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STABILIZATION OF KAOLINITIC CLAY SOIL USING SILICA FUME, EGGSHELL ASH AND LIME

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ABSTRACT: Soft kaolin clay is a problematic soils encountered in various construction projects that lead to the implementation of soil stabilisation. The utilisation of industrial and agricultural wastes in altering the characteristics of kaolinitic soil can be considered as an ideal solution to enhance the characterisation of problematic soils in the field of construction. To assess the impact of silica fume, eggshell ash, and lime on the various characteristics of kaolinitic soil, a series of laboratory experiments containing Atterberg limits, specific gravity, compaction test, unconfined compression test, X-ray fluorescence, X-ray diffraction, sieve analysis, and field emission scanning electron microscope is carried out. In this study, 2%, 4% and 6% of silica fume, 3%, 6% and 9% of eggshell ash and lime and the optimal combination of silica fume, eggshell ash with 3%, 6% and 9% of lime are used. The results present that the optimal utilization of silica fume, eggshell ash, and lime can alter the engineering characteristics of the soft kaolin clay by reducing the specific gravity, consistency limits, linear shrinkage, and maximum dry density, while increasing the value of optimum moisture content. In terms of strength improvement, the highest unconfined compression strength was recorded when soft kaolin clay was treated with 6% silica fume, 6% eggshell ash and 9% of lime is 81.03%. Therefore, this study concludes that optimal use of silica fume, eggshell ash, and lime can alter the characteristics of kaolinitic soil and open the way to economical and sustainable materials in improving the problem soil.

Keywords: Eggshell Ash, Lime, Silica Fume, Soft Kaolin Clay, Soil Improvement.

1. INTRODUCTION

Kaolinitic soil is among the complex soils faced in construction projects [1] and recognized for its problematic characteristics due to the volumetric alterations corresponding to the modifications in the dampness regime [2]. Some of the main engineering characteristics and resistance problems associated with these soil forms include severe settlement, low welding resistance, insufficient plasticity, greater compressibility, dispersion, expansion, erosion, and resistance to climate variables [3]. Furthermore, the consequent calamities and estimated expenses of recovery and reconstruction of structures based on the problematic soils are a national concern [4]. Kaolin among the most common types of clay minerals [5]. Kaolin are the most sensitively distributed high-resistance clays between each other [6]. Hence, unstable soils, such as soft clay soils, were altered to change technical properties and increase soil cutting strength [7]. For this reason, previous researchers suggested several methods, such as soil stabilization [8], soil improvement, [9] and, etc. in altering the characteristics of kaolinitic soils.

Soil improvement is executed to allow improving the existing material characteristics to satisfy the construction designation [10]. Among the latest approach to soil improvement is to substitute disconcerted soil with material such as concrete, geotextiles, and geocross sections [11]. Recent investigations have highlighted the use of waste from industrial in various development projects as a cost-effective construction supplies option [12]. Many researches focus on the utilisation of industrial waste, such as fibre waste, sludge, fly dust, rubber chips, etc. as a substitutes for soil improvement [13]. Furthermore, previous researchers have also focused on the utilisation of pozzolan in the manufacture of composite cement. Pozzolan, for example, igneous ash [14] and fly ash [15, 16] are notable additional cement substitution materials owing to the rich content in silica, substantial availability, and manifest pozzolanic responsiveness. Nevertheless, agrodegradable products have currently captivate the attention of researchers owing to the enormous availability of waste in this field [17,18].

Therefore, the agroresidue material utilized as soil improvement binder is eggshell waste (ESA). Egg shells commonly called calcite ($CaCO_3$) contain calcium carbonate [19] can be used to decrease cement in concrete manufacturing [20]. There is a minor growth in egg production around the world and it is essential to deliver an overabundance of more than 9 million tons of eggshell waste every year. The total number of eggs consigned in Canada and France is by and large more than 2 billion and 1 billion individually. Prudently, 6500 tons of calcium carbonate powder are imparted from 1 billion eggs [21]. 8979 million eggs were depleted in 2011 and this figure had been enlarged to 12235 million eggs in 2017 and it is required to rise strenuously in the imminent years [22]. Approximately 150 thousand tons of eggshell waste is conceived in dumpsites [23]. Therefore, it could be shown that as the common inhabitants continue to produce, eggshell waste increases substantially [24]. Hence, owing to the large generation of eggshell waste, the eggshell waste were assessed and utilised as ideal materials to alter the characteristics of kaolinitic soils blends with silica fume and lime using the soil improvement technique. Nevertheless, it is extremely difficult to discover a producer that can recycle the ESA owing to the latest material implementation utilised in the construction development projects [20].

2. RESEARCH SIGNIFICANCE

Consequently, the environmental benefits of egg shell ash can be linked to the elimination of the need to dispose of eggshell waste at landfills as an alternative supply of raw materials when used as a replacement for traditional fragile aggregates. Using egg shell ash as a sustainable substitute for soft clay soil to improve soils must be thoroughly understood about the characteristics of egg shell ash and its effects on the characteristics of kaolinitic soil. The utilization of silica fume and egg shell ash with lime can provide an ideal and sustainable solution in cement replacement material as it can reduce the pollution by reducing the production of waste in the landfill and reducing carbon dioxide emission to the environment.

3. MATERIALS AND METHODS

3.1 Materials

Fig. 1 illustrates the location of the kaolin, SF, ESA and lime used in the study. Kaolinite is a clay mineral that has a water-resistant polymer structure and tends to mix and wet with water and form sludge to generate uniform soft clay. Table 1 demonstrates the basic characteristics of the soil used in this study.

Silica fume, produced as a by-product in the production of silicon in the electrometallurgy industry, is a substance with high pozzolanic value as a result of its high content of amorphous silica. The SF used in this study was a concrete-densified SF, Scanfume, with a surface area of at least 1500 m^2/kg. The reaction reactivity of pozolanic reactions is affected by the overall surface area of SF. As the total surface area is larger, the reactivity is higher [25].

The massive availability of egg shell waste was the main reasons why egg shell ash was chosen as a stabiliser in this study. It is also more sustainable than other normal soil stabilisers such as cement and others [28, 26]. Lime was used as one of the soil stabilisation materials together with SF and ESA.

3.2 Experimental Design

3.2.1 Sample Preparation

Laboratory tests were performed on the kaolin, silica fume (SF), eggshell ash (ESA), lime (L), mixtures of kaolin with SF, mixtures of kaolin with SF and ESA, mixtures of kaolin with SF and lime, and mixtures of kaolin with SF, ESA and L. Soft kaolin clay was oven dried using the universal oven at 105 °C for one (1) day and after that was admixed with various percentage of SF (2%, 4% and 6%) by the overall dry weight of the soil. The kaolin-SF mix was induced with different percentages of ESA (3%, 6% and 9%) and L (3%, 6% and 9%) by the total weight of dry soil. The ESA used in this investigation was the calcined product of raw chicken egg shells that were thoroughly cleaned with tap water, followed by air drying for 7 days.

The air dried egg shells were then crushed using a jaw crusher and then calcined at 800 °C for 60 minutes in the chamber furnace. The ESA was then kept in a desiccator for one (1) day for a cooling process. After that, an ESA was stored in an airtight container. The percentage of SF-ESA and SF-lime adopted in this investigation was selected based on Hasan et al. [25] and Zaini et. al., [26].

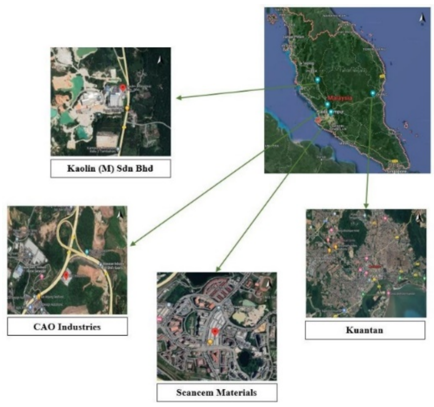

Fig.1 Location of kaolin clay, silica fume, eggshell ash, and lime used in this study.

3.2.2 Determination of Physical Properties

Atterberg limit and specific gravity are the physical properties examined in this study. The plasticity range of clay soil can be quantify numerically with Atterberg limits. Kaolin clay soil tend to materialise in four (4) states: solid, semi-solid, plastic, and liquid depending on a certain moisture content. Using cone penetration methods, liquid limit tests and plastic limit test were performed in accordance with BS 1377: Part 2: 1990 [27]. The term plasticity index [27] is derived from the numerical subtraction between the liquid and plastic limits.

Small-scale pycnometer test was utilised to determine the specific gravity of the treated and untreated soft kaolin clay. Soft kaolin clay were placed in a small pycnometer bottle, with half of the bottle are already filled with distilled water and was then placed in a vacuum room for one (1) day. The vacuum chamber was used to remove air in the sample containing distilled water and the mixture of the material. Lastly, the mass of the pycnometer was measured.

3.2.3 Determination of Mechanical Properties

The mechanical properties of the materials used in this study are examined via standard compaction test. Through this test, the optimal moisture content (OMC) and the maximum dry density (MDD) for treated and untreated soft kaolin clay was determined according to BS 1377-2:1990 [27]. Three (3) layers were compacted by a free fall hammer method with 25 blows per layer. The OMC and MDD were determined from the graph plotted between the dry unit weights against the moisture content.

3.2.4 Determination of the Undrained Shear Strength

The unconfined compression test (UCT) was performed according to ASTM E1621-16 [28] to determine the strength of the soil. In this test, the data on the axial load of the failure and the corresponding axial stress were recorded together with the failure mode pattern. Tests were carried out with 2%, 4%, 6% SF; 6% SF with 3%, 6%, and 9% of ESA and L; 6% SF and 6% ESA with 3%, 6% and 9% of L.

3.2.5 Determination of Morphological Characteristics

The sieve analysis was performed in accordance with BS 1377: 2: 1990 [27] and the hydrometer analysis was performed in accordance with ASTM D422 [29]. The grain size distribution of fine soil, was determined by performing the hydrometer test. Besides, the sieves used to analyse the particle sizes of the untreated and treated soft kaolin clay were 20 mm, 10 mm, 4.75 mm, 2.36 mm, 1.18 mm 0.6 mm, 0.3 mm, 0.15 mm, and 0.063 mm.

A distribution curve was then plotted with the percentage of particles retained in each sieve. In this research, dry sieve analysis was selected. The percentage passing versus the particle size results were plotted in the semi-logarithmic graph. The results of the treated and untreated soft kaolin clay were utilised to determine the similarity of the soil material with the group in the classification system.

4. RESULTS AND DISCUSSION

4.1 Physical Properties of Soil

Fig. 2 presents the specific gravity of four (4) different types of soft kaolin clay treatment compared to the untreated kaolin clay and SF, ESA and L. Based on Fig. 2(a), the specific gravity of the soft kaolin clay when treated with 2%, 4% and 6% of SF is significantly higher than the raw SF with a different margin (MD) of 0.21, 0.18 and 0.17 while slightly lower than the untreated kaolin clay with an MD of 0.10, 0.13 and 0.14. Inclusion of SF in the soft kaolin clay treatment leads to the reduction of the specific gravity of the soft kaolin clay as the portion of the SF increases. Similar investigations have been revealed by Zaini et al. [26] for the utilization of SF in the soft kaolin clay treatment.

Furthermore, similar trending was observed when the soft kaolin clay was treated with different ESA, L and the combination of ESA-L (see Fig. 2(b) to Fig. 2(d)). The highest reduction in specific gravity was observed when soft kaolin clay was treated with the combination of 6% SF, 6% of ESA and various percentages of L (K6SF6ESA3L, K6SF6ESA6L, and K6SF6ESA9L) with a specific gravity value of 2.51 (4.92% reduction), 2.45 (7.20% reduction) and 2.38 (9.85% reduction). 3.41%, and 4.55% for the utilization of L.

Based on Fig. 3(a), the use of SF slightly decreases the PL and LL of the soft kaolin clay at 2% and 4% from 33.3% to 29.8% and 31.6%; from 40.9% to 37.1% and 38.4% while further inclusion of SF at 6% increases PL and LL up to 34.5% and 41.1% with an MD of 1.2% and 0.2% . The PI of the SF treated kaolin sample continuously decreases at 2%, 4% and 6% from 7.6% to 7.3%, 6.8% and 6.6%. Therefore, the PI of the treated soft kaolin clay was diminished with respect to increases in the SF content, resulting in an increase in soil workability. There were continuous increases in PL with an increase in the SF content at 6% of use, a reaction that may be owing to the cation interchange that takes place between clay minerals of kaolin and positive cations in SF [30].

The increase in LL at 6% of SF was due to an expansion of disperse dual layer (articulation related to hovering cations and a small amount of anions around kaolin clay molecules) created by an increase in the particular surface area which then increases the water retention capacity of the soft

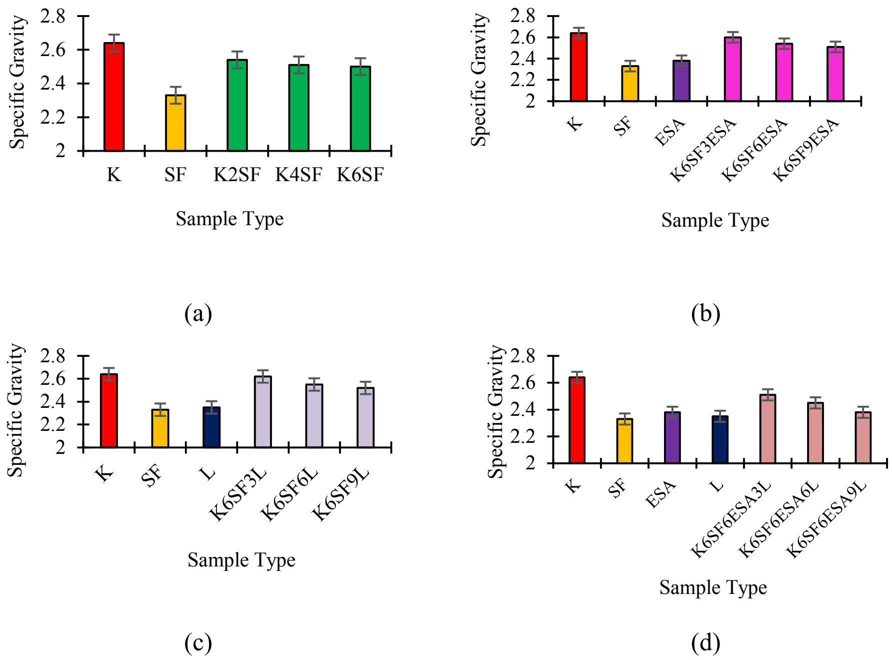

Fig. 2. Effect of different ratio of: a) SF; b) SF-ESA; c) SF-L and; d) SF-ESA-L to the specific gravity of the soft clay treatment. SF, Silica Fume; ESA, Eggshell Ash; L, Lime; 2, 3, 4, 6 and 9, percentage of stabilizer utilized in the soft kaolin clay treatment.

kaolin clay. The depletion in plasticity characteristics of the soft kaolin clay can be ascribed to the substitution of highly plastic clay molecules with non-amiable SF molecules. Furthermore, the inclusion of SF in soft clay soils causes flocculation, thus diminishing the plasticity index. Identical scenarios have been investigated by Hasan et al. [25] and Türköz et. al., [30].

4.2 Mechanical Properties of Soil

The relationship between MDD and OMC of soft kaolin clay treated with various ratios of SF, ESA, and L is illustrated in Fig. 4. The MDD for untreated soft kaolin clay was 1.55 g/cm^3, with an OMC of 21%, which is in the range of values stated by Bozyigit et al., [31]. Based on Fig. 5, when soft kaolin clay was treated with 2%, 4% and 6% SF, the reduction of MDD and OMC was initiated in the K2SF sample with MDD and OMC of 0.04 g/cm^3 and 3.0%, then gradually increases in MDD when 4% and 6% of SF were utilized with MDD of 1.51 g/cm^3 and 1.52 g/cm^3 while OMC constantly decreases to 17.5% and 17.9%.

The increase in OMC was proportionally restricted. Suppose that the lower value of specific gravity and the coarser particle sizes of the SF resulted in the additional void volume developed. However, the result obtained was not in good agreement with the investigation conducted by Türköz et al. [30] in terms of particle size, which

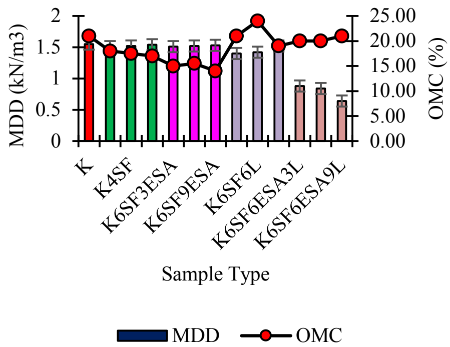

Fig. 4. Relationship between OMC (%) and MDD (kN/m^3) of the untreated and treated soft kaolin clay

shows that the utilisation of the 2%, 4% and 6% of SF does diminish the specific gravity of the soft kaolin clay, but do not significantly affect the particle size of the soft kaolin clay, resulting in the slight reduction of OMC in the various utilisation ratio of SF.

At optimum utilization of 6% of SF, soft kaolin clay was further treated with 3%, 6% and 9% of ESA and L individually and in combinations of ESA-L, resulting in a significant reduction in MDD with a MDD value of 1.51 g/cm^3, 1.52 g/cm^3, 1.53 g/cm^3; 1.40 g/cm^3, 1.42 g/cm^3, 1.52 g/cm^3 and 0.88 g/cm^3, 0.84 g/cm^3 and 0.64 g/cm^3 from 1.55 g/cm^3

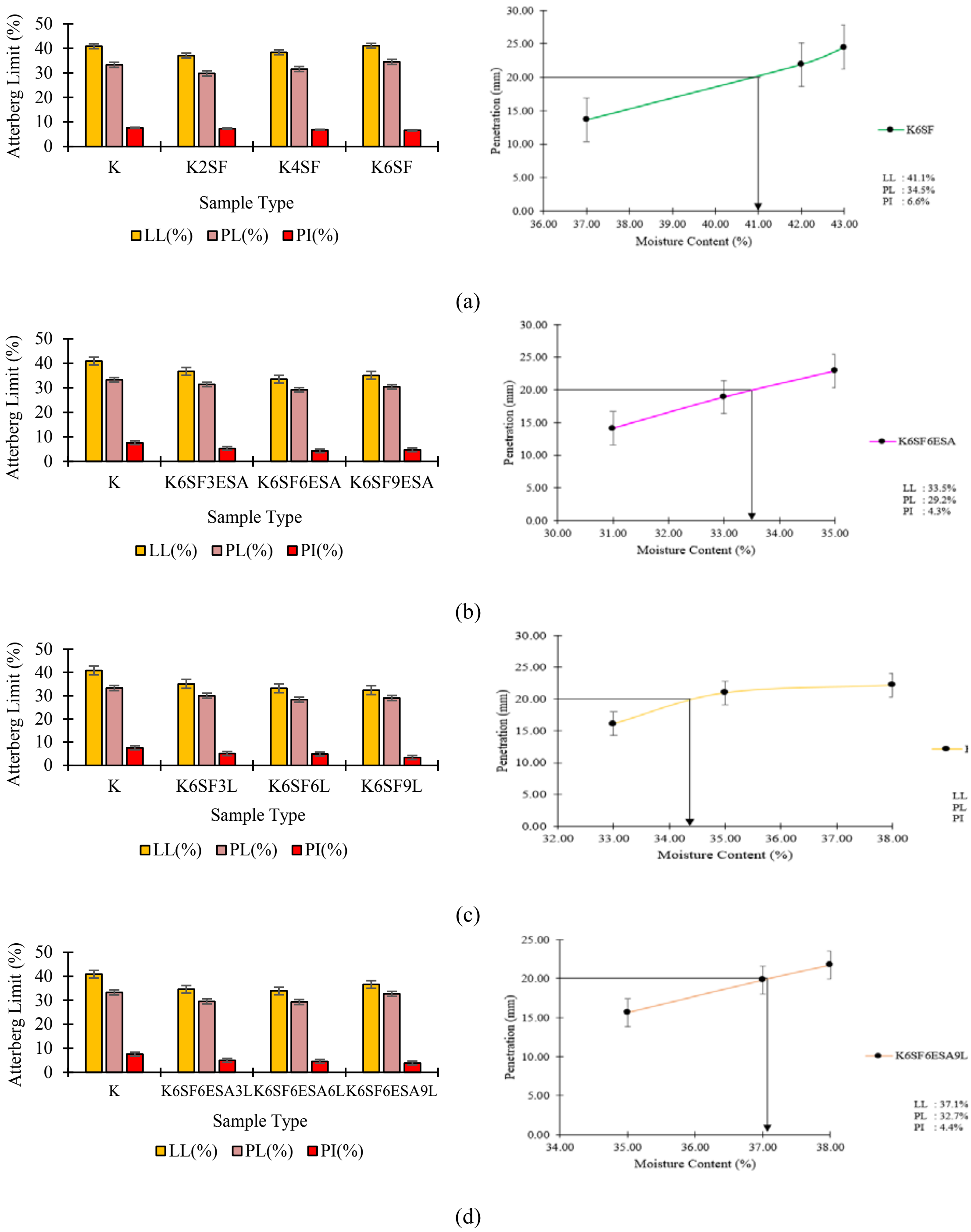

Fig. 3. Effect of different ratios of: a) SF; b) SF-ESA; c) SF-L and; d) SF-ESA-L to the consistency limits of soft kaolin clay treatment. SF, Silica Fume; ESA, Eggshell Ash; L, Lime; 2, 3, 4, 6 and 9, percentage of stabilizer utilised in the soft kaolin clay treatment.

of the untreated soft kaolin clay. Depletion in MDD can be ascribed to the hydration, dissociation, and pozzolanic reactions that lower the density of the SF-ESA and SF-L mixtures individually or in combinations of SF-ESA-L.

The removal of the MDD is reliable on the OMC. Therefore, the OMC of the treated sample undergoes fluctuation owing to the adsorption capacity of ESA and L, ascribable to the porosity characteristics, and the increased OMC with an increasing ratio of ESA and L up to 6% and 9%, respectively. This phenomenon was affected by the increase in CaO content in the treated sample, so a large quantity of water is required [32] for the emergence of CSH molecules and the pozzolanic reaction with the existence of SF.

4.3 Unconfined Compressive Strength of Soil

Initially, the soft kaolin clay was treated with 2%, 4%, and 6% silica fume (SF). Based on the SF mixture, the result urges that the compressive strength of the soft kaolin clay rise gradually when 2% of the SF is mixed with the soft kaolin clay from 13.154 kN/m^2 to 123.794 kN/m^2 with a strength improvement of 4.64% and reached its optimal strength at 15.512 kN/m^2 when 6% of SF was utilised. The enhancement of soil strength was due to the sufficient amount of the amorphous silica and alumina in SF that lead to the pozzolanic reactivity of the soil. Similar observations have been reported by [24,28].

6% of SF utilisation is maintained for the next improvement in the strength of soft kaolin clay. At this stage, eggshell ash (ESA) and lime (L) were tested differently as to assess whether ESA can surpass the strength improvement of soft kaolin clay when L is used as the soil stabilizer. The results suggested that, the utilisation of the ESA at the optimal percentage of 6% (49.87% of strength improvement) exceeds the utilisation of L at 3% (38.33% of strength improvement) but does not exceed the optimal utilisation of L at 9% (51.95% of strength improvement) with a margin difference of 1.136 kN/m^2. Based on the results obtained, both stabilisers (ESA and L) can be used as soil stabilising agent as both materials enhance the strength of soft kaolin clay from 13.154 kN/m^2 to 26.24 kN/m^2 and 27.376 kN/m^2 respectively.

The results obtained suggested that continued use of SF-ESA-L mixture lead to a higher UCS achievement of up to 81.03% of strength improvement (69.344 kN/m^2). The utilisation of 3%, 6% and 9% of L utilised with 6% of SF and ESA exceeded the UCS value of untreated kaolin clay and treated kaolin clay with SF, SF-ESA and SF-L with the UCS value of 31.582 kN/m^2 (58.35% of strength improvement), 56.034 kN/m^2 (76.52% of strength improvement) and 69.344 kN/m^2 (81.03% of strength improvement).

4.4 Morphological Characteristics of Soil

When soft kaolin clay was treated with 6% SF, 6% of SF and 6% of ESA, 6% of SF and 9% of L and 6% of SF, 6% of ESA and 9% L, the quantity of the soil that was retained at 0.075 mm to 4.75 mm increases from 61.6% to 76.6%, which shows that the soil particles became coarser with the reduction of the particle size retained at 0.075 mm to 23.4% from 38.4%. The particles size of the SF utilized in this study can be classified as MH (sandy/silty soil) with a high plasticity property.

Moreover, ESA exists under a coarser condition ranging from 0.063 to 0.3 mm with 26% of the particles passing the 0.075 mm sieve, while 74% of it retained above 0.075 mm sieve. ESA is classified as SC (sandy-clay) particles and is classified as A-2-4 based on the AASHTO classification due to its Atterberg limit properties. The incorporation of SF, ESA and L to stabilise kaolin clay induced the restructuring of the kaolin clay molecule, establishing a coarser kaolin fusion where the sieve graph of the treated kaolin clay transposes vaguely to the coarser side (see Fig. 5).

The improved soft kaolin clay is classified as a sand-silt soil (SM) and is classified as sandy-silt (A-2-4) according to AASHTO. It consists of 0% gravel, 68.2% fine sand and 31.8% of clay and silt when treated with 6% of SF, 0% gravel, 67.4% fine sand and 32.8% of clay and silt when treated with 6% of SF and ESA, 0% gravel, 76.6% fine sand and 23.4% of clay and silt when treated with 6% of SF, 9% of L and the combination of ESA-L.

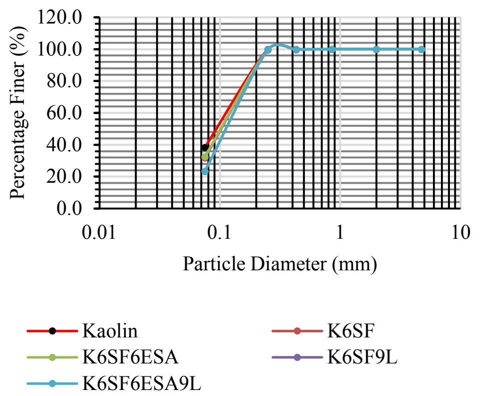

Fig. 5. Effect of using SF, ESA and L to the PSD curve of the soft kaolin clay.

5. CONCLUSION

Kaolin clay can be classified as ML, which indicates as low plasticity silt or inorganic silt of medium compressibility with a liquid limit (LL) of 40.9%, Plastic Limit (PL) of 33.3%, and plasticity index (PI) of 7.6% with a specific gravity of 2.64 and shrinkage limit (SL) of 23.93%. Furthermore, based on the compaction test, the MDD of kaolin was 1.55 kg/m^3 with an OMC of 21.00%. Soft kaolin clay with SF-ESA-L falls into category A-2-4 group which predominantly contains fine sand and was classified as sandy-silt soil (SM) with a specific gravity of 2.38 and SL of 26.31%. In addition, the LL, PL, and PI of the treated soft kaolin clay with optimal utilisation of SF-ESA-L is 36.6%, 32.7% and 3.9% respectively. The MDD of the soft kaolin clay with SF-ESA-L was 0.64 kg/m3 with an OMC of 21.00%.

The shear strength of the soft clay was significantly enhanced by optimal utilization of SF-

ESA-L. The use of SF-ESA-L at the ratio of 6:6:9 significantly improved the shear strength of soft kaolin clay from 13.154 kN/m^2 to 69.344 kN/m^2 with a strength improvement of 81.03%. The increase in the strength of the treated soft kaolin clay soil was owing to the adequate portion of amorphous silica and alumina in the SF that triggered the pozzolanic reactivity of the soil. However, the interchange reaction of the flocculation of kaolin clay molecules, the pozzolanic reactivity and agglomeration are the main physiochemical reactions that regulate the engineering characteristics of kaolin-treated mixtures. Dissociation and interchange of cation assist to instantaneous alterations in the workability of the soil which strengthen the link between the soil molecules and increase the strength of the soft kaolin clay.

Therefore, the study concludes that the utilization of SF, ESA and lime firmly influenced the engineering properties of kaolin clay as an effective soil stabiliser. It is therefore recommended that the utilisation of 6% SF, 6% of ESA and 9% of lime as a problematic soil strength enhancement to improve the kaolin clay for construction application as the improvement to the ground can be reached up to 81.03%.

6. ACKNOWLEDGMENTS

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