Soil Stabilisation of Marine Clay Soil With POBA/SLAG-Based Geopolymer

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ABSTRACT

Stabilisation of soil is important and it becomes increasingly used as an alternative to replacing and landfilling unsuitable construction ground. This paper focuses on stabilisation of marine clay soil using palm oil boiler ash (POBA) based geopolymer incorporated with slag. Different Comprehensive experimental programs were conducted including soil particle investigation, and unconfined compressive strength (UCS). Sodium silicate solution (Na_2SiO_3) and sodium hydroxide (NaOH) at a concentration of 10 molars were combined as the alkaline activator (AA), with solid-to-liquid ratio 3.0 and Poba: Slag 100:0, 70:30, 50:50, 30:70, and 0:100 were used in this studies. All the samples were tested on 7 and 28 days of curing period under 40ºC. The results showed a clear improvement in strength as the Poba and Slag were combined. The UCS value of 70:30 (Poba: Slag) showed the highest value of strength achievement with 0.93 MPa and 1.44 Mpa, respectively. These illuminating discoveries help advance environmentally responsible and sustainable soil stabilisation strategies, particularly in coastal clay soil construction projects. This work provides viable alternatives to the existing cement-based stabilisation techniques and opens new options for innovation and advancement in building and geotechnical engineering.

Keywords: Geopolymer, soil stabilisation, alkali activated material, palm oil boiler ash, slag.

1. INTRODUCTION

Soft clay, commonly found in coastal areas, poses challenges due to its high settlement and poor mechanical properties. Because of their limited shear strength, extreme compressibility, and weakness, clay soils provide a significant risk when building on them or installing infrastructure. Due to these, they are vulnerable to different settlements. Therefore, it is crucial to improve soil qualities by utilising stabilisation procedures that can adapt to more demanding situations [1].

One approach to address the unfavourable swell-shrink behaviour of expensive soils is chemical stabilisation, which involves stabilisers such as cement and lime [2]. Ordinary Portland Cement (OPC) has been widely used in geotechnical projects due to its mechanical properties and availability. However, OPC production raises environmental concerns as it consumes extreme energy, which can cause CO_2 emissions and resource depletion. Furthermore, lime and cement often show their weakness and reduced mechanical strength as they have much shrinkage and cracking when they dry out, so they can't be used in high-quality road bases as well as soil stabilisation [3].

A more environmentally friendly alternative to cement stabilisation is the use of geopolymers. Geopolymers are composed of silica (Si) and alumina (Al) combined with an alkaline activator [4]. According to Davidovits (1994), geopolymerisation involves dissolving Si and Al in an alkaline solution, allowing them to form an aluminosilicate gel paste through polycondensation and

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solidifying the gel. Geopolymers offer advantages such as excellent mechanical strength, resistance to acid and fire, and the ability to utilise waste materials containing Al and Si, such as fly ash, furnace slag, rice husk ash (RHA), palm oil fuel ash (POFA) and palm oil boiler ash (POBA). Therefore, this research investigates the mechanical properties of POBA-based geopolymer in various Poba replacements.

2. EXPERIMENTAL PROCEDURE

2.1 Soil

The soil is marine clay obtained from Kuala Perlis, Perlis, Malaysia, and was slurry. Table 1 illustrates the physical and engineering characteristics of marine soils investigated in this study according to the British Standard (BS 1377:1990). The particle size distribution of marine clay is depicted in Figure 1. The result shows that it can be classified that there are 29.18% of gravel, 27.51% of clay, 30.45% of silt, and 12.86% of clay. The Unified Soil Classification System (USCS) states that marine soil is categorised as high plasticity clay (CH). These marine soils must be more robust and stable for infrastructure construction, such as highways.

Table 1 Geotechnical characteristics of untreated soil

Soil Properties	Unit	Standard	Soil
Specific gravity	-	BS 1377: Part 2	2.3
Plastic Limit	%	BS 1377: Part 2	23
Liquid Limit	%	BS 1377: Part 2	62
Plasticity Index	%	BS 1377: Part 2	39
Unifies Soil Classification System (USCS)	-	-	CH
Gravel	-	-	29.18%
Sand	-	-	27.51%
Silt	-	-	30.45%
Clay	-	-	12.86%

2.2 Palm Oil Boiler Ash (Poba)

Poba was obtained from the palm oil factory located in Pulau Pinang, Malaysia. Poba is a coarse powder of unburned palm oil nutshells, fibers, and kernels. The coarse particles are removed by grinding and sifting with size 0.0045 mm sieve size. Poba: Slag ratios of 100:0, 70:30, 50:50, 30:70, and 0:100 were used. The Poba are formed as the primary aluminosilicate source of material of the geopolymer mixture while slag was used to enhance the performance of the geopolymer product. The fixed weight ratio of Poba + slag at 50% from the weight of soil was used.

2.3 Sample Preparation

The Poba: Slag-based geopolymer was treated at a constant water content of 62% of the liquid limit. The sample is mixed with the alkaline activator combination sodium hydroxide, NaOH, and sodium silicate, Na_2SiO_3 with a ratio of 1.4 at 10 molar concentration. The samples were mixed and placed for the curing process in a cylindrical PVC pipe of 2:1 size in a 45mm rod. The samples were cured for 7 and 28 days at 40ºC in the oven.

Table 2 Mixing proportions of Poba: Slag

Precursor	Specimen	Temp (ºC)	Curing Period (day)
Poba: Slag	100:0	40	7 and 28
	70:30		
	50:50		
	30:70		
	0:100		

3. RESULTS AND DISCUSSION

Figure 2 represents the result of the effectiveness of various Poba: Slag-based geopolymer ratios on unconfined compressive strength (UCS) that cured at 40ºC for 7 and 28 days. The strength of POBA: Slag-based geopolymers are influenced by the different ratios added. The lowest UCS of POBA: Slag-based geopolymer with a 100:0 balance is very low due to lower alumina content. Lower alumina content may be the source that affects the strength at the earlier stage [5], [6].

The UCS rose due to the addition of silica from slag. Geopolymerisation can thus occur in any raw material rich in silica and alumina and pozzolanic materials that can be dissolved in an alkaline activator solution [7]. Slag contains a lot of amorphous silica and alumina, both needed to make geopolymer gels. When slag particles are combined with an alkaline activator solution, typically a mixture of sodium hydroxide and sodium silicate, they form geopolymer gel, similar to the reaction in Portland cement-based materials. This gel links the aggregate particles, resulting in a solid and robust structure, as seen by various combinations that demonstrate acceptable strength enhancement with slag inclusion [8], [9]. It can be represented in Figure 4, where 0:100 achieves the highest UCS strength.

At 70:30, the greatest unconfined compressive strength was 0.93 MPa after 7 days and 1.44 MPa after 28 days. The POBA: Slag 70:30 ratio was chosen to represent the POBA as the primary material with slag addition. As the length of the curing period increased, so did the strength. Adequate curing times allow materials to achieve their potential strength. Most of POBA: Slag increased strength twice for 28 days compared to 7 days.

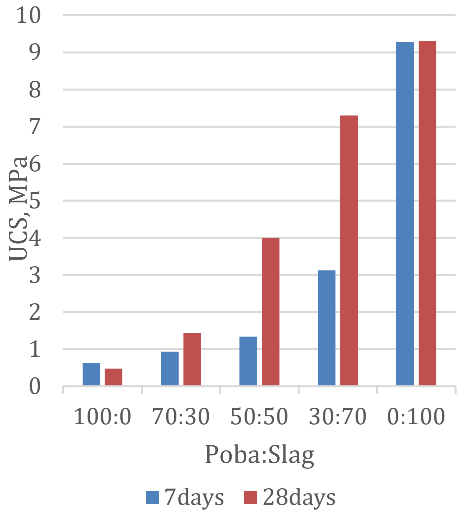

Figure 1. UCS of Poba: Slag-based geopolymer curing at 40ºC on 7 and 28 days.

4. CONCLUSION

These studies showed that palm oil boiler ash could replace the commonly used stabiliser agents, cement, and lime, as the strength gained from the research showed improvement. The maximum unconfined compressive strength was accomplished by consisting of 70:30 of Poba: Slag. The curing days at 28 days showed excellent strength development compared to 7 days of curing. This is due to the geopolymer substance going through solidified and becomes stronger as the curing days increase.

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