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Influence of Blended Lime-GGBS Slag on the strength of Laterite

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Abstract. Residual soils are referred to soils that formed through process of physical and chemical weathering of in-situ rocks. Reactions of various physical and chemical weathering agents had resulted in physical and chemical variability of residual soil and site dependent. The structure and minerals of in-situ rock were degraded physically and chemically and thus making its less resistance to load compared to un-weathered parent rock. Hence, it is important to stabilize the residual soil. Different ratios of blended hydrated lime and Ground Granulated Blast Furnace Slag (GGBS) namely 10:0, 9:1, 8:2 and 5:5 were utilized in this study. The percentage of admixtures was set at 10% with respect to its dry mass of soil. Unconfined compressive strength of treated soil specimens were determined after 7 days, 14 days and 28 days of humid curing. The water contents of the specimens were found to decrease slightly with an increment of curing periods while the strengths of the stabilized specimens were increased with curing periods. The highest unconfined shear strength at 28 days was recorded as 321.74 kPa with 8.18% axial strain. Thus, it showed that the use of blended lime and slag can improve the strength of residual soil. However, the treated samples failed to achieve the minimum strength increment of 345 kPa to be considered as an effective stabilization as stated in ASTM D4609. Some other factors namely curing temperature and Initial Consumption of Lime (ICL) should be considered to optimize the strength of the stabilized materials.

1. Introduction

Residual soils are referred to soils that undergoes physical and chemical weathering. The exposure of in-situ rocks to various degrees of weathering processes had resulted in residual soils with variety of geophysical and geochemical properties which are different from those of transported soils. The physical rock texture of residual soil was normally lost and contains secondary minerals resulting from the weathering process [1]. Commonly, the characteristics of residual soils still resemble to their parent rocks in certain extent.

Previous study [2] highlighted that failure cases of residual soil slopes were high compared to other types of geotechnical structures. The majority of failed residual soil slopes were cut slopes in addition to some poorly maintained fill embankment. The great challenges faced by designers during the early design stage of cut slopes were to identify the unforeseen weak geological structures, variation of groundwater regimes in slopes, strength reduction or degradation rate of residual soils when exposed to



extreme weathering conditions and the inherent variation of the earth material properties are the main causes of the high failure [3].

The variability of geophysical and geochemical properties make the strength of residual soils vary over their depositional area. Thus, there is a need to stabilize the residual soils with the aim to increase the strength and bearing capacity. Over the years, many studies had been carried out by various researchers on the use of calcium based stabilizer namely cement and lime and other pozzolanic ash [4] in stabilizing soils. Studies also found that the unconfined compressive strength of the treated soil was found to increase significantly with increase in cement content, especially after a long curing period [5]. However, in certain cases, cement is a low efficiency stabilizer because the varieties and amounts of its hydrates unable to meet the demand for soil stabilization.

Apart of cement, lime is another commonly used soil stabilizer. Lime is well known for its high pH and pozzolanic reaction, which make it widely utilized in various industries. Lime is capable to dissolve more silica and produce more cementations compounds under a condition of high alkalinity ($\text{pH} > 11$) [6]. Generally, the application of lime can be categorized as lime modification and lime stabilization. Lime modification is referred to the process of pH changing which causes particle coagulation and flocculation, whereas lime stabilization is known as the pozzolanic reaction in which some newly crystalized reaction products will be formed over hardening periods. Other application of lime (quick lime) is the drying process through heat generation when in contact with water. Hence, lime is getting popular in construction industries namely road construction, tunnel construction and deep soil stabilization.

Meanwhile, slag was reported to be an effective stabilizer to improve workability and durability of treated soils and economical in application. Slag is capable to increase the compressive strength of material when used as cement replacement due to its fineness and the chemical hydration. The slag provides additional alumina, calcium, silica and magnesia to the system, depending on the type and amount of slag. Slag, which is categorized as natural pozzolan is able to undergo pozzolanic reactions in the presence of water and calcium hydroxide, $\text{Ca}(\text{OH})_2$. This secondary pozzolanic reaction yields a denser microstructure because the $\text{Ca}(\text{OH})_2$ is consumed and C-S-H paste is formed. Hence, even though partial replacement of slag by weight may decrease the early strength, it can increase the later strength through secondary pozzolanic reaction [7]. Besides that, some slag which are in aggregate size were used in construction as partial replacement of fine aggregate [8]. The application of aggregate slag as partial replacement of fine aggregate is beyond the scope of this study.

Lime is known as an efficient stabilizer for soil but receive low acceptance among practitioners because of the slow strength gain. Thus, the main objective of this study is to evaluate the feasibility of partial replacement of lime with Ground Granulated Blast Furnace Slag (GGBS) in soil stabilization. The GGBS is anticipated to supply reactive alumina silicate with the aim to speed up pozzolanic reaction.

2. Materials and testing methods

A tropical laterite soil was utilized in this study and the additives used were hydrated lime and GGBS. The effectiveness and effects of additives on the strength of laterite soil were identified by determining the unconfined compressive strength of the treated soils.

2.1 Materials

The soil tested in this study was locally available residual soil found in this region which is mainly of lateritic origin. Soil samples were obtained from the depth of 2 m below the ground surface of undulating lands in the area of Sri Lalang, Kluang, Johor with insignificant organic content. The soil was sieved through a 2.36 mm aperture sieve so as to ensure its uniformity and eliminating some other remaining roots.

Lime was proposed as a stabilizing agent in this study in which hydrated lime was utilized. Hydrated lime (Calcium Hydroxide [$\text{Ca}(\text{OH})_2$]) is produced through hydration process of quick lime (Calcium

Oxide [CaO]). The hydrated lime was kept in an airtight container at room temperature in order to prevent further carbonation process when exposed to humidity.

GGBS Slag was obtained from Slag Cement Sdn Bhd, Pasir Gudang and it was originally imported from Japan. The slag is a granulated product ground to fineness of 390 m²/kg + 5% with particle size smaller than 15 micron. The GGBS is certified to be safe to the environment by the supplier. Hydrated lime was blended with GGBS Slag in different ratios based on dry weight of lime and slag. The ratios are listed in Table 1.

2.2 Testing methods

2.2.1 Sample preparation & testing. Disturbed laterite soil samples were tested to determine the physical properties and chemical properties in accordance to specification BS1377:1990 [9]. The bulk chemical compositions of the laterite soil were determined using X-ray fluorescence (XRF) machine and analysed using Bruker's Standardless method. Table 1 shows the mix ratios of slag and lime that were used as additives to improve the strength of the soil. The additive was mixed with the soil by using laboratory scale mechanical mixer. The dried soil was mixed with natural water content (determined earlier) and remoulded manually in cylindrical shape with 38mm in diameter and 76mm in height. The specimens were stored in an airtight container at room temperature for different curing periods of 7, 14 and 28 days in order to allow for strength enhancement. After specific curing periods, the specimens were taken out from the airtight container; the specimens were tested for its unconfined compression strength by using Geocomp LoadTracII. The strain rate for the tests was set as 1%/min in accordance to specification [10].

2.2.2 Experimental scheme. Three variables were considered in this experiment. The curing periods (i.e. 7 days, 14 days, & 28 days), effect of additive (with and without additive), and percentage of lime replaced with slag were studied. Three replicate samples were prepared for each variable. Hence, the total numbers of specimen required for this experiment are shown in Table 2.

Table 1. Composition of test samples.

Composition	Soil (%)	Additive Type		
		Specimen Code	Lime (%)	Slag (%)
1	100	A	0	0
2	90	B	10	0
3	90	C	9	1
4	90	D	8	2
5	90	E	5	5

Table 2. Number of specimens.

Effect of curing periods (level)	Effect of additive (level)	Percentage of lime replaced with slag (level)	Replicate	Number of Specimens
3	2	4	3	72

3. Results and discussions

3.1 Physical and chemical properties of untreated soil

The physical properties of untreated soils were determined with the aim to unveil the nature characteristics of soil. The particle size distribution of untreated soil is shown in Figure 1. The base soil is categorized as inorganic well-graded sand (SW) with fine content less than 3%. The coarse-grained particle of laterite will not favour for lime stabilization [11]. The base soil-laterite is identified as inorganic soil with an average specific gravity of 2.73. The natural moisture content of untreated soil was determined as 13.86% which is less than the plastic limit (28.26%). The maximum dry density of the soil is determined as 1493kg/m³ with the optimum moisture content of 27%.

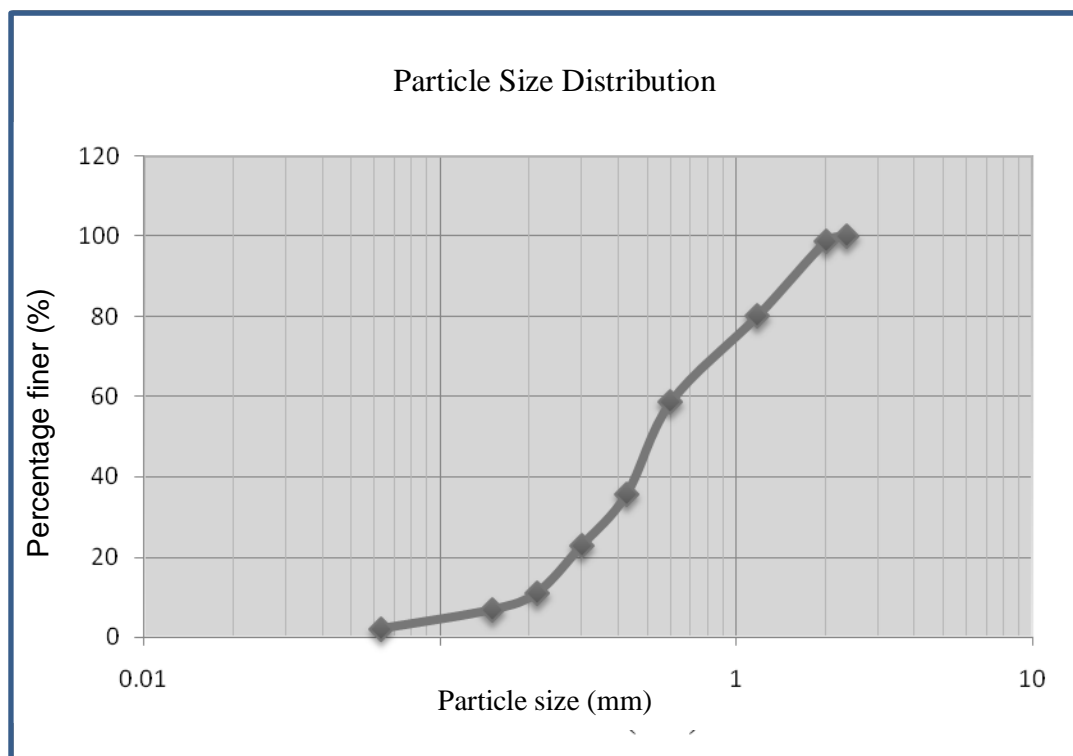


Figure 1. Particle size distribution of untreated soil.

The pH of soil was determined as 5.5, which falls in the category of weak acidic soil. The chemical compositions of the laterite soil are as listed in Table 3. Based on the analysis, the laterite soil is determined to be rich in ferrous with its reddish colour even though the dominant compositions are silica and alumina.

Table 3. Bulk chemical compositions of laterite soil.

Chemical composition	Concentration (%)
CO ₂	0.1
SiO ₂	41.30
Al ₂ O ₃	36.10

Fe ₂ O ₃	19.70
TiO ₂	1.81
K ₂ O	0.47
SO ₃	0.26

3.2 Physical and chemical properties of additives

The pH of the pure lime was tested and listed in Table 4. Its pH is found to be greater than the requirements of pH 12.4 as specified in specification BS1924:Part 2 [12]. High pH is required to make sure the suitability of lime to be used for soil stabilization. Besides that, the quality of the hydrated lime was also confirmed using XRF and XRD. It was determined that the hydrated lime contents of high percentage of Calcium (Ca) (refer to Table 5) and confirmed as Portlandite (CaOH₂) via XRD (refer to Figure 2).

The GGBS Slag is identified as a source of reactive pozzolan in which its phase was determined as amorphous via X-ray diffraction method (Figure 3). The total percentage of silicate and aluminate of GGBS is greater than 45% as shown in Table 5. The pH of the pure additives (lime and GGBS) and blended additives (lime with GGBS) were tested and summarized in Table 4. It is clearly shown that the partial replacement of lime with slag did not significantly reduce the pH of the mixtures. Besides that, the bulk chemical composition of blended lime-GGBS slag were also determined via XRF. Partial replacement of hydrated lime with GGBS showed that the calcium contents were reduced while the silica and alumina contents of the mixtures increased significantly as shown in Table 6.

Table 4. pH value of lime, slag and lime-slag.

Material	pH
100% Lime	12.87
90% Lime + 10% Slag	12.5
80% Lime + 20% Slag	12.43
70% Lime + 30% Slag	12.46
60% Lime + 40% Slag	12.45
50% Lime + 50% Slag	12.44
40% Lime + 60% Slag	12.44
100% Slag	11.51

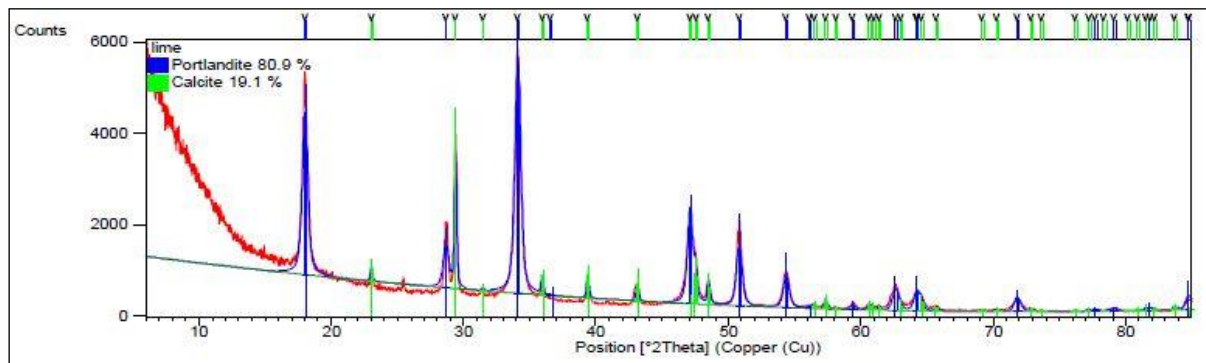


Figure 2. Diffraction pattern of hydrated lime.

Table 5. Bulk chemical composition of additive.

Chemical composition	Raw additive	
	Lime	GGBS Slag
	Concentration (%)	Concentration (%)
CO ₂	0.1	0.1
SiO ₂	0 < LLD	31.7
Al ₂ O ₃	-	14.1
Fe ₂ O ₃	0 < LLD	0.37
CaO	97.7	45.5
TiO ₂	-	0.57
K ₂ O	-	0.41
SO ₃	0.66	2.28
MgO	1.23	4.43
MnO	-	0.29
Na ₂ O	-	0.2
SrO	-	0<LLD

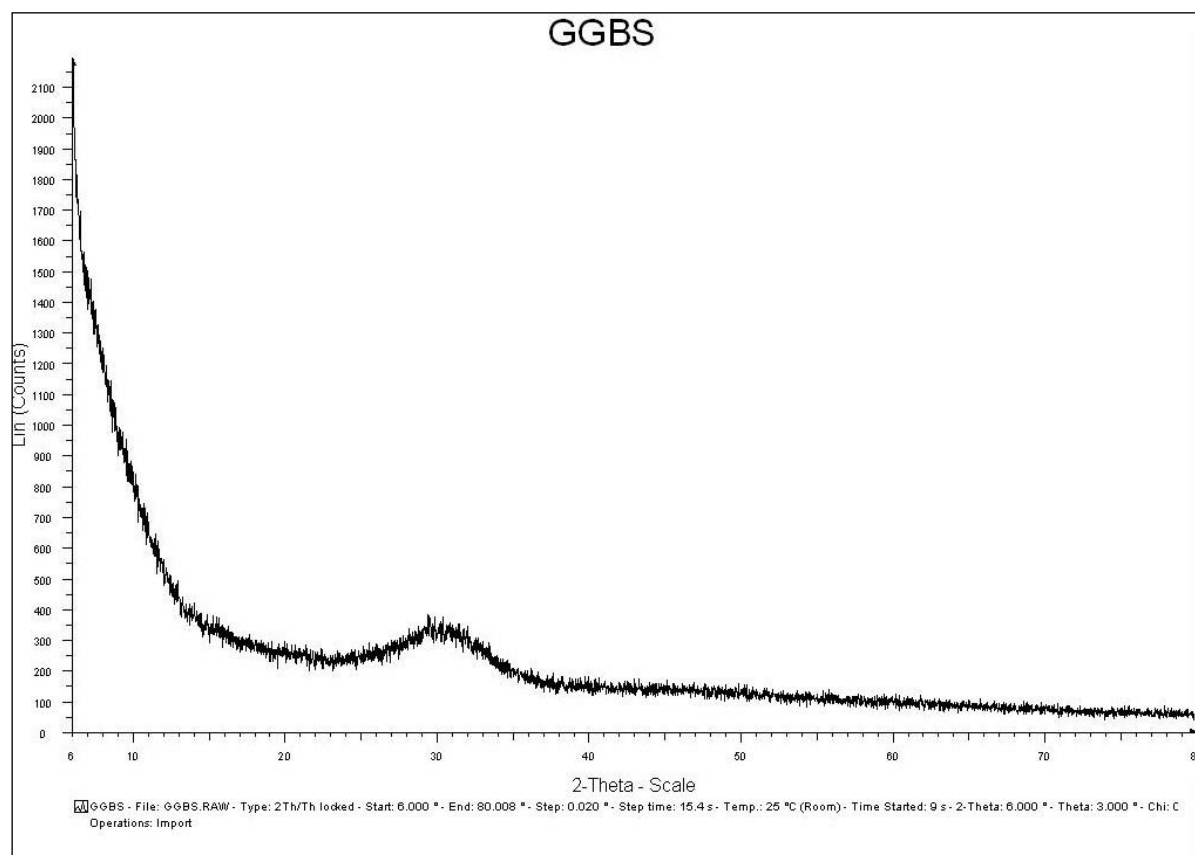


Figure 3. Diffraction pattern of GGBS slag.

Table 6. Chemical composition of soil, lime and slag.

Chemical Composition	Blended Lime –GGBS (%)		
	90%L + 10%S	80%L + 20%S	50%L + 50%S
CO ₂	0.1	0.1	0.1
SiO ₂	3.96	8.25	19.8
Al ₂ O ₃	1.89	3.94	9.4
Fe ₂ O ₃	0<LLD	0.16	0.21
TiO ₂	-	0<LLD	0.28
K ₂ O	-	0<LLD	0.25
SO ₃	1.01	1.16	1.65
MgO	2.05	2.49	3.77
CaO	90.7	83.5	64.3
MnO	-	-	0.14
Na ₂ O	-	-	0<LLD

3.3 Engineering properties of stabilized and unstabilized soil

The soil specimens were remoulded and tested for the unconfined compressive strength. The average strength of each mix is shown in Figure 4. The graph shows that overall the strength of the treated soil specimens were increased with curing periods. The values of unconfined compressive strength of the untreated soils were in the range of 105 kPa to 140 kPa, whereas the strength of the treated soil specimens were in the range of 62 kPa to 162 kPa. The findings showed that the strength of some treated soil specimens possessed lower strength compared to the untreated soil specimens. In addition, the bar chart clearly shows that most of the treated soil specimens yielded lower strength compared to the strength of untreated specimens in the early curing periods (7 and 14 days). The additives are found to be effective as strength enhancer in the long term. The calcium liberated from the lime and slag during hydration hardened and crystallized with the silica from soil [8], thus increased the strength of stabilised soil. Since the pozzolanic reaction proceeded slowly, it generally becomes necessary to continue the curing process for periods exceeding 28 days as suggested in the standard [12].

Generally, the partial replacement of lime with GGBS slag showed better strength enhancement when compared to the soil treated with pure lime at 28 days. The findings agreed well with the previous works done by other researchers [13]. The highest strength in this study was found to be soil stabilized with blended lime-Slag type D (lime: 8% and GGBS: 2%) and cured for 28 days.

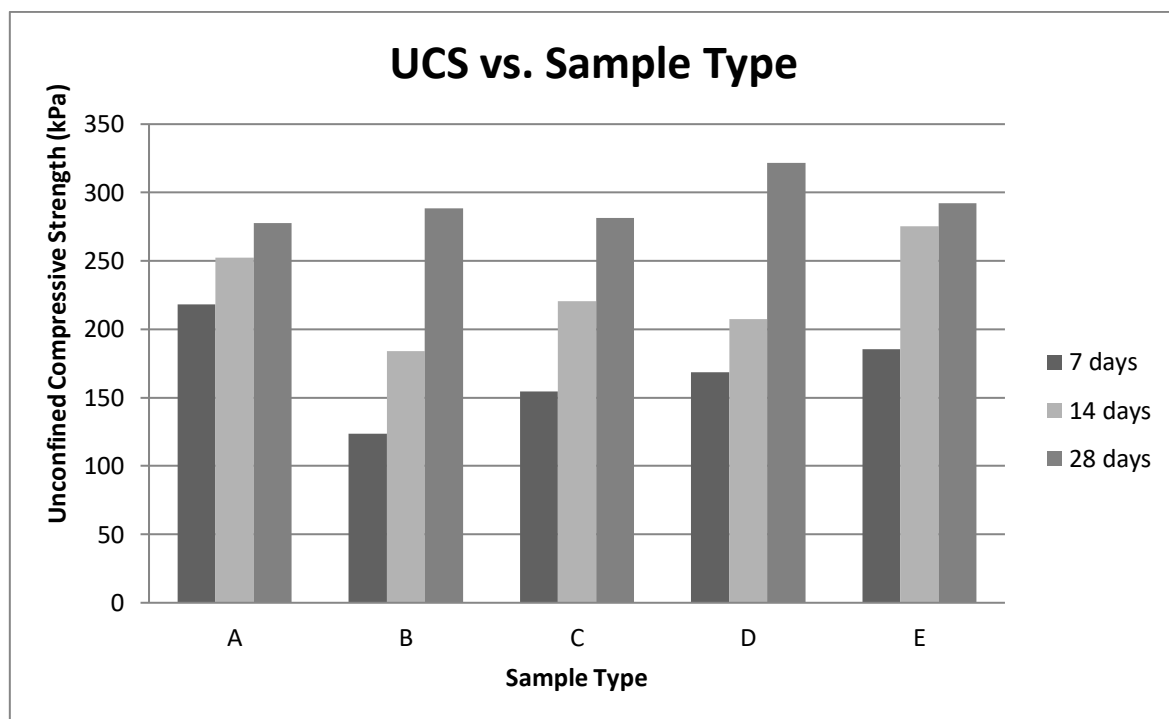


Figure 4. UCS vs. type of specimens.

The particles structure of the soil stabilized with lime and slag is found to be more dispersed when compacted at lower water content. The dispersion had resulted in random orientation of the particles and thus creating a closer and compact structure. The closer and compacted structure is capable in resisting higher load and thus contributes to the strength increment. Same phenomenon was also observed by other researcher [14]. However, the mixture was found to be weak with added moisture. The percentage of soil solids will decreased with added water content with the total volume remain constant. Moreover, the soil particles were found to be parallel oriented when the water content was increased and thus showing a weaker structure.

The overall strength enhancement of soils treated with additive were lower than the guidelines as proposed in the standard [15] in which a strength enhancement of 345 kPa is required for a stabilizer to be categorized as an effective stabilizer. Hence, the factors namely the minimum percentage of lime required and curing condition need to be determined in order to gain better strength enhancement. Researcher [8] suggested that the specimen should be cured at 60°C for periods between 7 and 28 days. It is because the temperature as high as 71°C had proved favour for stabilization. Other researcher [12] suggested that a well-balanced lime and GGBS mix is required to achieve sustainable increment in strength, and a pH value of greater than 12 is required for soil treated with lime and GGBS to promote pozzolanic reactions over longer curing periods. It is recommended in the specification [10] to test the initial consumption of lime (ICL) with the aim to determine the minimum percentage of lime required for stabilization. Besides that, past study [16] found that the effects of lime content on strength enhancement is almost bell-shaped when plotted in graph and suggested that the optimum lime content is required to maximize the strength enhancement of soil. Thus, the ICL is required for each type of soil that going to be treated with lime.

4. Conclusions

Based on the results of this study, it can be concluded that blended lime and slag can improve the strength of residual soil. Lime and slag with suitable ratio is able to enhance the strength through cementitious process. The long-term strength of the stabilized soil was found to be slightly higher than the untreated soil. The addition of slag and lime which improved the strength of the soil is concluded as a result of pozzolanic reaction. The newly produced compound during pozzolanic reaction had bound the soil particles together. However, low strength enhancement in the early days had upset the aim to speed up the pozzolanic reaction by supplying reactive alumina silicate through lime replacement with GGBS. Thus, it is recommended that further studies should be carried out by taken into consideration of the Initial Consumption of Lime (ICL) and the effects of temperature on pozzolanic reactions. Different percentages of additive and different curing conditions should be considered as well to optimize the strength enhancement of lateritic soil treated with blended lime GGBS.

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