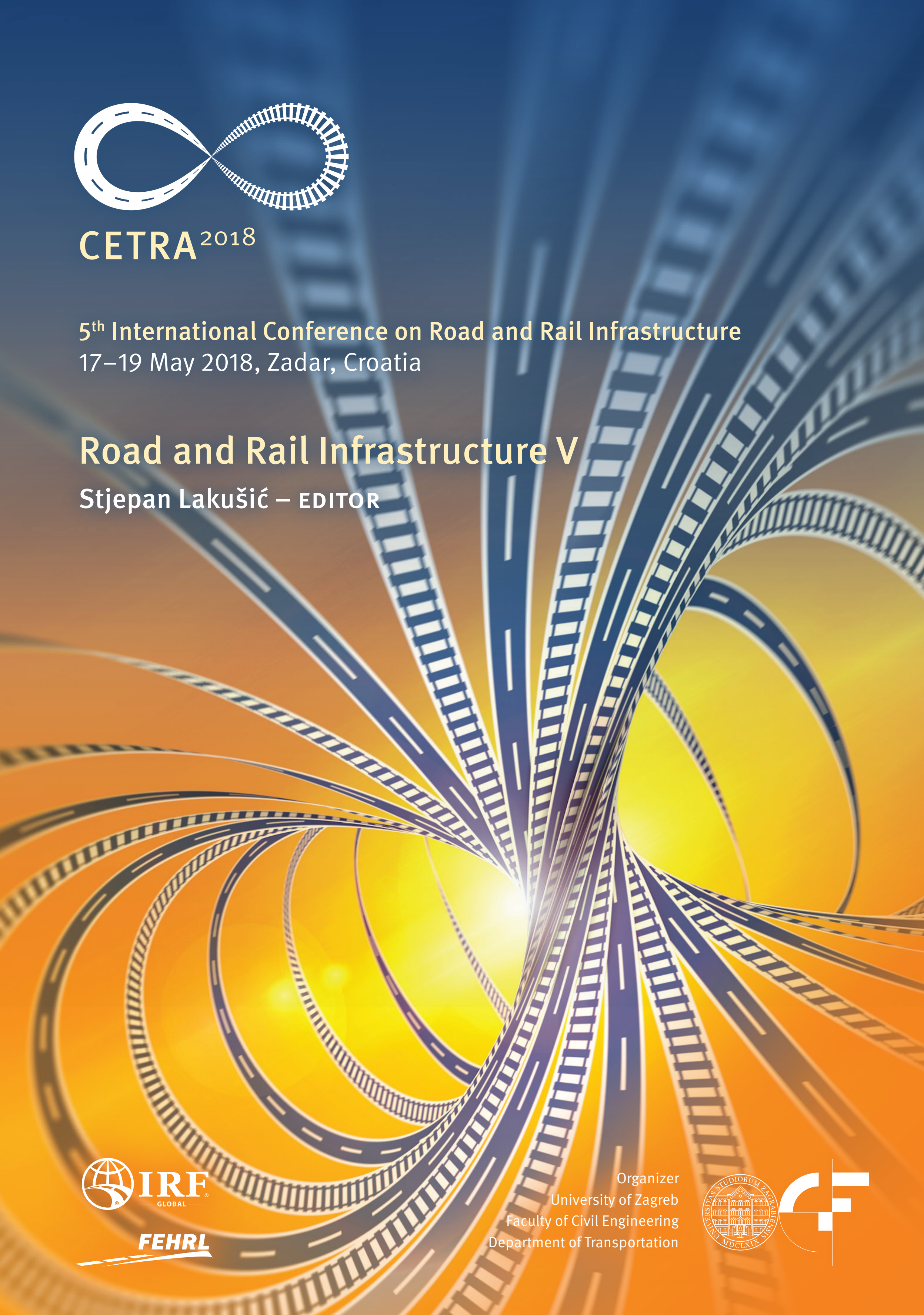

CETRA[2018]

5th International Conference on Road and Rail Infrastructure
17–19 May 2018, Zadar, Croatia

Road and Rail Infrastructure V

Stjepan Lakušić – EDITOR

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TITLE
Road and Rail Infrastructure V, Proceedings of the Conference CETRA 2018

EDITED BY
Stjepan Lakušić

ISSN
1848-9850

ISBN
978-953-8168-25-3

DOI
10.5592/CO/CETRA.2018

PUBLISHED BY
Department of Transportation
Faculty of Civil Engineering
University of Zagreb
Kačićeva 26, 10000 Zagreb, Croatia

DESIGN, LAYOUT & COVER PAGE
minimum d.o.o.
Marko Uremović · Matej Korlaet

PRINTED IN ZAGREB, CROATIA BY
“Tiskara Zelina”, May 2018

COPIES
500

Zagreb, May 2018.

Proceedings of the
5th International Conference on Road and Rail Infrastructures – CETRA 2018
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STABILIZATION OF CLAYEY SOIL USING GGBF SLAG WITH PORTLAND CEMENT AND HYDRATED LIME

Alpa J. Shah, Ankit D. Adwani
L.D. College of Engineering, Ahmedabad, India

Abstract

Soil existing at a particular site may not be suitable for construction works. The purpose of this study is to investigate the utilization of Ground Granulated Blast Furnace (GGBF) Slag with lime and cement as stabilizer.Soil sample collected for this study was classified as clayey soil of low plasticity (CL).The optimum cement content has been fixed as 7 % by dry weight of soil, which was replaced with GGBF as Cement:GGBF Slag ratio 7:0, 6:1, 5:2, 4:3, 3:4, 2:5,1:6 and 0:7. The optimum lime content was determined by Eades & Grim's pH method as 5 % of dry soil. Lime: GGBF Slag contents 5:0, 4:1, 3:2, 2:3, 1:4 and 0:5 were used. Optimum content of GGBF Slag with Lime and Portland cement was determined based on the UCS. The results show that Cement:GGBF ratio of 3:4 gives 13.5 times higher strength than virgin soil at 28 days of curing and Lime:GGBF ratio of 2:3 gives about 10 times higher strength compared to raw soil.

Keywords: soil stabilization, GGBF slag, cement stabilization, lime stabilization, Unconfined Compressive Strength

1 Introduction

In the developing countries like India, due to scarcity of land within the city area has created major problems. Lack of construction space has made it mandatory to carry out construction activity on soft soil. To make these type of soils capable enough to take higher loads coming from the structures above it, soil stabilization is the most effective and efficient method of improving the performance of such soils. Other than compaction, soil reinforcement methods, soil stabilization using additives like cement, lime, Ground Granulated Blast Furnace slag, fly ash, rice husk ash improve the strength of soil.

Another major problem the world facing these days is the disposal of industrial wastes like ground granulated blast furnace slag, fly ash, rice husk ash etc. Waste products are generally toxic in nature and cause serious environmental hazard. It is a great challenge for the industries to find out the effective, economic and environmental friendly solution of waste disposal. If these materials can be used in construction, the pollution caused by them would be greatly reduced. Ground granulated blast furnace slag is a byproduct from the blast-furnaces used to make iron.Some literature supports the effective use of Ground Granulated Blast Furnace (GGBF) Slag as an additive in soil stabilization.

Anil Kumar Sharma & P.V. Sivapullaiah (2012) investigated in their study that the strength improvement of soil depends upon the amount of GGBS used. The strength of soil increases with the addition of GGBS up to 20 % for curing period of 7 and 14 days and up to 40 % for the curing period of 28 days.

DOI: https://doi.org/10.5592/CO/CETRA.2018.685

Ruqayah Al-Khafaji et al.(2017) investigated that the liquid limit of soil decreases and plastic limit increases with increase in GGBF Slag content. Based on the UCS tests, the optimum amount of GGBS was 6 % as it increased the strength by about 80 % of that of soft soil.
Wild S. et al. (1998) examined the strength of soil by partially substituting the lime with GGBS increases at 7 days and 28 days for kaolinite and Kimmeridge clays. If sufficient amount of Lime is added with GGBS it has the potential to improve the strength of soil.

2 Materials used

Soil sample
Soil sample for the current research work was collected from Sanand region of Gujarat, India using method of disturbed sampling. Chemical compositions of collected soil sample have been described in Table 1.

GGBF slag
Ground Granulated Blast Furnace slag was procured from the RMC plant where it is being used as the partial replacement of cement in manufacture of concrete. Chemical properties of GGBF slag have been mentioned in the Table 1.

Table 1 Chemical Composition of Virgin Soil and GGBF Slag

	SiO_2	Al_2O_3	FeO	MgO	K_2O	CaO	Na_2O	MnO_2
Virgin Soil	62.4 %	18.3 %	10.78 %	2.94 %	2.48 %	2.05 %	1.04 %	–
GGBF Slag	30 %	19 %	–	5 %	–	42 %	–	0.15 %

Lime
Quick lime was purchased from the market and it was hydrated in the laboratory using distilled water.

Ordinary Portland cement
Ordinary Portland cement (OPC-53 grade) used in the study was in accordance of BIS 12269:2013.

3 Experimental design

For the current research work 7 % ordinary Portland cement by dry weight of soil was determined as optimum content to be use with soil as a stabilizer which is to be replaced by GGBF Slag in Cement:GGBFS ratio as 7:0,6:1, 5:2, 4:3, 3:4, 2:5, 1:6, and 0:7. Cylindrical specimens of 40 mm in diameter and 80 mm height were prepared in PVC moulds for Unconfined Compressive Strength test. Three specimens were tested of each content and mean values of compressive strength were determined at 3 days, 7 days and 28 days.
Optimum lime content for soil stabilization has been determined using pH method by Eades and Grim. Optimum content corresponding to pH value of 12.4 was noted as 5 % lime by dry weight of soil. Lime: GGBFS replacement ratio is taken as 5:0, 4:1, 3:2, 2:3, 1:4 and 0:5. Total 126 specimens of stabilized soil were prepared at Optimum Moisture Content (OMC) and Maximum Dry Density (MDD).
A simple sample formulation technique is used in the current research work. For example, if sample formulation is 5L0S indicates 5 % lime by dry weight of soil and 0 % GGBF Slag. Similarly, 4C3S represents soil having 4 % cement and 3 % GGBF slag by dry weight. Specimens were kept in a desiccator covered with a sealed plastic bag until the desired curing period to retain the moisture content.

3.1 Testing methods

The laboratory tests conducted on virgin soil include Atterberg's limits, pH value, Specific Gravity, Free Swell Index, Standard Proctor Compaction, and UCS. All the properties of soil were determined as per the methods given by Bureau of Indian Standards (BIS).

3.2 Properties of virgin soil

The properties of virgin soil sample were determined in the laboratory in accordance of Indian standards. The soil is identified as low plastic clay (CL) type as per Indian Standard Classification System. The Specific Gravity and pH of virgin soil was found out to be 2.70 and 7.50 respectively. The engineering properties of virgin soil have been tabulated in table 2.

Table 2 Properties of Soil

Soil Characteristics		Value
Specific Gravity		2.70
Grain Size Distribution	% Sand	36
	% Silt	50.09
	% Clay	14.91
Liquid Limit		32 %
Plastic Limit		21 %
Plasticity Index		11 %
Soil Classification		CL
Free Swell Index		9.09 %
pH Value		7.5
Unconfined Compressive Strength		47.75 kPa

4 Result analysis and discussion

4.1 Compaction characteristics of treated soil

The Standard Proctor test was carried out on each variation in accordance with IS: 2720 (Part VII). The Optimum Moisture Content (w) and Maximum Dry Unit Weight (γ_d) were evaluated as 12.80 % and 19.18 kN/m^3. With addition of lime the optimum moisture content (w) increases to 14.10 % and maximum dry unit weight (γ_d) decreased to 17,90 kN/m^3. By replacing lime with GGBF Slag the optimum moisture content (w) reduced and Maximum Dry Unit Weight (γ_d) increases. A fluster in Maximum Dry Unit Weight (γ_d) takes place at 3L2S. Figure 1 shows the compaction curves for various proportions of GGBF Slag and Lime.
Addition of cement in soil decreases the OMC and Dry Unit Weight of the soil. When GGBF Slag is used as replacement of cement the OMC (w) decreases as GGBF content increase except flusters take place at 5C2S and 4C3S. Maximum Dry Unit Weight decreases up to 5C2S but then after Maximum Dry Unit Weight increases constantly. The compaction curves for various proportions of GGBF Slag and Cement is shown in Figure 2.

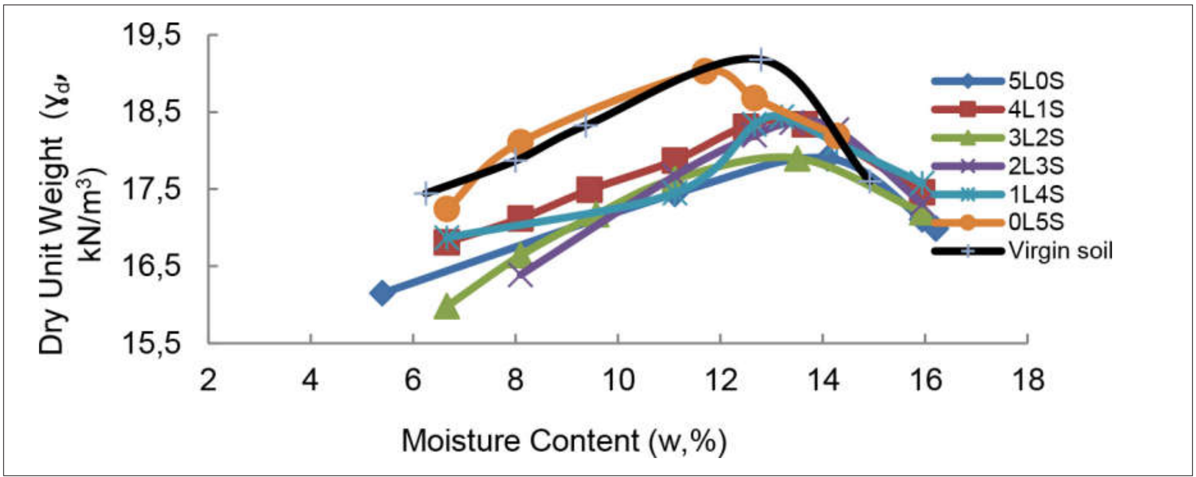

Figure 1 Compaction Characteristics of various proportions of GGBF Slag and Lime

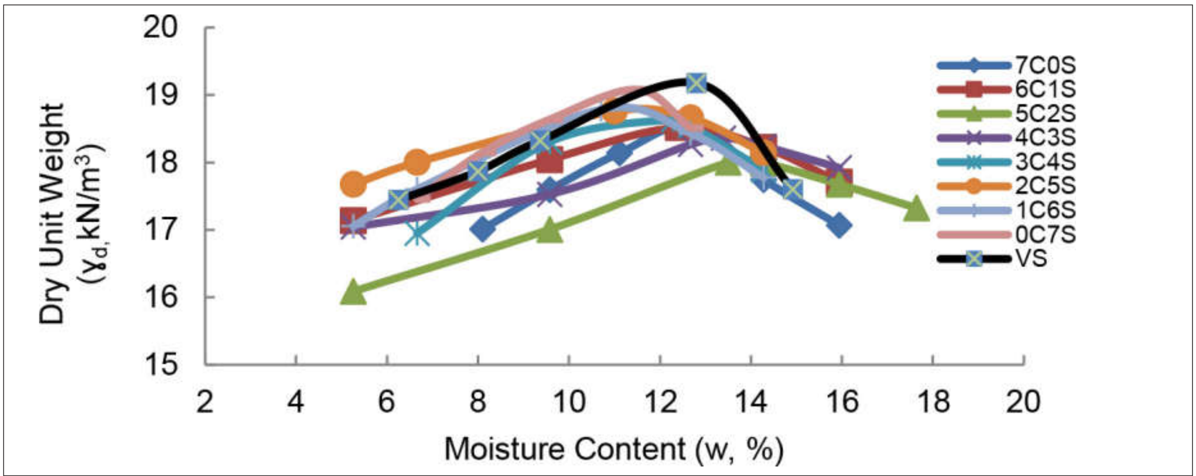

Figure 2 Compaction Characteristics of Various Proportions of GGBF Slag and Cement

4.2 Unconfined Compressive Strength

The unconfined compressive strength test on all the contents were carried out in accordance with IS 2720 (Part 10):1991. The mean UCS value of virgin soil at failure was calculated as 47.75 kPa. The strain at failure was observed to be about 5 %. Figure 3 shows the stress-strain relationship in Virgin soil.

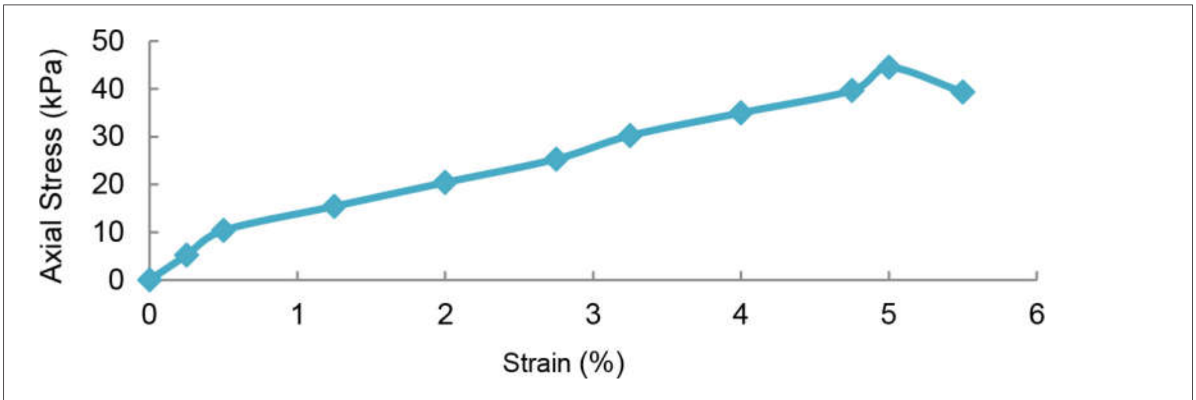

Figure 3 Stress-Strain Curve of Virgin Soil

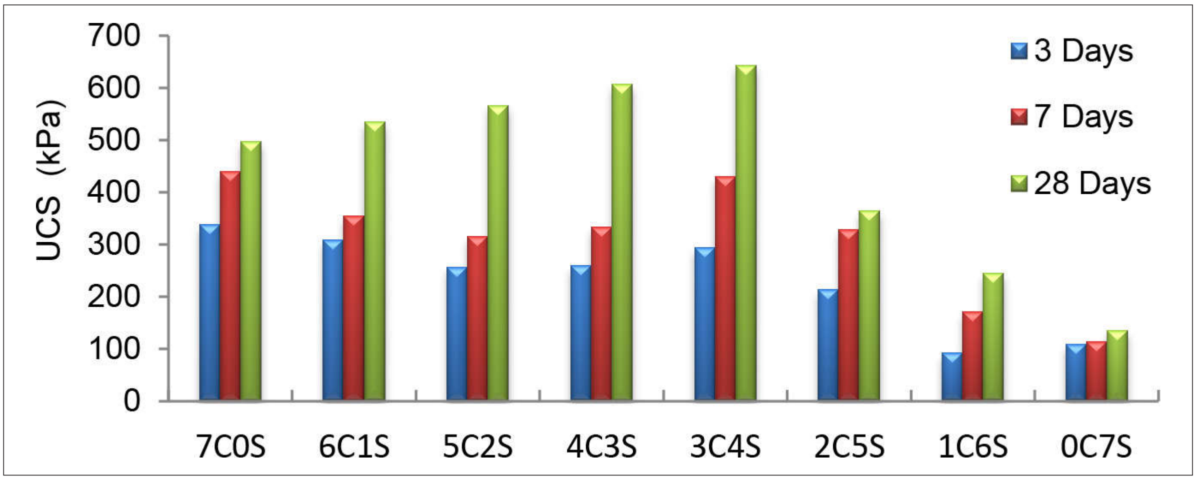

Figure 4 UCS Values of GGBF Slag replacing Cement

To retain the moisture in samples prepared at different lime,cement and GGBF slag content, the specimens were kept in a sealed plastic bag at room temperature. The curing conditions were in accordance with ASTM D 4609-01 "Standard Guide for Evaluating Effectiveness of Admixtures for Soil Stabilization" for desire curing period.

From Figure 4, it can be observed that the unconfined compressive strength of soil treated with Cement & GGBF slag shows lower early strength compared to the cement content alone. Though the 3 days and 7 days unconfined compressive strength of 3C4S is low compared to 7C0S, the UCS values of 7C0S and 3C4Sat 28 daysare 497.7 kPa and 643.99 kPa respectively. Hence, there is a significant effect of curing period on Cement & GGBF slag stabilized soil.

Figure 5 depicts that the Unconfined compressive strength of GGBF Slag replacing lime increases upto about 60 % of replacement. The unconfined compressive strength of 5L0Swas determined to be 209.95, 307.82 and 352.31kPa at 3,7 and 28 days respectively.The UCS values of 2L3S were calculated were 290.93, 387.72 and 472.76 kPa at 3,7 and 28 days of curing which shows increment of about 10 times in UCS value comparing to raw soil, Figure 5. The pozzolanic reaction between calcium and silica is dependent upon time and results in formation of cementitious compounds such as Calcium-Silicate-Hydrates (C-S-H),Calcium-Aluminate-Hydrates (C-A-H) and Calcium-Aluminate- Silicate- Hydrates (C-A-S-H).

As per ASTM D 4609-01, the effectiveness of stabilizers such as cement, lime, fly ash and other chemicals in improving the engineering properties of fine-grained soils can be assesed on the basis of Unconfined Compressive Strength.This standard suggests that an increase inUCS of 345 kPa (50 psi) or more due to treatment be considered effective for stabilization. In Cement and GGBF Slag stabilized soil only 1C6S and 0C7S do not fulfill the requirements of the standard. Whereas, in Lime and GGBF Slag stabilized soils 5L0S, 1L4S and 0L5S content has failed to match the criteria of ASTM D 4609-01.

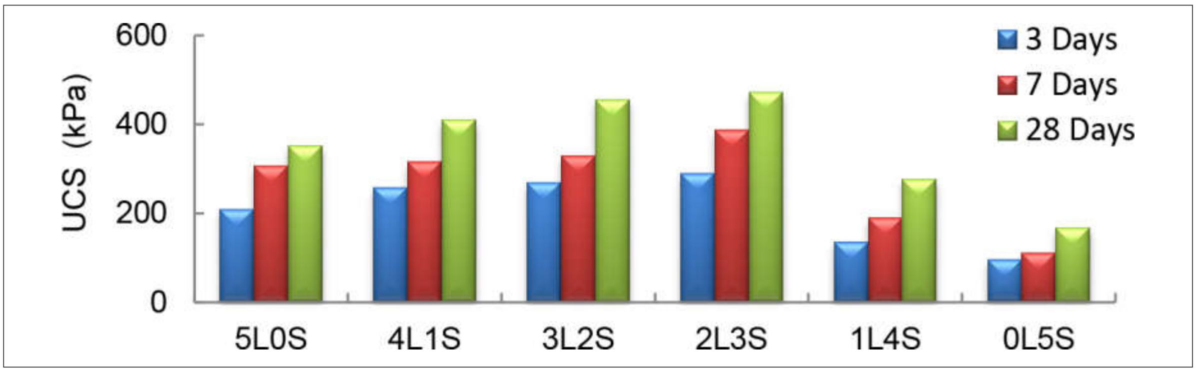

Figure 5 UCS of GGBF Slag replacing Lime

The peak values of Unconfined Compressive Strenght in cement and GGBF slag combination was achieved at 3C4S and in lime and GGBF slag combination was 2L3S. The stress-strain relationship in 3C4S and 2L3S obtain from Unconfined Compressive Strength test at 3 days, 7 days and 28 days has been shown in Figure 6. Failure pattern observed in 3C4S and 2L3S is shown on Figure 7.

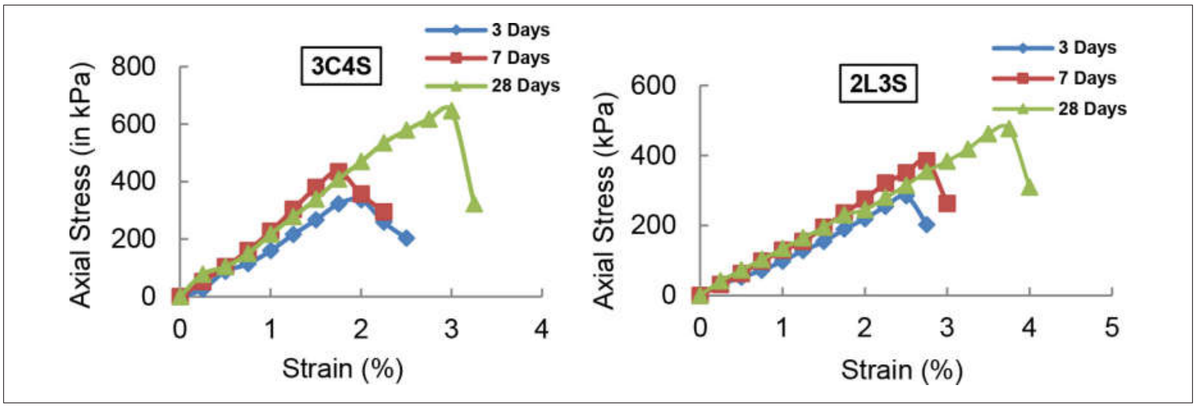

Figure 6 Stress- Strain Relationship of 3C4S and 2L3S

Figure 7 Failure Pattern observed in 3C4S and 2L3S

5 Conclusion

Study shows that the self hardening properties of GGBF slag are very little in the absence of any chemical activators. From the experimental work, following conclusions can be drawn:

- The UCS value of 3C4S content is highest which is almost 13.5 times higher than the virgin soil hence using GGBF Slag as a replacement of Portland cement up to 55 % will be economical and environment friendly.
- The Compressive Strength of 2L3S shows dramatical increase compared to raw soil hence by using only lime as a stabilizer the use of GGBF Slag with lime as an activator in small amount can be beneficial in larger projects.
- The unconfined compressive strength of soil has though increased but strength achieved at 28 days is not much desirable when GGBF Slag alone is used. Hence the self hardening process of GGBF Slag alone is not much effective.

- 1C6S, 0C7S, 5L0S, 1L4S and 0L5S contents do not satisfy the criteria of ASTM D 4609-01 standard. Other contents show increase of at least 400 kPa in Unconfined Compressive Strength.

This study peresented here evaluates the potential of Ground Granulated Blast Furnace(GGBF) Slag as partial replacement of cement and Lime. Considering the higher cost of cement and lime, the use of GGBF slag gives benefit of savings in construction cost. Though cement and lime are conventionally used as binder the production of same is a hazardous process to environment. Whereas, Ground Granulated Blast Furnace slag is a byproduct of Iron industry and produced in abudant quantity across the globe. Hence, GGBF Slag can be used as a soil stabilizer in the presence of activators like Portland cement and lime.

Acknowledgment

Authors would like to extend their sincere thanks to Dr. G.P. Vadodaria, Principal, L.D.College of Engineering, Ahmedabad for providing all required research facilities for this project and Dr.M.V. Shah for for his invaluable contribution to the experimental program and manuscript drafting.

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