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RESEARCH ARTICLE

Basic Geotechnical Characteristic of Soft Clay Stabilised with Cockle Shell Ash and Silica Fume

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ABSTRACT - Soft clay soils can present challenges such as expansion, high malleability, limited water flow, and reduced load-bearing capability especially in areas with periodic rainfall. Therefore, it is imperative to employ soil enhancement methods in order to alter the problematic characteristic of soft clay soil. Presently, the predominant technique for soil stabilisation is the utilisation of traditional stabilisers such as cement and lime which harm the environment. This investigation examines the geotechnical characteristic of clay soil that has been treated with waste materials which are cockle shell ash and silica fume for stabilisation purposes. The objective is to comprehend the impact of integrating cockle shell ash and silica fume on the geotechnical parameters of clay, with the aim of enhancing its suitability for construction applications. Several laboratory experiments were performed to assess adjustments in important characteristics such as Atterberg limits, specific gravity and compaction behaviour of soil sample. The result shows a significant decrease in liquid limit (13.8% depletion), reduced specific gravity (4.2% depletion), decreased maximum dry density (3.8% depletion) and higher optimum moisture content (2.9% enhancement). The presence of cockle shell ash and silica fume greatly modify the characteristic of soft clay soil, implying its potential as a viable and environmentally-friendly soil stabiliser.

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1. INTRODUCTION

Soil stabilisation is essential for construction and infrastructure projects in Southeast Asia due to the region's problematic clay soil which is characterised by their weakness and extensive expansion [1]. Soil stabilisation is a method used to enhance soil problematic properties for construction and engineering applications that requires changing the attributes of the soil [2-4]. This method entails incorporating cementitious binder materials into weaker soil profiles to enhance the geotechnical qualities. The process of stabilising soft clay soil has typically involved soil mixing on site. This approach is extensively and effectively employed in Southeast Asia [5]. Deep soil mixing, commonly referred to as deep cement mixing (DCM), involves the blending of soil with binders such as lime and cement. Nevertheless, the utilisation of binders like cement poses an environmental hazard in the present construction sector because of their substantial carbon dioxide concentration. Ordinary Portland cement (OPC) production results in the release of roughly 950 kg of carbon dioxide per tonne of cement [6].

Considering to the potential advantages, researchers have thoroughly examined the application of various forms of ash in soil stabilisation. The low-cost and environmentally friendly material known as eggshell ash, bottom ash, coffee husk ash, sawdust ash and charcoal ash has been extensively researched for its potential to enhance soil characteristics [7-11]. Since significant research has shown their ability to enhance soil performance in infrastructure and construction projects, modern geotechnical engineering methods greatly benefit from these materials. There has been a substantial increase in research on silica fume's synergistic advantages (SF) when used in conjunction with additional materials as stabilisation agent [12-14]. Introducing 6% SF to soft clay improves optimal water content, decreases maximum dry density and increases strength [2]. Cockle Shell, a byproduct of seafood production have been recognized as potential materials because of their plentiful availability, cost-effectiveness, and negative impact on the environment [15-17]. Cockle shell , mostly consisting of calcium carbonate ($CaCO_3$) is chemically stable and inert [18-19]. Further research is needed to establish the effects of SF and cockle shell ash (CSA) on the basic geotechnical qualities of clay soil. Laboratory tests will assess specific gravity, compaction, and Atterberg limit to measure the effect of these suggested stabilisers on soil geotechnical properties. The primary aim of this study is to look into the possible uses of CSA with SF as an environmentally sustainable and effective problematic soil stabiliser.

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2. METHODOLOGY

2.1 Preparation of Sample

The soft clay sample was obtained from Kaolin (M) Sdn Bhd, a supplier of kaolin located in Selangor, Malaysia. The engineering features of the soft clay sample are presented in Table 1. The silica fume sample was acquired from Chemrex Sdn. Bhd, Malaysia. The cockle shells, composed mainly of calcium carbonate ($CaCO_3$), were collected from local restaurants located in Tanjung Lumpur, Pahang, Malaysia. The cockle shells were then cleaned, subjected to air-drying and crushed using a jaw crusher. The crushed cockle shells were then incinerate at a maximum temperature of 800 °C for 1 hour to ensure thorough calcination while optimizing the ash's properties for soil stabilisation [20]. This process resulted in the conversion of $CaCO_3$ into calcium oxide (CaO). The calcination process resulted in the whitening of the CSA which was subsequently transferred to a desiccator for a period of one day to facilitate cooling and prevent any potential interaction with atmospheric moisture. Figure 1 displays the uncrushed cockleshell sample, cockleshell powder, and CA.

Table 1. Geotechnical characteristic of soft clay sample

Parameters	Unit	Data
Size range	mm	0.0008 – 0.063
USCS classification		ML
AASHTO classification		A-5
Specific gravity		2.63
Liquid limit, LL	%	40.5
Plastic limit, PL	%	31.4
Plasticity index, PI	%	9.1
Compaction properties:		
Maximum dry density, MDD	g/cm^3	1.6
Optimum moisture content, OMC	%	19.8

Collected Cockleshell Sample | Crushed Cockleshell Powder | Calcinated Cockleshell Ash

Figure 1. Different condition of cockle shell sample

Six (6) percent blend of SF was mixed with soft clay sample and different amount of CSA (3%, 6%, and 9%) for stabilisation purpose. The geotechnical parameters of the soil mix, as well as the optimal concentration of SF and various percentages of CSA were examined to evaluate the suitability of CSA as soil stabilisers. The selection of optimal percentage of SF was based on previous study [21-23]. Table 2 displays the list of samples and their coding.

Table 2. Basic geotechnical characteristic of soft clay sample

Sample	Sample Coding
Clay sample	C
Cockle shell ash	CSA
Silica fume	SF
Clay + 6% Silica fume	CSF
Clay + 6% Silica fume + 3% Cockle shell ash	CSF3CSA
Clay + 6% Silica fume + 6% Cockle shell ash	CSF6CSA
Clay + 6% Silica fume + 9% Cockle shell ash	CSF9CSA

2.2 Atterberg Limit Test

Moisture inside soil system leads to the formation of fine-grained soil in various situations. The Atterberg Limit Test determines the limits of different soil conditions by analysing their moisture content. Plasticity index (PI) is proportional to water content which provides a quantitative measure of soil plasticity. The liquid limit (LL) of soil is the total water content available at the interface of the liquid and plastic phases. Soil expands fluidly as a result of increased water volume. When the soil reaches a certain water content known as the plastic limit (PL), it transitions from a plastic to a semisolid state. The Atterberg limits of all sample was calculated using experiments, following the guidelines outlined in BS 1377: Part 2: 1990: 4 and BS 1377: Part 2: 1990: 5 respectively.

2.3 Specific Gravity Test

A pycnometer test was employed to measure the specific gravity of soft clay sample, SF, CSA and stabilised soft clay sample. The specimens utilised for mass calculations were placed within a pycnometer, which was thereafter enclosed within a vacuum chamber to eliminate any ambient air from the specimen which consisted of a mixture of the material and distilled water. After 24 hours, the sample was not disturbed and then distilled water was poured into the little pycnometer until it was completely full. The specific gravity test was performed following the guidelines stated in BS 1377: Part 2: 1990: 8.

2.4 Standard Compaction Test

The study utilised the Standard Proctor compaction test, in accordance to the standards given in BS 1377: Part 2: 1990. A 3 kg clay sample, which underwent the process of drying in an oven and filtration through a 4.75 mm screen, was utilised. A minimum of four compaction points is necessary, with the initial point carried out at a moisture content ranging from 5% to 10% of the sample's weight. A graph is constructed to illustrate the relationship between the dry density of soil and the moisture content received from the compaction test, with the purpose of determining the optimal moisture content (OMC) and maximum dry density (MDD).

3. EXPERIMENTAL RESULTS

3.1 Atterberg limit of stabilised soft clay soil

The inclusion of cockle shell ash (CSA) and optimum amount of silica fume (SF) causes considerable changes in the Atterberg limits. Figure 2 illustrates the results of the Atterberg limits for both untreated clay soil and treated clay soil with optimal SF content and various percentage of CSA. Figure 2 depicts that the plastic limit (PL) of the soft clay sample decline from 35.1% to 34.1%, 30.5%, 28.7%, and 29.4% correspondingly, with increasing amounts of CSA applied. The application of SF and CSA to the soft clay sample resulted in a higher concentration of SiO_2 and CaO, leading to an enlarged surface area and enhanced molecular bonding of the stabilised clay sample. The reaction is most likely a result of cation exchange between the soft clay minerals and calcium ions in CSA. As a result, this caused a decrease in vacant areas and the water present in these areas. The soft clay molecules are formed when monovalent ions are replaced by Ca^{2+} ions, resulting in a decrease in plasticity and an improvement in workability [20,24]. Therefore, it is recommended to utilise CSA to bind and consolidate the soft clay particles, leading to a coarse texture and minimising expansive properties of soft clay soil.

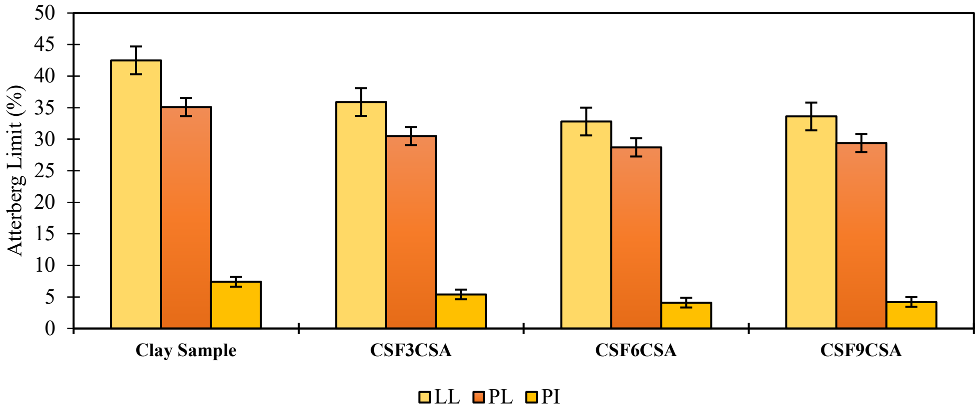

Figure 2. Atterberg limits of soft clay sample stabilised with SF and CSA

3.2 Specific Gravity of Stabilised Soft Clay Soil

The addition of cockle shell ash (CSA) and optimum amount of silica fume (SF) in clay sample leads to substantial changes in the specific gravity. According to Figure 3, the specific gravity of the soft clay sample dropped as it was added with the ideal quantity of SF and varying quantities of CSA. When 9% of the CSA was added to the soft clay sample, its specific gravity reduced from 2.63 to 2.52. The specific gravity of the clay soil has reduced due to matrix remodelling, resulting in a lower particle density. The findings show that using SF and CSA as soil stabilisers reduces the specific gravity of clay soil due to CSA's lower specific gravity compared to clay soil. The shift in soil particle size from a more compact to a less compact condition provides more evidence that soil stabilisation procedures including the waste products suggested may assist minimise specific gravity of problematic soils. [25-27].

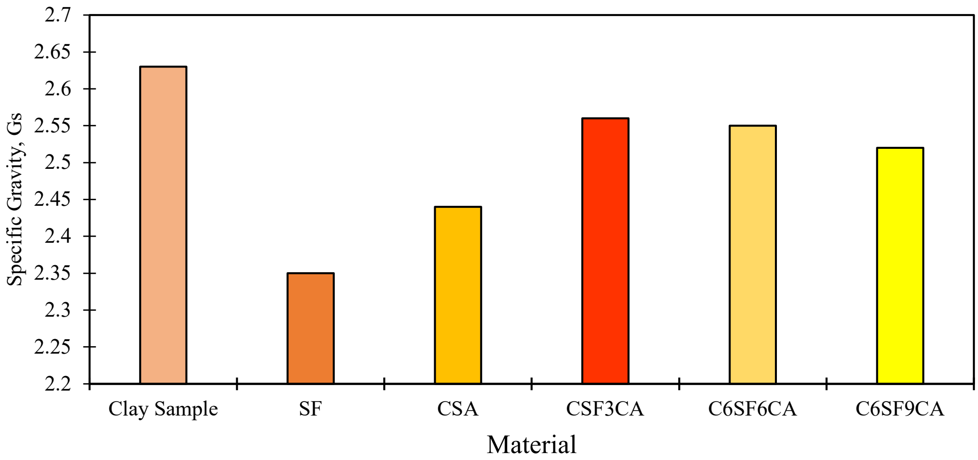

Figure 3. Specific gravity of soft clay sample stabilised with SF and CSA

3.3 Compaction Properties of Stabilised Soft Clay Soil

The presence of cockle shell ash (CSA) and silica fume (SF) in the clay sample results in significant alterations to the compaction properties. Figure 4 displays the moisture content and dry density of soft clay based on SF and CSA concentration. The initial MDD of the soft clay sample is 1.60 g/cm^3 with an OMC of 19.8%. The MDD decrease varies from 1.59 g/cm^3 to 1.54 g/cm^3, whereas the OMC value increases from 19.8% to 21.1%. Upon analysis, it was discovered that when the recommended amount of soil stabilisers increased, it resulted in the decrease of MDD, while increasing the OMC. Consequently, the depth of the two-layer decreased, causing the accumulation of grains as calcium ions replaced sodium ions in the scattered zone of the kaolin clay sample. The high occurrence of silty soil type in the clay mixed with SF and CSA matrix encourages dense molecular packing, thereby preventing the creation of extra empty space [28]. As the cohesive forces between soil molecules strengthen, the molecules undergo a closer proximity that led to a decline in the value of MDD. The decrease in MDD seen in clay samples mixed with SF and CSA may be attributed to the reduction in soil matrix density produced by hydration and pozzolanic processes. The introduction of CSA and SF affected the molecular ordering of the clay sample, resulting in a reduced packing structure [29-30]. This change in the exterior area of the particles requires the absorption of moisture to aid in hydration and pozzolanic reactions, which in turn initiates soil enhancement [31]. The findings achieved are consistent with the study conducted by previous researchers [22,32]. Hence, SF combined with CSA have the ability to greatly modify the compaction properties of the soft clay soil.

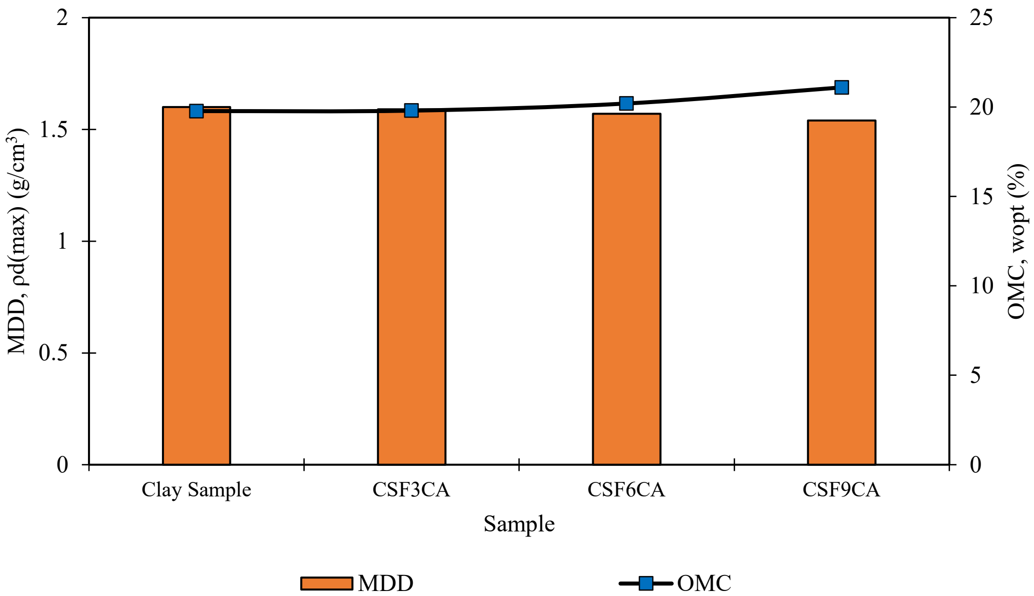

Figure 4. Relationship between OMC (%) and MDD (g/cm3) of soft clay sample stabilised with SF and CSA

4. CONCLUSION

The stabilised clay sample combined with SF and CSA resulted in a considerable reduction in PL. This shows that the treated soil is now less susceptible to significant volume fluctuations caused by moisture variations, and the soft clay's expansive properties have been successfully minimised. The soft clay sample's specific gravity dropped when supplemented with SF and CSA, indicating a rearrangement of soil particles that lead to a thinner soil formulation. The reduction in MDD of the clay stabilised sample is due to structural rearrangement of the soil particles. Nonetheless, the pozzolanic interaction between the stabilisers and soft clay was enhanced, requiring a greater amount of water for the synthesis of the CSH compounds. This resulted in an increase in the OMC. The absorption of CSA and SF into the soft clay sample significantly increased the content of CaO, a crucial component in soil improvement. In summary, the addition of CSA and SF greatly impacts the geotechnical characteristics of clay soil, indicating its potential as a viable and environmentally friendly soil stabiliser.

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AUTHOR CONTRIBUTIONS

Anang Rustanto Suwito: contributed significantly by conceptualizing and designing the study, as well as preparing and editing the manuscript.

Muzamir Hasan: gave valuable assistance through supervision and contributed by evaluating the manuscript.

Muhammad Syamsul Imran Zaini: reviewed the material and contributed to establishing the approach.

DATA AVAILABILITY STATEMENT

The data collected to support the findings are included within the article.

CONFLICTS OF INTEREST

The authors declare no conflict of interest.

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