Effects of Ground Granulated Blast Furnace Slag and Lime on the Strength and Durability of Clayey Soil

GhulamSakhi Darwish and Aman Preet Tangri

Abstract: One of the most problematic soils which lay several challenges to civil engineers is expansive soil. Swelling, shrinking and strength instability is the salient problems of this soil, which necessitates the treatment. In this study, different percentage of lime (2,4,6,8,10%) and GGBS (5,10,15,20,25%) are used to stabilize the clayey soil. A set of experimental tests (Atterberg limits, Standard Proctor compaction, Unconfined compressive strength (UCS), and durability) is carried out for investigating the effects of binders on the strength and durability of the clayey soil. The outcomes of this experimental study showed that optimum moisture content (OMC) increases while maximum dry density (MDD) decreases by the addition of lime and vice versa case of GGBS. Furthermore, the combination of lime and GGBS significantly enhanced the strength characteristics and durability of the clayey soil.Strength properties of all soil specimens increased by the extension of curing time (7,14 and 28 days). Atterberg limits of the treated soil declined by raising the percentage of GGBS.

Keywords: Ground granulated blast furnace slag, wetting-drying test, UCS, clayey soil, lime.

I. INTRODUCTION

Soil stabilization means an improvement in both strength and durability which are linked to performance. Generally swelling and shrinking of soil takes place on the surface of the ground because it is subjected to environmental and seasonal variation directly[1]. Expansive soil has a broad range of mineralogical composition and most of the foundation damages especially savers are related to the monovalent cations taken by the clay soil. Construction of civil engineering structures on expansive nature soil is unsafe, such soils are susceptible to drying-wetting cycles including shrink-swell behavior of foundations which ended to cracks of building elements constructed on it. These injuries drive to some inevitable failures to the buildings that require billions of dollars to treat them [2]. The primary target is to improve the strength, durability and mechanical behavior of soil. Many researchers have tried to treat expansive soil by using different stabilizers [3]–[5].

Lime (Ca O) recognized as the most appropriate stabilizer in pavement projects [6], [7] particularly in the repair of clayey foundations. Addition of lime to the expansive soils carrying water ends in hydration, cations and ions replacement takes place between lime and water.

Revised Manuscript Received on June 15, 2019

GhulamSakhi Darwish, Dept. of Civil Engineering, Chandigarh University, Mohali, India.

Aman Preet Tangri, Dept. of Civil Engineering, Chandigarh University, Mohali, India.

lime absorbs water of the mixture ends in a hydrated lime ($Ca(OH)_2$) compound within an accelerated reaction and generates a substantial amount of heat throughout the process.

Internal reaction process between lime, soil, and water is very similar to Portland cement(PC) including environmental hazards and heat production process. Nowadays, the consumption of lime in such ways has risen the negative impacts such as carbon emission, energy consumption and cost. Moreover, although lime addition improves the engineering behavior and performance of clayey soil to a concluded range, there are some defects also. For example, the addition of lime to soil cause in reducing the plasticity of the soil [8] and results in brittle failure specimens that abruptly lost strength at the moment of collapse and failure. Hence, the stabilization of clayey soil by other additives such as fibers and different environmentally friendly stabilizers partially or full replacement with lime reduce the lime consumption and this trick approved by many researchers [9]–[11].

In this contemporary world knowledge and technology have become improved, the production of new materials results in the production of some new by-products. For instance, GGBS, which used in a broad range in geotechnical engineering lately is a by-product of the steel industry. This by-product is not only environmentally friendly and saves energy but also is a cost-efficient and easily available material. Recently clayey soil stabilized by some researchers with GGBS [12]–[14]. In this case, [15], investigated the effects of partial replacement of GGBS by lime on the engineering performance of clay soil. The Ring shear strength, UCS, and volumetric shrinkage strength tests have been conducted on the soil. The results showed that VSS reduces by replacing of lime with GGBS also it demonstrated that shrinkage reduction of the soil depends on the curing time. Furthermore, higher UCS, greater shear strength and formation of cementitious reactivity have been observed with the aforementioned replacements. In another study, [16], investigated the impact of lime on the compressibility of soil. The research concluded that lime reduces the plasticity index and liquid limit of expansive soil. Pozzolanic reaction ensues with the introduction of lime, MDD decreased while compressibility of soil improved by dropping the coefficient of volume compressibility(mv).

The stated papers noted that lime is an effective binder for clayey soil, mainly in the pavementareas. Furthermore, the application of lime with other binders such as byproduct materialssignificantly enhances the geotechnicalcharacteristics of the soil.Therefore, this research meant to study the

Published By:
Blue Eyes Intelligence Engineering & Sciences Publication

influences of lime and GGBS contribution in clayey soil. There are many investigations that studied the soil's properties such as shear strength, volumetric changes, and UCS that apex the momentous of these characteristics of the soil [17], [18]. Therefore, to detect the influences of lime and GGBS application on the strength, durability and compaction characteristics of the treated clayey soil, a set of experimental tests comprise of Atterberg limits, standard Proctor, UCS, and durability conducted on the soil.

II. MATERIAL USED

Soil: The soil having the properties drawn in table 1 has been brought up from Gharuan district of Punjab, India. Large segments of soil sample crushed into smaller particles and then passed through IS sieve (4.75mm) for specimen fabrication.

Table 1 Virgin Soil Properties

No	Parameter	Value
1	liquid limit (LL)	31.301%
2	plastic limit (PL)	15.03%
3	plasticity index (PI)	16.271%
4	specific gravity	2.68
5	O.M.C	15.7%
6	M.D.D	1.75 gr/cm^3
7	U.C.S	0.4 Kg/cm^2

GGBS: It provided from Mandi Gubindgarh, Punjab, India steel industries and crushed into small particles. The crushed particles of the slag passed through IS sieve (2.5mm) and then added to the soil.

Lime: The lime selected to use is an industrial hydrated lime. An amount of (2,4,6,8,10%) lime and (5,10,15,20,25%) of slag stabilizer is added to establish the optimum amountof stabilizers.

III. METHODOLOGY

To ascertain the effects of lime and GGBS, experimental studies conducted on the soil. In the experimental part, Atterberg limits, standard Proctor, UCS and durability tests were carried out. First of all, an optimum amount of lime obtained by conducting the U.C.S test then the strength of soil evaluated by adding various percentages of GGBS to find out the optimum amount. Table 2 shows the mechanism and a summary of mix design for preparation of specimens.

Table 2 Summary of Mix Design For Preparation of Specimens

No	Mix ID	Lime(%)	GGBS(%)	Curing(day)
1	0L-0G	0	0	7
2	2L-0G	2	0	7
3	4L-0G	4	0	7
4	6L-0G	6	0	7
5	8L-0G	8	0	7
6	10L-0G	10	0	7
7	7L-0G	7	0	7,14,28
8	7L-5G	7	5	7,14,28
9	7L-10G	7	10	7,14,28
10	7L-15G	7	15	7,14,28
11	7L-20G	7	20	7,14,28
12	7L-25G	7	25	7,14,28

In the Mix ID column, L-G stands for (%lime-%GGBS)

A. Atterberg Limit Test

Liquid limit: By using IS 2720 part 5, an amount of 120 gr soil passed through IS sieve (425-microns) and thoroughly mixed with distilled water. A portion of uniform paste placed in the cup of Casagrande machine. The past shredded and trimmed to shape a one-centimeter thickness at the deepest position of the cup. A clean groove made by stroking the grooving tool at the center of the cap. By turning the crank of the machine, the cap dropped from one-centimeter distance twice a second time and the number of drops recorded until the two halves of the soil cake closed for the length of 12mm. Three samples prepared, in each sample, the amount of water increased and the same procedure repeated.

Plastic limit: As per guidance of IS code an amount of 20 gr soil passed through IS sieve (425-micron) and mixed thoroughly with distilled water in an evaporating dish for evaluating the plastic limit of the soil. After moulding the mass of soil a ball about 10 gr has shaped and then the rolling of the ball started at a rate of 80 stocks per minute. Rolling of the soil by fingers continued until crumbling of soil thread. The diameter of the thread at the time of crumbling was about 3 mm. The pieces of crumbled thread collected for the water content determination.

Plasticity index: PI of the soil determined by subtracting the plastic limit (LL) from liquid limit (PL).

B. Standard Proctor Test

As per IS 2720 part 7 guidance, lightweight compaction test conducted to Figure out the relationship between water content and maximum dry density of the soil. In this case, a 1000cm^3 cylindrical mould weight 4.7Kg and a 2.5 Kg hummer with a falling distance 31cm used to perform the test. An amount of about 5Kg air-dried soil passed through the sieve size 4.75 mm and mixed thoroughly with different amounts of water and stabilizer. The mould filled in three layers, each layer is given 25 drops by hummer above the soil. Five samples made for each increment of 2% water and put into the oven for determining the OMC.

C. Unconfined Compressive Strength Test

According to IS 2720 part 10 guidance, the UCS test carried out to determine the strength of the soil. The mould used for making specimens has the size of 38mm internal diameter and 76mm height. The MDD and OMC obtained by light compaction tests were considered as a reference for the formation of the specimens. The predetermined soil, water, and agent mixed thoroughly with each other and then compacted by a loading machine. Also, extra specimens provided for testing the dry side (2% water less than O.M.C) and wet side (2% water more than O.M.C) of the optimum moisture content. After three ageing periods of curing 7,14 and 28day the specimens compressed and tested. Table 2 indicates the summary of planned and implemented UCS test.

D. Durability Test

The strength reduction index or durability index is an experimental method of evaluating the strength of soil specimens several times immersed in the water as an amount of the same material in its initial state.Based on IS 4332 part 4 instructions, wetting-drying procedure performed on the soil specimens for evaluating the durability of the treated soil. In this method the UCS test performed on the soil specimens to study the strength losses after subjecting to 12_{w-d} cycles. The procedure for making specimens was the same as the UCS test The samples identified as No1 and No2. Wetting and drying cycles started after 28 curing days, No1 was the reference specimens and were not immersed in the water. Each cycle of No2 specimens contains putting of sample in the water for about 4 hours and then putting it in the oven for 42 hours at a temperature of 70 C^o degree. After 12_{w-d} cycles the UCS test performed on both No1 and No2 specimens. The strength results of both samples analyzed and compared with each other.

IV. RESULT AND DISCUSSION

E. Determinationof Atterberg limits for Classification of Virgin Soil

Liquid limit: Fig 1 depicts the number of drops on X-axis (logarithmic scale of 10) and moisture content on the Y-axis. Thus the liquid limit equals to 31.3% corresponding to the drop number 25.

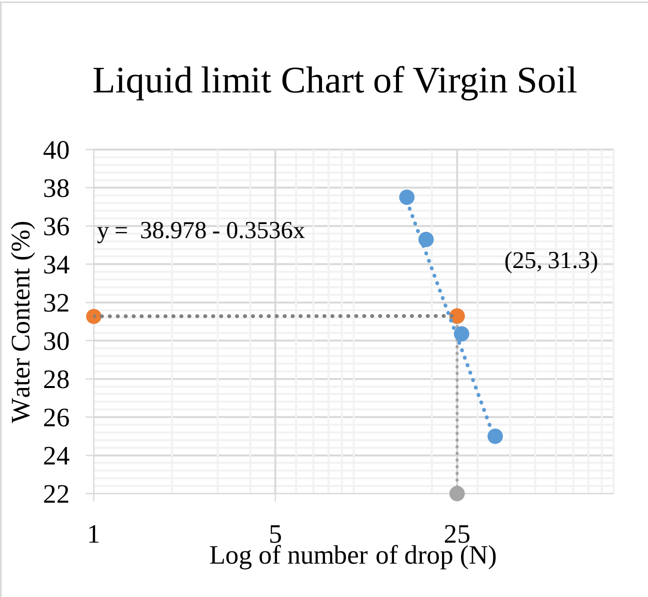

Fig 1(LL) value corresponding to the blow no 25th.

Plastic limit: three samples prepared and the average value of three specimens obtained as the plastic limit of the soil. In this case table 3 contains the plastic limit values of virgin soil.

Table3 Shows Calculation of LL for Virgin Soil.

Plastic Limit Test Result				
No	Element	Trail 1	Trail 2	Trail 3
1	Plastic limit(%)	15	14.7	15.4
2	Plastic Limit = 15.03%			

Plasticity index: PI of the soil can be determined by subtracting the (LL) from (PL).

Plasticity Index (PI) = Liquid Limit (LL) – Plastic Limit (PL)

Plasticity Index (PI) = 31.3 – 15.03 = 16.27%

Hence, the results showed that the soil can be classified as low plastic poor clay.

F. Effects of binders on Atterberg limit

The Atterberg limit test results concerning GGBS and lime combination is displayed inFig 2.Atterberg limits are decreasing due to GGBS % increment. The LL and PL of the treated soil (7% L-15% GBBS) decreased by 41.85% and 24.37% respectively as compared to virgin soil. The decline in LL is an outcome of replacements of calcium and cations of the clay mineral.So that, size of the spread water layer surrounding the clay bits starts to decreasing and commences in contraction between clay particles which ends to flocculation and agglomeration of the soil bits.

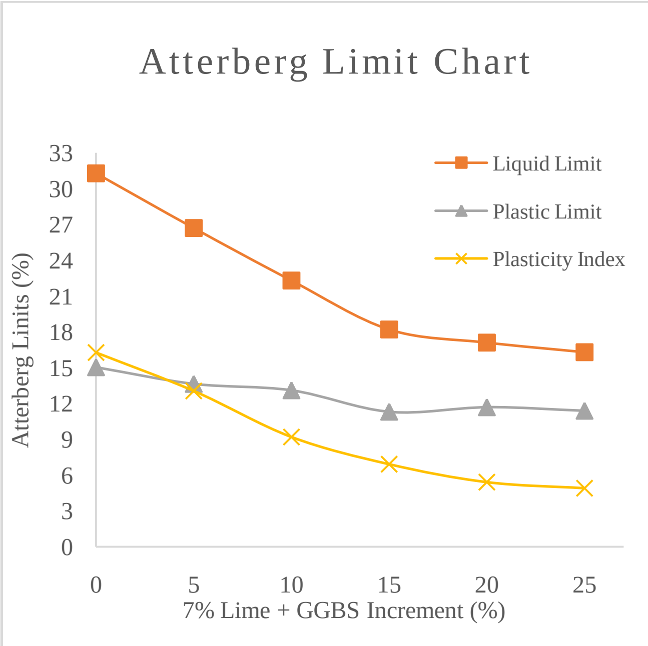

Fig 2 Shows Atterberg Limit Test Results of Virgin and Treated Soil

G. Effects of Binders On Compaction Characteristics

Overall, with the increment of lime content, MDD decreased while OMC increased. However, by increasing the amount of GGBS percentage in the soil the MDD increased but OMC decreased. Fig 3 displays the surging of moisture content with lime increment. Fig 4 portrays the OMC declines at a fixed rate of 7 % lime and differing rates of GGBS. Fig 5 depicts changes in soil density at a different percentage of lime andFig 6shows increments of soil density at a fixed rate of 7 % lime and varying rates of GGBS.

The flocculation of soil bits shows that mixture is compactable at a lower water content ending in a decline in OMC. Meantime, the shreds of soil get closer due to the reduction in rebuff among the clay bits, ending in a high density even at a low level of moisture.

Published By:
Blue Eyes Intelligence Engineering &
Sciences Publication

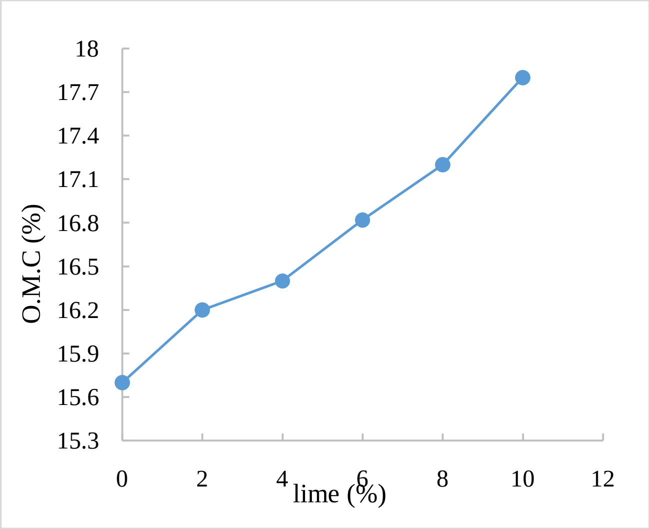

Fig 3Variations of soil optimum moisture content at different percentage of lime.

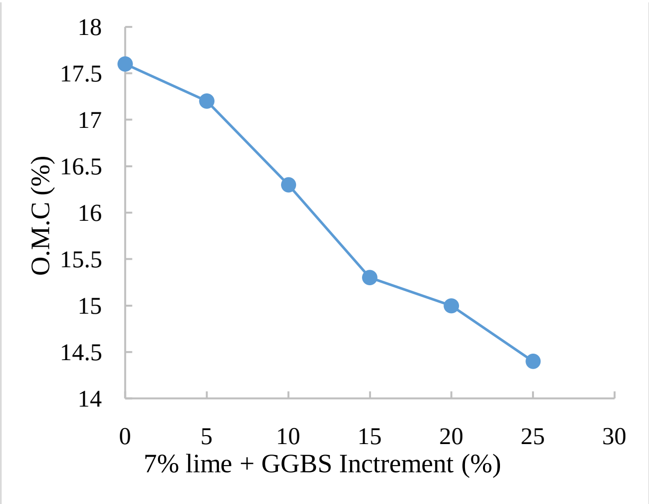

Fig 4 O.M.C. Changes in the soil at a fixed rate of 7 % lime and differing rates of GGBS.

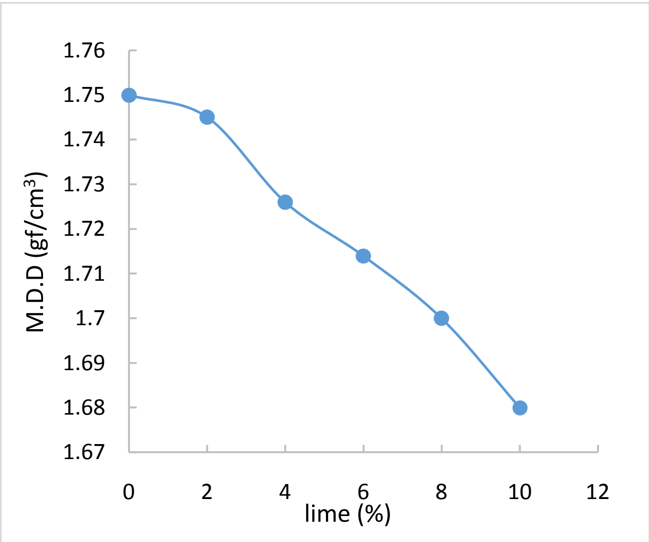

Fig 5 Changes in soil density at a different percentage of lime.

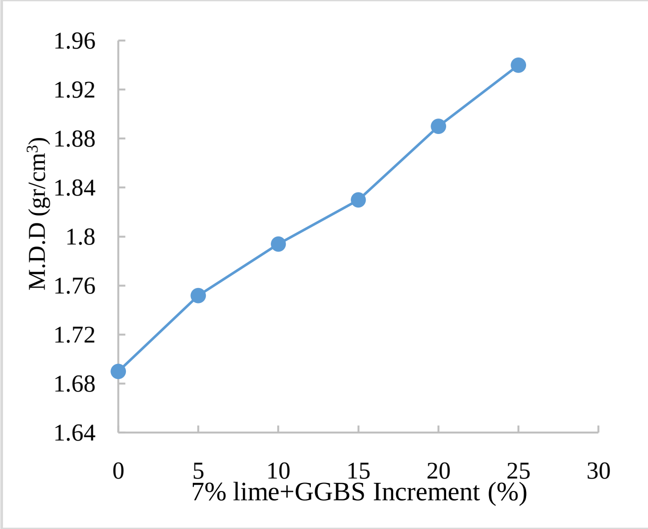

Fig 6 Variations of soil density at a fixed rate of 7 % lime and varying rates of GGBS.

H. Effects of Binders On Strength Characteristics

Strengthof soil improved with an increase in the amount of GGBSand lime to a concluded range. Fig 7 depicts the strength changes of lime added soil (without GGBS) for 7day curing periods concerning the amounts of the binder. Lime extension resulted in the formation of cementitious compounds which provided more strength to the soil. The strength of soil rises up to 7% of the lime addition and then declines after that. Declining strength after a certain amount of stabilizer has been proclaimed by many researchers [19], [20]. The pozzolanic reaction between calcium and silica ends in the production of cementitious composites notably calcium–silicate–hydrates, calcium–aluminate–hydrates, and calcium aluminum–silicate–hydrates. The composition of these Pozzolanic compounds in the soil-lime mixture increases the strength of the treated soil.

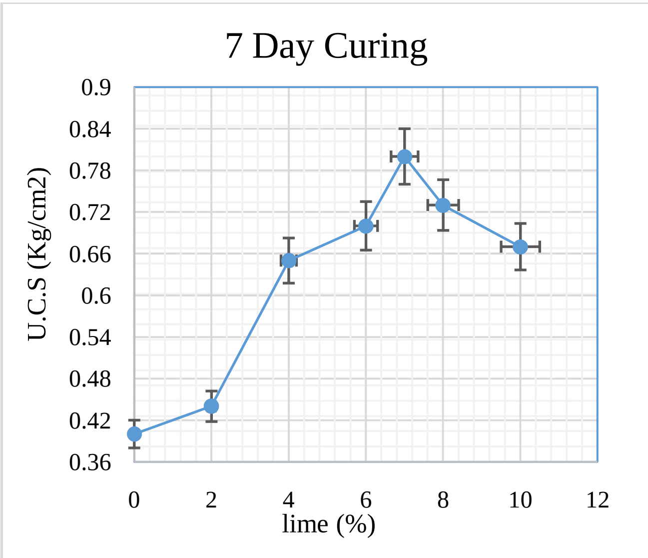

Fig 7 Variation of soil strength when different amount of lime added to the soil after 7 days curing

GGBS is a weak self-hardening stabilizer if used without any other chemical-activator like cement or lime. Contribution of lime with GGBS significantly improved the strength of the soil. Fig 8 depicts the changes in the soil strength at a fixed value of 7% lime and varying amounts of GGBS after 7 days curing. Fig 9 portrays variations of soil strength at different percentages of GGBS after a curing age of 14 days. Also, the strength characteristics of soil at the various percentage of GGBS after 28 days curing has displayed by the Fig 10.

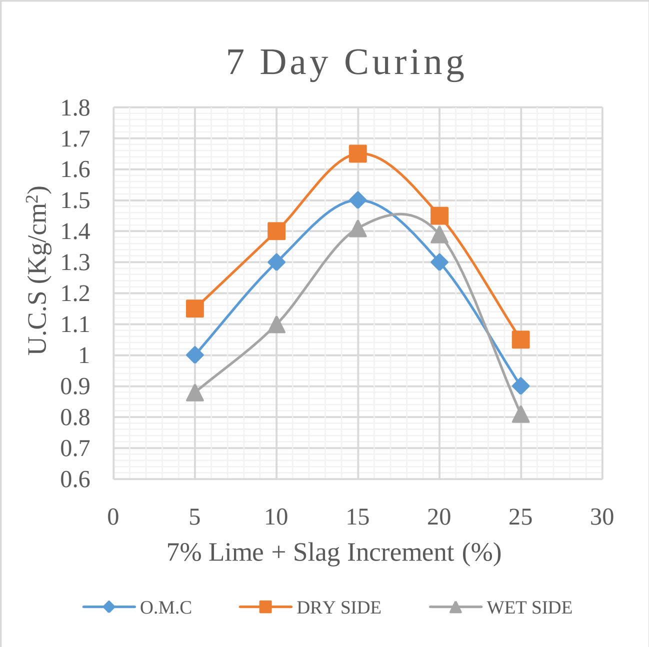

Fig 8 Changes in soil strength when a fixed amount (7%) of lime and a varying amount of GGBS added to the soil after 14 days curing.

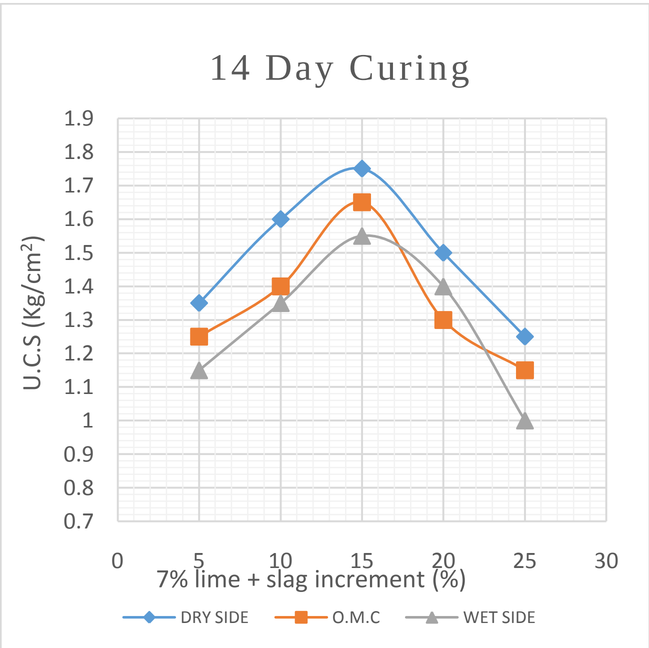

Fig 9 Effects of 7% lime and varying amount of GGBS on the strength of soil after 14 days curing.

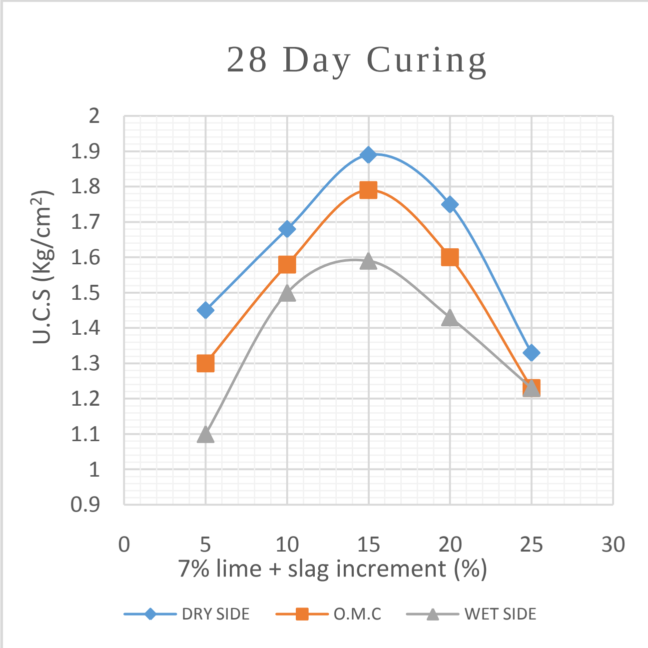

Fig 10 Alteration of soil strength when a fixed amount (7%) of lime and a varying amount of GGBS added to the soil after 28 days curing.

er

surges until an increment of 15% GGBS and declines after that. The strength improvement of soil attributes to the solidification of soil particles by the composition of cementitious material and crystals. These crystals are directly correlated to the curing time and develop after introduction of stabilizer to the mixture. Evolution of bonds between particles and crystals of the mixture ends in joining the soil particles, which is an inducement of strength improvement.

Hence, based on the UCS test results with and without GGBS, the addition of 7% lime and 15% GBBS binder is suggested as an excellent content to treat the expansive soil efficiently.

I. Effects of Binders On the Durability of the Soil

Fig 11 depicts the consequences of strength reduction indexes taken on the completely submerged specimens in water for 4 hours and $12_{w\text{-}d}$ cycles after a 28day curing time. The strength of soil decreased modestly up to $4_{w\text{-}d}$ cycles and dramatically declined thereafter but, after $8_{w\text{-}d}$ cycles, the strength of soil started declining steadily. By the increase of $N_{w\text{-}d}$, crack generation and mass losses seen in the soil specimens which ends to the reduction in soil strength and stability.

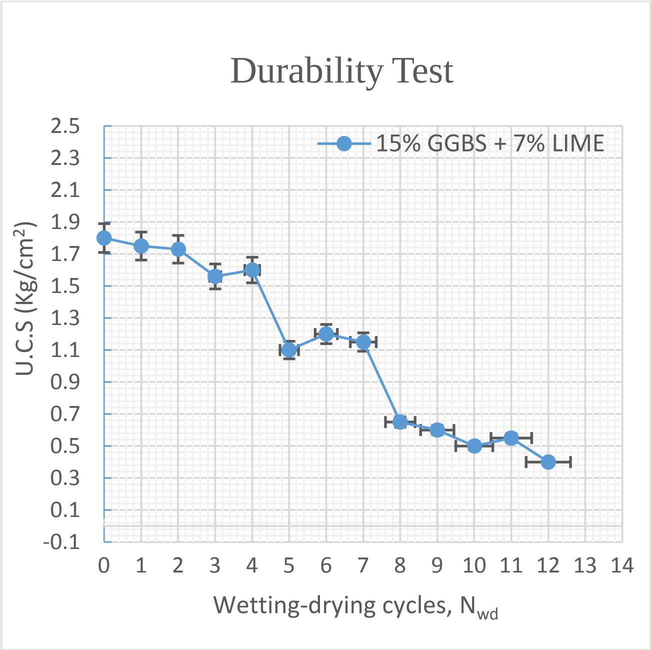

Fig 11Influences of 12 wetting-drying cycles of 7% lime + 15% GGBS on the strength of the soil

When the various percentage of slag added to stabilize the soil, strength and resistance of soil to N_{w-d}raised gradually. Fig 12 compares the strength of treated soil immersed 12 times in the water with its initial state (0 times immersed in the water) and virgin soil. Therefore, the strength of the soil after 28 days curing and 12 $_{w-d}$ cycles reduced almost 77.7% as compared to 0_{w-d} cycle samples. Above all, the strength of treated soli is more than the virgin soil even after 12_{w-d} cycles see Fig 12.

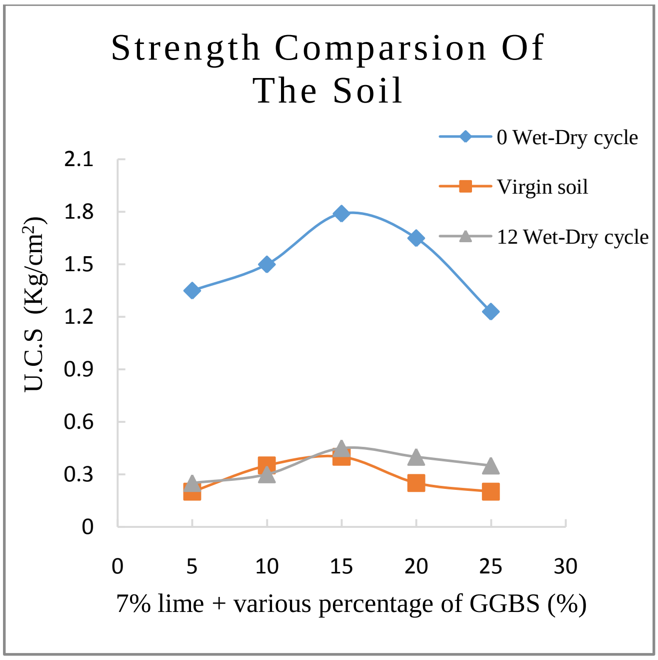

Fig 12a comparison of soil strength between virgin, 12 times immersed in water, and 0 times immersed specimens.

As the results showed, the strength of soil increased by the increase of curing time and continued until the application of 15% GGBSand then decreased by adding a greater amount. The results noted to be regularly better at 15% GGBS and 7% lime as durability at the various moist curing ages.

J. Effects of Curing Time On the Strength of Soil

The reaction of bonding soil bits together and strengthen them by curing is called Pozzolanic reaction and it ultimately depends on curing time. Production of crystals and cohesion of soil particles ends to a notable improvement in the strength and stability of the soil. It has seen that at all percentages of lime and GGBS the coherence level of soil particles is going to increase by increasing the amount of curing time. Fig 13 shows the results of 7,14 and 28 days curing periods on the strength parameters of 7% lime along with the different percentages of GBBS.

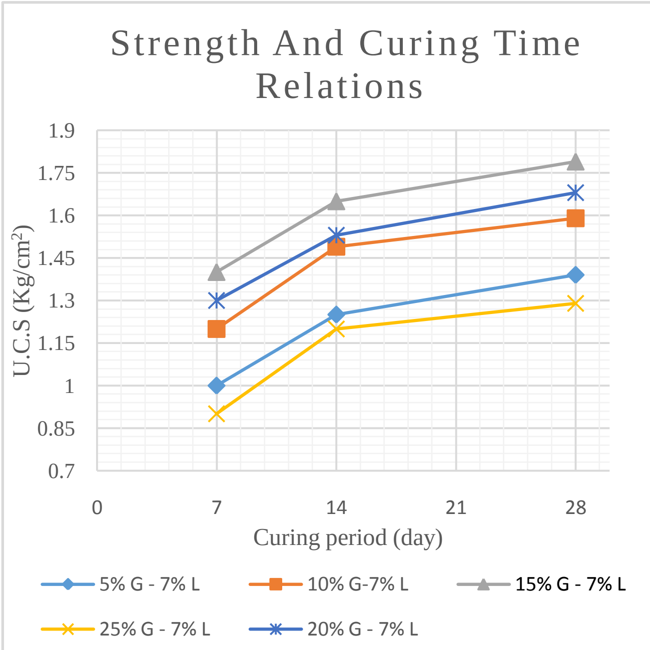

Fig 13 effects of curing time on the strength of treated soil.

V. CONCLUSION

In this study, the influences ofGGBS and lime on the strength characteristics and durability of soil were investigated.Atterberg limits, Standard Proctor test, UCS, and wetting-drying test for durability investigation were performed on the clayey soil at a curing period of 7,14 and 28 days. The following conclusion shows the outcome of the test result.

1. The optimum amount of lime and GGBS suggested to be used for stabilizing the clayey soil is 7% and 15% respectively.
2. The strength of soil increased by about 100% with 7% lime alone and 347.5% by adding the blend of 7% lime + 15% GGBS.
3. The OMC increased from 15.7% to 17.8% while MDD decreased to 1.68gr/cm^3 from 1.75 gr/cm^3 by adding the optimum amount of 7% lime to the soil.
4. By applying a fixed percentage of 7% lime and varying percentages of GGBS until 15%, The OMC of the soil decreased to 15.3% from 17.6% while MDD of the soil increased from 1.69gr/cm^3 to 1.83gr/cm^3.
5. About 77.7% of strength reduction observed in the UCS test of soil after subjecting to 12_{w-d} cycles as compare to their initial state (*0 N_{w-d} cycle*).

6. The strength of treated soil was more than un-treated soil even after subjecting to $12_{w\text{-}d}$ cycles.
7. Strength characteristics of all soil specimens increased by the increase of curing time.
8. Liquid Limit and Plastic Limit of the treated soil decreased by 41.8% and 26% respectively as compared to virgin soil.

The bellow pie chart, shows the combination of soil, lime and GGBS by-product which showed the best result.

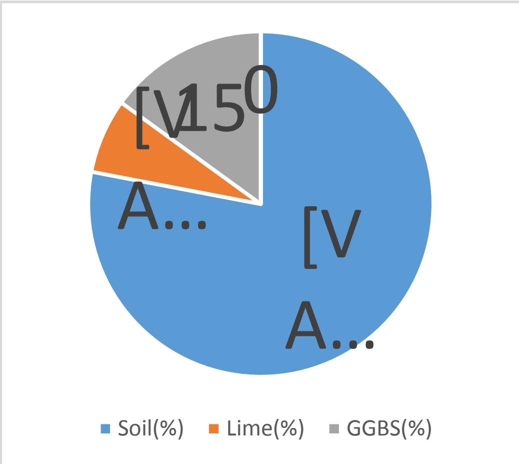

Fig 14Soil, lime and slag composition

REFERENCE

1 L. C. Dang, B. Fatahi, and H. Khabbaz, "Behaviour of Expansive Soils Stabilized with Hydrated Lime and Bagasse Fibres," *Procedia Eng.*, vol. 143, no. Ictg, pp. 658–665, 2016.

2 T. M. Petry and D. N. Little, "Review of Stabilization of Clays and Expansive Soils in Pavements and Lightly Loaded Structures—History, Practice, and Future," *J. Mater. Civ. Eng.*, vol. 14, no. 6, pp. 447–460, 2002.

3 H. Canakci, F. Celik, M. O. A. Bizne, and M. O. A. Bizne, "Stabilization of Clay with Using Waste Beverage Can," *Procedia Eng.*, vol. 161, pp. 595–599, 2016.

4 A. M. Mosa, A. H. Taher, and L. A. Al-Jaberi, "Improvement of poor subgrade soils using cement kiln dust," *Case Stud. Constr. Mater.*, vol. 7, no. June, pp. 138–143, 2017.

5 P. Ghadir and N. Ranjbar, "Clayey soil stabilization using geopolymer and Portland cement," *Constr. Build. Mater.*, vol. 188, pp. 361–371, 2018.

6 A. Zukri, "Pekan soft clay treated with hydrated lime as a method of soil stabilizer," *Procedia Eng.*, vol. 53, pp. 37–41, 2013.

7 B. Kanddulna, N. Kisku, K. Murari, and J. P. Singh, "Experimental Study of Clayey Soil with Lime and Rice Husk Ash," *Int. J. Eng. Trends Technol.*, vol. 38, no. 7, pp. 365–372, 2016.

8 A. M. Asma Muhmed, "Effect of Lime Stabilisation on the Strength and Microstructure of Clay," *IOSR J. Mech. Civ. Eng.*, vol. 6, no. 3, pp. 87–94, 2013.

9 N. Dave, A. K. Misra, A. Srivastava, and S. K. Kaushik, "Setting time and standard consistency of quaternary binders: The influence of cementitious material addition and mixing," *Int. J. Sustain. Built Environ.*, vol. 6, no. 1, pp. 30–36, 2017.

10 N. M. Ilieş, A. P. Cîrcu, A. C. Nagy, V. C. Ciubotaru, and Z. Kisfaludi-Bak, "Comparative Study on Soil Stabilization with Polyethylene Waste Materials and Binders," *Procedia Eng.*, vol. 181, no. June, pp. 444–451, 2017.

11 D. Gupta and A. Kumar, "Strength Characterization of Cement Stabilized and Fiber Reinforced Clay–Pond Ash Mixes," *Int. J. Geosynth. Gr. Eng.*, vol. 2, no. 4, pp. 1–11, 2016.

12 F. I. Shalabi, I. M. Asi, and H. Y. Qasrawi, "Effect of by-product steel slag on the engineering properties of clay soils," *J. King Saud Univ. - Eng. Sci.*, vol. 29, no. 4, pp. 394–399, 2017.

13 M. V. Vakili, A. Chegenizadeh, H. Nikraz, and M. Keramatikerman, "Investigation on shear strength of stabilised clay using cement, sodium silicate and slag," *Appl. Clay Sci.*, vol. 124–125, pp. 243–251, 2016.

14 A. Tangri, "Improvement in Strength and Durability of Soil using Blast Furnace Slag and Lime PERCENTAGE OF SLAG OF," pp. 23–25, 2016.

15 M. Keramatikerman, A. Chegenizadeh, and H. Nikraz, "Effect of GGBFS and lime binders on the engineering properties of clay," *Appl. Clay Sci.*, vol. 132–133, pp. 722–730, 2016.

16 A. J. Alrubaye, M. Hasan, and M. Y. Fattah, "Engineering properties of clayey soil stabilized with lime," *ARPN J. Eng. Appl. Sci.*, vol. 11, no. 4, pp. 2434–2441, 2016.

17 M. Mohammadia and A. Hussain, "Stabilization of Clay Subgrade Soils for Pavements Using Ground Granulated Blast Furnace Slag," vol. 5, no. 4, pp. 764–773, 2017.

18 P. P. Dahale, P. B. Nagarnaik, and A. Y. Gajbhiye, "Engineering Behavior of Remolded Expansive Soil with Lime and Flyash," *Mater. Today Proc.*, vol. 4, no. 9, pp. 10581–10585, 2017.

19 J. A. Baldovino, E. B. Moreira, W. Teixeira, R. L. S. Izzo, and J. L. Rose, "Effects of lime addition on geotechnical properties of sedimentary soil in Curitiba, Brazil," *J. Rock Mech. Geotech. Eng.*, vol. 10, no. 1, pp. 188–194, 2018.

20 M. Al-Mukhtar, A. Lasledj, and J. F. Alcover, "Behaviour and mineralogy changes in lime-treated expansive soil at 20°C," *Appl. Clay Sci.*, vol. 50, no. 2, pp. 191–198, 2010.

AUTHORS PROFILE

Er. Aman Preet Tangricurrently Ass. Prof. in Civil Eng. Dept. at Chandigarh University, Gharuan, Mohali, India. He received his B.Tech. degree in Civil Eng. And M. Tech. degree in Geotechnical Engineering.

Ghulam Sakhi Darwish is currently doing M.E in Construction Technology and Management at Chandigarh University, Gharuan, Mohali, India. He received his B.E degree in Civil Eng.