing period of 60 and 180 days LCDL system shown better strength values compared to LCDP system. Lime in the system enhances the formation of strength contributing silicate (C-S-H) and aluminate hydrates (C-A-H) from the hydration of clay-lime system.

3.3. Durability Index (DI)

Figure 4(a) and (b) shows the Durability Index of LCDL and LCDP systems respectively. For durability Index test, specimens were cured for 7, 28, 60 and 180 days prior to fully soaked in the water for 4 days. This is to simulate of flash flood in the low flood-plain situation. Generally the DI for both systems is identical to UCS test results which increasing the amount of stabiliser, increased the DI for both system and increased curing period marginally increased the DI. To compare two systems, again LCDL system recorded higher DI, means that stabilisation of LS with lime is more durable in case of flooding but LCDP is more consistent. Incorporation of 30% stabiliser dosage gives higher DI in both systems.
3.4. Linear Expansion (Lexp)
Figure 5(a) and (b) illustrate the linear expansion of LCD$_{L}$ and LCD$_{P}$ systems. Linear expansion was monitored for 100 days. Readings were recorded every day for the first 10 days and then weekly readings were taken. For both systems, high rate of absorption occurs during the first 10 days of soaking. LCD$_{L}$ system recorded higher linear expansion, which is about 2.2% compared to LCD$_{P}$ system that only absorb about 1.2% of water.

4.0 Conclusion
The introduction of CD as blended stabilisers CD:lime, CD:PC to LS clearly increases the compressive strength of the clay soils. Increased amounts of stabiliser dosage from 10% to 30% generally resulted in increased unconfined compressive strength and durability index with increasing curing period for stabilised LS especially in the prolonged curing of 180 days. Over a 100-days period, stabilised LCD$_{P}$ system exhibited less expansion compared to those specimens LCD$_{L}$ system and specimen stabilised using 100% CD. This study has shown that Ceramic dust based binders can be produced using a combination of CD, blended with Lime or PC with appropriate ratios. It also indicated that there is an increasing number of potential non-traditional sustainable soil stabilising agents for the better strength and durability achievement of low-load bearing capacity soil. Laboratory investigation of cylindrical soil specimens of LCD$_{L}$ and LCD$_{P}$ system recorded better engineering performance compare to stabilised LS with CD alone.

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