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Effect of Lime Activated Ground Granulated Blastfurnace Slag (GGBS) and Lime on the Strength and Swelling Properties of Kalomato Soil

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Abstract

Extensive studies have been carried out in Nepal on the stabilization of organic soil using various additives such as lime, cement, fly ash and many other stabilizers like rice hush ash, sugarcane bagasse ash, fly ash etc. However, minimal studies have been carried out using industrial by products, named ground granulated blastfurnace slag (GGBS). GGBS is an industrial waste (by-product) from the blast-furnaces used to make iron and steel. If it is activated by a small amount of lime, the slag reacts with water to give cementitious products and can be used for altering the characteristics of soil. Typical kalomato soil of Kathmandu valley possess typical characteristics of organic soil such as dark color, low density, low permeability, high water content, low shear strength, high Atterberg limit, low specific gravity and high compressibility. Kalomato shows recurrent volume changes with the change in moisture content, causing serious problems to the civil engineering structures such as road pavements and buildings resting on them. In this paper, unconfined compression strength(UCS) at different curing periods (7, 14 and 28 days) and one dimensional oedometer test has been performed for the kalomato soil stabilized with various proportions of lime (3%, 6% and 9%) and slag : lime ratio of 0.67:1, 1:1, 2:1, 3:1 and 4:1 fixing proportion of lime to 3% lime. The mineralogical composition of untreated soil sample, GGBS and of the best resulted treated samples has been presented through X-Ray powder diffraction patterns. The results obtained from the experimental study indicate that the measured Free Swell, Swelling Pressure are reduced substantially with remarkable increase in strength on increasing percent of lime activated blastfurnace slag and remain stable after reaching certain concentration. The test results showed that with 6% lime, the UC strength is 5.36 times and with slag/lime ratio of 4:1, the UC strength is 6.03 times higher than the raw soil. Likewise, the swelling potential of raw soil decreased from 44.00% to 2.70% with 3% lime and to 9% with slag/lime ratio of 4:1.

Keywords
Kalomato, Ground Granulated Blastfurnace Slag (GGBS), X-ray Diffraction

1. Introduction

Kalomato soil found in Kathmandu valley is formed by lacustrine deposit. Because of its high swelling and shrinkage characteristics, the Kalomato soil has been a challenge to the Engineers. It is very hard when dry but loses its strength completely when in wet condition [1]. It is made of varying properties of minerals like montmorillonite, kaolinite or illite, chemicals like Iron Oxide and Calcium Carbonate and organic matter like humus [2]. This soil of valley is known for its high swell potential, low shear strength and highly compressibility nature. Due to its insufficient bearing capacity, low shear strength and excessive settlements; civil structures such as pavements, walkways, roads, foundations, channel lining etc. possess a high risk of failure.

It has been trend to search new innovative materials for the treatment of such soft and weak soil in Nepal. Extensive studies on stabilization have been carried out in Nepal using various additives like lime, cement and their combinations and industrial wastes such as Sugarcane bagasse ash, Rice husk and Fly-ash. However, no such research has been found for slag stabilization. Using industrial by-products GGBS is gaining momentum all over the world [3].

Ground Granulated BlastFurnace Slag (GGBS) has been widely used as a replacement of cement in concrete production and as an effective soil stabilizer in countries like U.K., South Africa, India and others. At present, year after year, most of these countries are producing millions of tons of blast furnace slag which is the by-product of steel industries. This is posing a big environmental problem, though ready mix concrete industry is using nearly half of this waste. And with time in near future, this may be the same case for Nepal. Hence an attempt has been made to carry out the investigation regarding the beneficial effect of this industrial by-product in kalomato soil of Nepal based on the engineering properties like strength and swelling potential.

2. Literature Review

2.1 Lime Stabilization

Lime is one of the oldest and still popular stabilizer used to improve soft and problematic fine-grained soils.JB Croft(1967) found that the lime addition effectively reduces the swelling potential, liquid limit, plasticity index and maximum density of the soil, and increases its optimum water content, shrinkage limit and strength.

1 to 3% lime is needed for modifying soil properties and 2 to 6% lime is required for soft soil stabilization, depending on clay content present in the soil [4]. The optimum amount of lime for maximum strength gain in stabilizing soil with lime is 4 to 6% for kaolinite and about 8% for illite and montomorillite [5].

2.2 GGBS Stabilization

GGBS is a non-metallic by-product of iron ore smelting process.It is produced by grinding granulated blast furnace slag into a fine powder. When it is activated by a small amount of lime, the slag reacts with water to give cementitious product. This property of lime activated GGBS tends to stabilize the soft and weak soil. Many researchers concluded that the addition of lime activated GGBS reduces the plasticity limit, shrinkage limit, free swell precent and swelling pressure while increases the UC strength and CBR value significantly.

Higgins, (2005)investigated the soil stabilization with ground granulated blast furnace slag; emphasizing the tends of various countries on proportioning of GGBS vs lime, order and timings of lime and GGBS applications. Significant resistance against swelling and sufficient strength can be achieved with a GGBS:lime ratio of 4:1, while the greatest resistance was found at high GGBS:lime ratios, typically 5:1 or greater [6].

Soil stabilization with GGBS is widely used in connection with road, pavement and foundation construction. It improves the engineering properties of the soil such as:

- Strength - to increase the strength and bearing capacity,
- Volume stability - to control the swell-shrink characteristics caused by moisture changes,
- Durability - to increase the resistance to erosion, weathering or traffic loading.[6]

3. Materials and Methods

3.1 Materials

3.1.1 Kalomato

The soil used for this research work was obtained from building site approximately outh of Balkhu, Kathmandu near T.U gate. The soil specimen was sampled from the depth of about 3m. The soil was gray to deep black in colour. Both disturbed and undisturbed samples were collected from the site.

3.1.2 Ground Granulated Blastfurnace Slag (GGBS)

Ground Granulated Blastfurnace Slag was provided by Sarbottam Cement Industry, Nawalparasi which was purchased from India. The colour of GGBS was greyish white.

3.1.3 Lime

Commercially available pure quick-lime CaO was used in the investigations.

3.2 Material Proportioning and Methods

1 to 3% lime is needed for modifying soil properties and 2 to 6% lime is required for soft soil stabilization, depending on clay content present in the soil [4]. Significant resistance against swelling and sufficient strength can be achieved with a GGBS:lime ratio of 4:1, while the greatest resistance was found at high GGBS:lime ratios, typically 5:1 or greater [6]. Hence, materials were proportioned as shown in Figure 1. These samples were stored maintaining required temperature and humidity and were tested at

laboratories namely, CMTL, Pulchowk and Geotech & Associates, Bakundole.

S.N.	Particular of the mix	GGBS/ lime ratio
1.	Soil + 3% lime	-
2.	Soil + 6% lime	-
3.	Soil + 9 % lime	-
4.	Soil + 3% lime + 2% GGBS	0.67:1
5.	Soil + 3% lime + 3% GGBS	1:1
6.	Soil + 3% lime + 6% GGBS	2:1
7.	Soil + 3% lime +9 % GGBS	3:1
8.	Soil + 3% lime +12% GGBS	4:1

Figure 1: Mix Proportions of lime and GGBS:lime Ratio

3.2.1 Unconfined Compression Strength Test

Strength characteristics of the untreated and treated samples were carried out using standard unconfined compression strength test. Uniformly mixed and oven-dried samples were mixed with water equal to optimum moisture content and was compacted immediately subjected to 3 layers and 25 blows per layer in Proctor Compaction Test Apparatus. These samples were moist cured for 7, 14 and 28 days.

3.2.2 One Dimensional Oedometer Test

The swelling potential and swelling pressure of the untreated and treated samples are carried out in consolidometer of diameter 60mm and thickness 2mm using Method A of (ASTM.D4546,1996,2003), (Sridharan et al 1986)) [7], [8] in CMTL, Pulchowk.

The swelling potential was determined by inundating the soil specimen with water and allowing it to swell freely in vertical direction under a token load of at least 1kPa (7kPa was used in this research). After the specimen reached the maximum swelling, the magnitude of % swell is obtained using the formula

$$\% freeswell = \frac{\delta h}{h_1} * 100\%$$

Where, δh= increase in specimen thickness,
h_i=intial thickness of the sample

4. Results and Discussion

4.1 Materials Properties

The geotechnical results of the untreated kalomato soil and GGBS are done as per the IS standard IS:2720 and ASTM codes and are shown in Table 1 and Table 2 respectively.

Table 1: Geotechnical results of Kalomato Soil

S.N	Properties	Values
1	Organic Content (%)	7.90
2	Specific Gravity	2.32
3	Liquid Limit (%)	56.26
4	Plastic Limit (%)	27.05
5	Plasticity Index (%)	29.22
6	Shrinkage Limit (%)	27.00
7	(%)clay fraction	21.50
8	Activity	1.42
9	Maxm̂ Dry Density gm/cc	1.42
10	Opt. Moisture Content(%)	27.24
11	Classification	CH
12	UC Strength (Mpa)	88.69
13	Swelling Potential (%)	73.00

Table 2: Geotechnical results of GGBS

S.N	Properties	Values
1	Specific Gravity	2.40
2	Coeff. of Uniformity (Cu)	2.05
3	Coeff. of Curvature (Cc)	0.91
4	Colour	Gray White

The phase diffraction pattern of the soil and GGBS was conducted in Nepal Academy of Science and Technology (NAST) in Satdhobato, Lalitpur and are shown in Figure 2 and Figure 3.

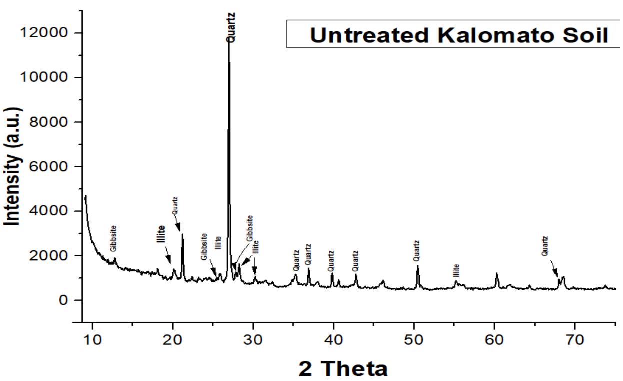

Figure 2: Phase diffraction pattern of untreated Kalomato

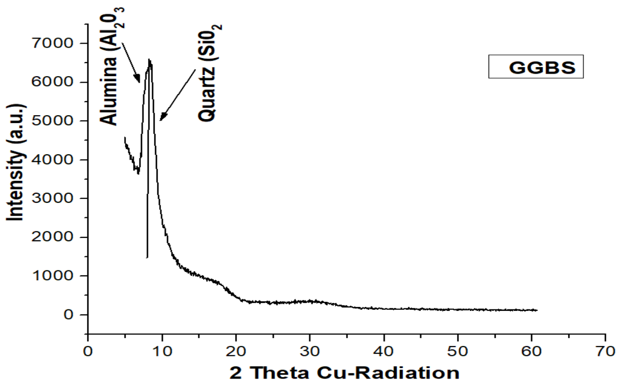

Figure 3: Phase diffraction pattern of Ground Granulated Blastfurnace Slag

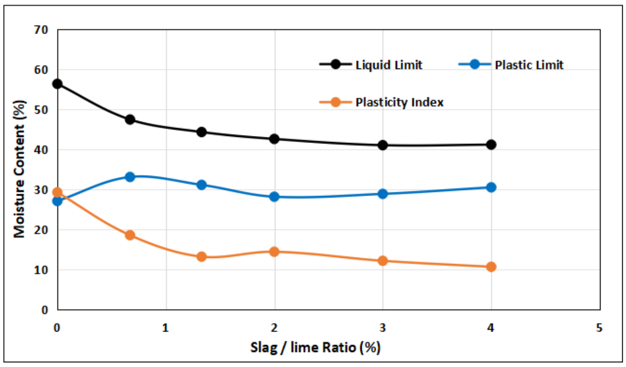

Figure 5: Effect of slag lime ratio on Atterberg Limits

4.2 Effect on the Atterberg's limits

4.2.1 Effect of lime content on the Atterberg's limits

Figure 4 shows the variation of atterberg's limits with lime content. Gradual reduction in liquid limit of soil sample was found from 56.26% to 43.42% with 3% lime as stabilizer, followed by slight increment with increased lime content to 6-9% as shown in Figure 4. The plastic limit increased sharply from 27.05% to 32.74% with 3% lime, followed by slight decrease with increase in lime content.

The plasticity index of lime stabilized sample tends to decrease from 29.21 to 10.67 up to 3% lime but for higher percent, PI increase gradually.

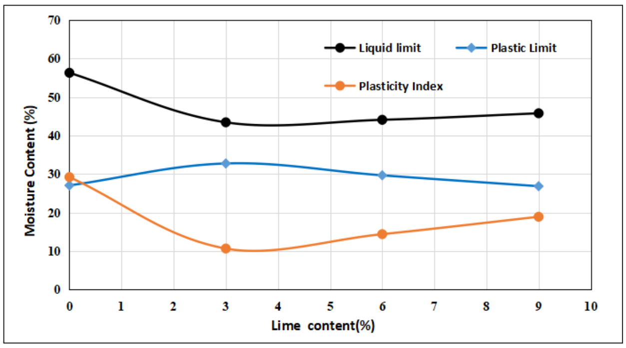

Figure 4: Effect of lime content on Atterberg's Limits

4.2.2 Effect of lime activated slag content on the Atterberg's limits

Figure 5 shows the variation of atterberg's limit with slag to lime ratio. The liquid limit of the soil was found to decrease in a constant rate on increasing the slag to lime ratio, while the plastic limit was found to increase almost with the same rate. The plasticity index of the soil gradually decreased from 29.21% to 10.64% on increasing the slag to lime ratio upto 4:1.

4.3 Effect on the compaction characteristics

Compaction characteristics namely optimum moisture content and maximum dry density were determined from Standard Proctor Test.

4.3.1 Effect of lime on the compaction characteristics

Figure 6 reveals the compaction curves of the lime treated samples. On increasing the lime content from 3 to 9%, the optimum water content is increasing to 34.73% while the maximum dry density is being reduced gradually to 1.30 gm/cc (13KN/m3). This phenomenon of lime on compaction characteristics is due to flocculation.

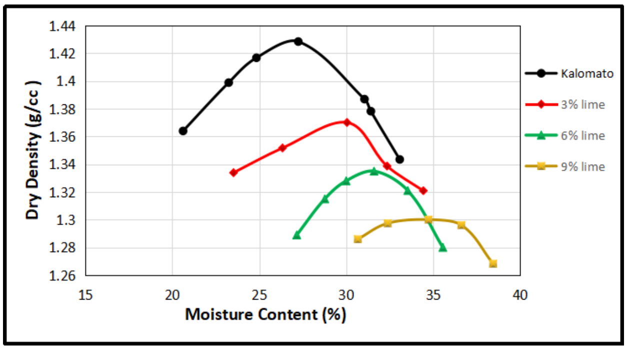

Figure 6: Compaction curves of lime treated samples

4.3.2 Effect of lime activated GGBS on the compaction characteristics

Effect of lime activated GGBS on the compaction curve is shown in the above Figure 7. With the addition of slag/lime ratio, the optimum moisture content(OMC) does not seems to vary much from the OMC of untreated soil but, the dry density is increasing considerably as the ratio increases. The dry

density of slag treated soil is 1.534 g/cc at 4:1 GGBS:lime ratio.
Also with increased ratio, the soil seemed to be much sensitive to water effects, i.e. the two branches of the Proctor curve run much closer to each other than in the case of untreated soil. Therefore, certain specified dry densities are attainable over a much narrow water-content range. This is exactly the results shown by cement treated soil. This property of addition of slag and lime in fixed ratio shows that the GGBS combines with lime to form cementitious product and hence stabilized the soil.

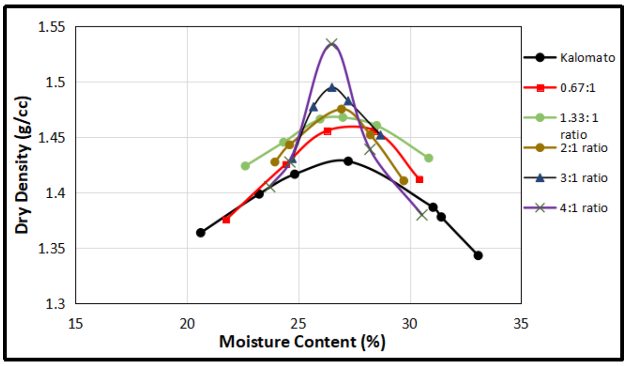

Figure 7: Effect of slag lime ratio on the compaction characteristics

4.4 Effect on Unconfined Compression strength

The unconfined compression tests were performed on treated and untreated compacted specimens following the procedure in ASTM D-5102 procedure.

Table 4: Effect of lime content on UC Strength

Lime %	7 days	14 days	28 days
3% lime	324.51	351.80	426.38
6% lime	413.20	428.76	497.17
9% lime	350.57	376.90	416.17

Table 5: Effect of GGBS/lime ratio on UC Strength

GGBS:Lime ratio	7 days	14 days	28 days
0.67:1	239.14	269.37	293.83
1:1	259.10	298.33	322.73
2:1	276.21	313.59	352.01
3:1	301.69	330.33	382.98
4:1	337.42	366.58	432.20

4.4.1 Effect of Curing time on UC Strength

From the above Table 4 and 5, it is evident that strength of either lime treated or lime activated GGBS treated samples is directly proportional to the curing period. Increase in lime content or slag content showed increase in the UC strength values and this value increased with the curing periods. The strength development of the treated samples is found to increase linearly with the curing periods of 7, 14 and 28 days and this behavior is clearly shown in the Figure 8.

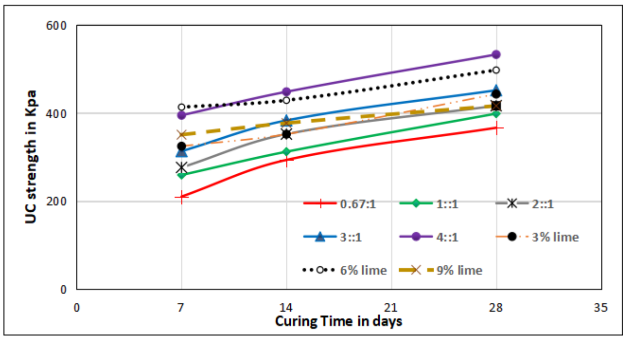

Figure 8: Effect of curing period on the UCC strength

From the above Table 4 and 5, it is evident that strength of either lime treated or slag treated samples is directly proportional to the curing period. Increase in lime content or slag content showed increase in the UCC values and this value increased with the curing periods. The strength development of the treated samples is

Table 3: Geotechnical results of the treated samples (Index parameters)

Samples	GGBS:lime ratio	Liquid Limit	Plastic Limit	Plasticity Index	Shrinkage Limit
3% lime	-	43.42	32.74	10.67	31.79
6% lime	-	44.07	29.66	14.40	28.87
9% lime	-	45.76	26.84	18.92	25.21
%GGBS:%Lime	0.67:1	47.36	26.93	18.54	29.74
%GGBS:%Lime	1:1	44.36	27.01	17.23	31.54
%GGBS:%Lime	2:1	42.52	28.12	14.40	29.24
%GGBS:%Lime	3:1	40.97	28.82	12.14	26.31
%GGBS:%Lime	4:1	41.10	30.46	10.64	26.40

found to increase linearly with the curing periods of 7, 14 and 28 days and this behavior is clearly shown in the Figure 7.

4.4.2 Effect of lime on the UC strength

Figure 9 shows the stress strain curves of the lime treated samples cured for 28 days and Table 4.and Figure 8 clearly shows the variation of UC strength with curing periods of 7, 14 and 28 days. The 28 days UC strength of 6% lime treated sample shows UC strength value of 497.17 kPa while the UC strength values are 426.38 kPa and 416.17 kPa for 3% and 9% lime. It is found that the 6% lime treated sample has higher strength than 3% and 9% lime treated samples for all curing periods. This reveals that optimum lime content for the kalomato soil lies either in between 6 to 9% or is 6%.

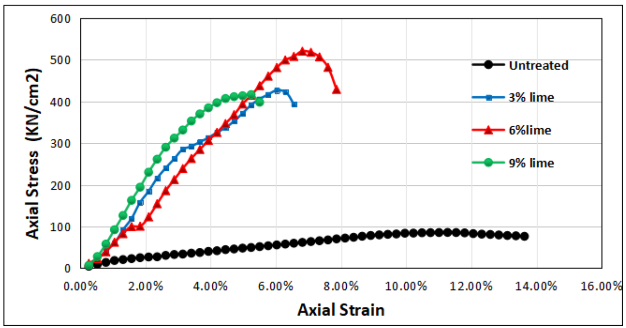

Figure 9: Stress strain curves of different lime proportions for 28 days curing period

4.4.3 Effect of lime activated GGBS on the UC strength

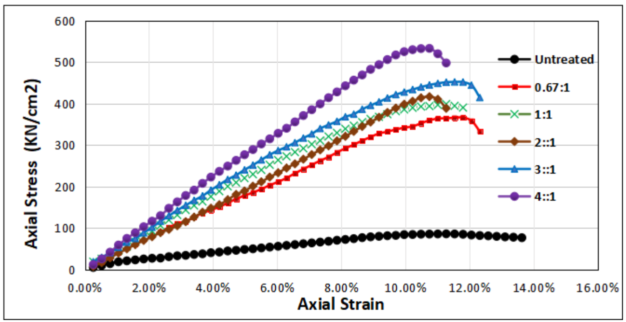

Figure 10: Stress strain curves of different slag lime ratio for 28 days curing period

Figure 10 shows the stress strain curves of the slag treated samples cured for 28 days and Table 5.and Figure 8 clearly shows the variation of UC strength with curing periods of 7, 14 and 28 days. The value of the compressive strength seems to increase with increase in slag content and also shows linear behavior with curing days. During loading the UCS sample in machine, the values of the stress strain is found to increase somewhat linearly till the samples fails. This behavior seems similar to the behavior shown by cement treated soils.

The 28 days UC strength of the ratio 4:1 was obtained as 432.20 kPa which is 4.87 times higher than the untreated soil. This also shows 4:1 GGBS:lime ratio is sufficient amount of slag required for strength development of the soil as was concluded by Higgins et.al,(2005). The optimum GGBS:lime ratio was not found within the ratio considered, it may lie beyond 4:1 ratio.

4.5 Effect on Swelling Parameters

4.5.1 Effect on activity of the samples

According to classification of soils based on activity, the soil is active if activity is ¿ 0.75; normal if activity lies between 0.75 to 1.25 and inactive if ¡0.75.[9]

The activity of the soil is found to be 1.42. This activity falls within the soil type category of "**Active**".This activity shown by the soil is shown by the soil containing mineral illite.

The activity of the samples with 3% lime and samples with GGBS:lime ratio of 3:1 and 4:1 falls under "inactive" category.

4.5.2 Effect on the swelling potential

Samples prepared were inundated with water in oedometer and was allowed to swell under a token load of 7kPa as per ASTM D4546, (1996, 2003) and Sridharan et.al, (1986) [7].

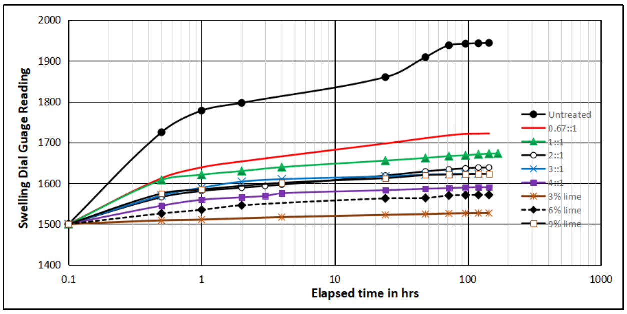

Figure 11: Swelling graphs of all the specimens in consolidometer under the token load of 7kPa

All treated samples showed a reduction in the swelling with the increase in the stabilizer content.

Table 6: Geotechnical results of the treated samples (Swelling parameters)

Samples	GGBS:lime Ratio	% Clay Fraction	Activity	Swell Potentials %
3% lime	-	13.5	0.68	2.70
6% lime	-	15.23	0.79	7.41
9% lime	-	16.1	0.89	12.34
%GGBS:%Lime	0.67:1	23.4	0.79	22.35
%GGBS:%Lime	1:1	22.43	0.76	17.30
%GGBS:%Lime	2:1	18.90	0.76	13.85
%GGBS:%Lime	3:1	19.11	0.63	12.35
%GGBS:%Lime	4:1	21.7	0.49	9.00

4.5.3 Effect of lime on the swelling potential

Figure 12 shows the effect of the lime contents on the swelling potential of the soil. The swelling potential of the untreated soil which was 44.00% drastically reduced to 2.70% with the addition of 3% lime. However, with further increase in lime content, the swelling potentials then increase slightly. This shows that the optimum lime content against swelling is about 3%. Treatment of Kalomato with 3% lime seems to be a better stabilizer for the swelling problem of the soil. This case resembles with the research carried out on lime as stabilizer on expansive soil of Oman. [10]

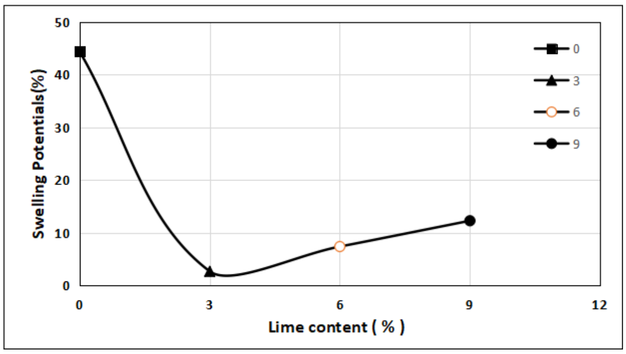

Figure 12: Effect of lime content on the swelling potential

4.5.4 Effect of lime activated slag on the swelling potential

Figure 13 shows the effect of the lime activated GGBS on the swelling potential of the soil. Swelling potential of the soil decreases gradually and proportionally with the increase in slag content. Swelling potentials of the raw soil reduces from 44.00% to 17.30, 13.85, 12.35 and finally to 9% with the slag/lime ratio of 1:1, 2:1, 3:1 and 4:1 respectively. This results showed that activated GGBS is also one of the good stabilizing method against swelling.

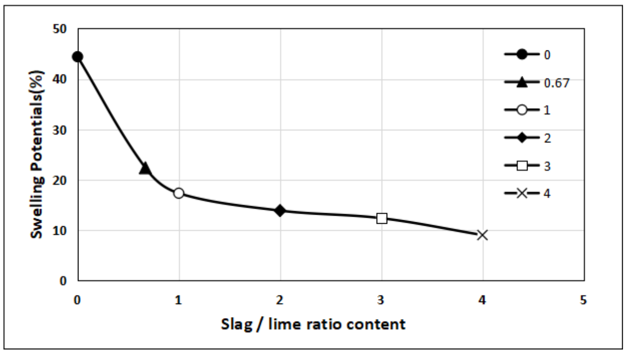

Figure 13: Effect of slag lime ratio on the swelling potential

5. Conclusion

Based on the literature review and experimental investigation the following conclusions are drawn.

- Based on the test result obtained, the UC strength of the soil is found to vary with the lime content, GGBS:lime ratio, and curing periods.
- The optimum lime content of the kalomato ranges from 6-9%.
- The UC strength of the stabilized soil tends to increase simultaneously with the increase in GGBS:lime ratio.
- The 28 days UC strength of the untreated soil which was 85.68kPa, increased to 497.17kPa when treated with 6% lime which is 5.80 times that of the untreated soil.
- The 28 days UC strength of slag treated soil with 4:1 GGBS:lime ratio was 432.20kPa which is 4.87 times that of the untreated soil.
- Swelling potential of the untreated soil was reduced from 44.00% to 2.7% on addition of 3% lime and this value was found to increase continuously with further addition of lime content.

- Swelling potential of raw soil was reduced to 9% by GGBS/lime ratio of 4:1.

Finally, this study concluded that lime stabilized soil at 6% lime content gave the maximum strength but from swelling point of view, 3% lime content suppressed the swelling to minimum. Whereas lime/slag ratio of 4:1 tends to enhance both the strength and swelling parameters of the soil. Hence, this study concluded that GGBS:lime ratio of 4:1 or higher ratio can be used effectively as a stabilizer for stabilizing soft soil.

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