

Utilisation of GGBS for Increasing the Compressive Strength of Black Cotton Soil

Deena Nath Gautam¹, Dr A.K. Sinha²

M. Tech. Student, Department of Civil Engineering, NIT Jamshedpur, Jharkhand, India¹

Associate Professor, Department of Civil Engineering, NIT Jamshedpur, Jharkhand, India²

ABSTRACT: About 20% of the land mass in India which is about 0.8 million sq. km. area consists of black cotton soil, especially the Deccan plateau region which is the central part and is sporadically located in the entire country. It is one of the most problematic soils as it shows major volume change due to alteration in the moisture content. The volume of soil increases when it comes in contact with water and decreases when water evaporates out. Due to this unpredictable nature of this soil it is not easy to have a construction or adequate use of soil without proper treatment as it furnishes differential settlements leads to danger for buildings or structures. In the present situation as the industrialization and urbanization is taking place has generated many wastes. This leads to depleting landfill space, soil contamination and many other hazardous effects, hence in this study utilization of steel industry waste i.e., Ground granulated blast furnace slag (GGBS) for improving the geotechnical properties of Black Cotton Soil is done. This research envisions the effect of GGBS on swelling and strength characteristics of black cotton soil. On addition of GGBS remarkable improvements in the properties like UCS and CBR is obtained.

KEYWORDS: Black Cotton Soil (BCS), GGBS, California bearing ratio, unconfined compressive strength.

I. INTRODUCTION

Utilization of industrial waste materials in the improvement of problematic soils is a cost efficient and environmental friendly method. It helps in reducing disposal problems caused by the various industrial wastes. One of the solid wastes generated by steel industries in huge quantities is Blast Furnace Slag. Very few studies have been reported on use of blast furnace slag in stabilizing the soils. The present study evaluates the potential of ground-granulated blast furnace slag (GGBS) generated from Tata Steel Jamshedpur, provided to us in powdered form by Lafarge India Ltd, Jojobera cement plant Jamshedpur in stabilizing the Black Cotton Soil.

In developing country like India due to the remarkable development in basic infrastructure facilities, soil stabilization has become the major issue in construction activity. Stabilization is unavoidable for the purpose of building, highway and runway construction. Soil stabilization can be explained as the alteration of the soil properties by chemical or physical means in order to enhance the engineering quality of the soil. The main objectives of the soil stabilization are to increase the bearing capacity of the soil, its resistance to weathering process and soil permeability. Soil stabilization has become the major issue in construction engineering and the researches regarding the effectiveness of using industrial wastes as a stabilizer are rapidly increasing. In this study emphasis is placed upon the effective utilization of waste product like ground granulated blast furnace slag GGBS, with a view to decrease the construction cost.

Black Cotton Soil and GGBS both are problematic in nature. First is problematic because of its peculiar characteristics of swelling and shrinkage and second one is problematic because of its unnecessary production in large quantity during manufacturing of iron and steel. Innovative research work is going throughout the world to utilize these industrial solid wastes such as GGBS in an effective way. Present study is also an attempt to utilize GGBS in constructive way for improving the properties of black cotton soil. In this study various tests has been performed with 10, 20, 30, 40 % replacement of soil with GGBS so that its effect on the black cotton soil can be observed.

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II. RELATED WORK

Expansive soils are a worldwide problem that poses several challenges for civil engineers. They are considered as potential natural hazard, which can cause extensive damage to structures if not adequately treated or stabilized. Stabilization denotes improvement in both strength and durability which are related to performance. Some of the literatures that deals with the stabilization of soil are mentioned below.

S. Wild, J. M. Kinuthia, R. B. Robinson et al (1995): The authors reported that Kaolinite clay containing gypsum and stabilized with lime, shows (when cured for short periods) very large levels of expansion when in contact with water. The addition of GGBS to the clay-lime-gypsum system results in a dramatic reduction in this expansion whilst producing only a small variation in compressive strength.

K.V. Manjunath, L. Govindaraju and P. V. Sivapullaiah(2012):The authors reported that when 20% slag & 4 % lime (5:1 slag to lime ratio) is added to soil, Su increased phenomenally almost by 16 times and with 40% slag & 4 % lime (10:1 slag to lime ratio) Su increased by 18 times. It is also observed that the free swell of Black cotton soil which was 60 % has reduced to 11.75 % when we used 40% slag & 2 % lime along with BCS. Thus, we could achieve volume stability also. But using 40% slag & 4% lime along with BCS reduced the free swell to 11.45% only that is it does not show further reduction in the free swell with higher slag content. Hence, to enhance the utilization of slag and optimal improvement in properties of soil, it is recommended to use 40% slag & 4 % lime along with Black Cotton Soil.

AbhilashDevanoor et al (2014): The authors concluded that Blast furnace slag can be used as a stabilizer in subgrade for road construction. Blast furnace slag was found to be very effective especially in California bearing ratio and unconfined compressive strength tests. The reduction in plasticity index of the Blast furnace slag treated soil decreased from 26.18% to 17.24% showed a decrease of 51.85% was found to be encouraging. Optimum moisture content decreased and maximum dry density increased due to the replacement of the Blast furnace slag when compared with native soil.

AkshatMehrotra et al (2014): This article reported that the unconfined compressive strength of the black cotton soil increased upon addition of HDPE plastic waste. The optimum UCS value was obtained at 4.5% of addition of HDPE plastic. Increase in UCS by adding HDPE occurred with increase in maximum dry unit weight at lesser OMC.

Haresh D. Golakiya and Chandresh D. Savani (2015): The use of recycled material in the stabilization of soil gives better option to disposal of waste material. Use of such materials in highway construction must provide a clear advantage in the terms of improvement of the geotechnical properties of foundation, subgrade, subbase, and embankment materials.

III. MATERIALS AND METHODS

Materials

Ground Granulated Blast Furnace Slag (GGBS)

The basic properties of GGBS as provided to us by Lafarge India ltd, Jojobera cement plant Jamshedpur listed in table 1.

Table 1 Chemical Properties of GGBS

	CaO	SiO ₂	Al ₂ O ₃	MgO	TiO ₂	SO ₃	MnO	Fe ₂ O ₃	Slag Basicity
Blast furnace slag	34.60	33.52	18.96	10.20	0.94	0.47	0.62	0.41	1.90

Black Cotton Soil (BCS)

The soil under observation was Black Cotton Soil which was brought from Ahwalwadi, Pune, (Maharashtra). It was collected at a depth of 15 cm below the natural ground level by removing the top cover of soil containing vegetation and foreign materials using rake. The soil is dried and pulverized to perform the various experimental studies. Basic geotechnical properties of the black cotton soil as observed during testing are listed below in the table 2.

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Table 2 Properties of Black Cotton Soil

PROPERTY	VALUE
Color	Black
Specific gravity	2.68
Free swell index (in %)	100
Liquid limit (in%)	72.8
Plastic limit (in %)	31.57
Classification as per IS 1498-1970	CH
Optimum moisture content (OMC) (in%)	28
Maximum dry density ($Y_{d\max}$) (in kN/m^3)	14.72
Cohesion intercept, C (in kN/m^2)	45
Angle of internal friction, ϕ (in degrees)	40.81

Methodology

Methodology includes the methods and procedures followed during testing. The laboratory tests carried out on the soil and the mix include Sieve analysis, Atterberg's Limits, Specific gravity, Free swell test, compaction test, Direct shear test, Unconfined Compressive Strength Test and California Bearing Ratio test. The sample was prepared by blending the BCS with varying percentage of GGBS. Both BCS and GGBS were first oven dried at $105^{\circ}C$ for 24 hours and BCS is then pulverized and passed through 4.75mm IS sieve to mix it with powdered GGBS. The amount of GGBS in the composite sample is the percentage of dry weight of GGBS in the total dry weight of composite sample. Table 3 shows the details of the composite mixture.

Table 3 Shows the details of the composite mixture

MIXTURE DESIGNATION	MATERIALS (in %)	
	BCS	GGBS
100% BCS + 0% GGBS	100	0
90% BCS + 10% GGBS	90	10
80% BCS + 20% GGBS	80	20
70% BCS + 30% GGBS	70	30
60% BCS + 40% GGBS	60	40

IV. RESULTS AND DISCUSSIONS

Grain Size Analysis

Grain size analysis is carried out to study the presence of different sizes of soil grains in Black Cotton Soil, further on this basis soil classification is done. This is done in two parts viz. coarse size analysis which was carried out using wet sieve analysis and fine grain analysis is done using hydrometer method and later the results were combined to get the overall sizes of the particle present in BCS.

Table 4 Grain Size Analysis of Black Cotton Soil

Designation	Diameter	Soil Particles (In %)
Gravel	$D > 4.75mm$	2.14
Sand	Coarse ($2mm < D < 4.75mm$)	4.14
	Medium ($0.425mm < D < 2mm$)	8.68
	Fine ($0.075 < D < 0.425mm$)	3.78
Silt	$0.002mm < D < 0.075mm$	51.01
Clay	$D < 0.002$	30.25

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Effect of GGBS on Free Swelling Index of Black Cotton Soil

Free swelling index test is carried out to determine the swelling potential of the black cotton soil under observation. FSI is observed for both untreated BCS and treated BCS, so that variation can be analysed with different percentages of GGBS. The result so obtained is presented below in table 5.

Table 5 Variation of FSI and expansiveness with GGBS

MIXTURE DESIGNATION	FREE SWELLING INDEX	DEGREE OF EXPANSIVENESS As per IS 1498 -1987	DEGREE OF SEVERITY As per IS 1498 -1987
100% BCS + 0% GGBS	100	Very high	Severe
90% BCS + 10% GGBS	87.5	Very high	Severe
80% BCS + 20% GGBS	60	Very high	Severe
70% BCS + 30% GGBS	32.5	Moderate	Marginal
60% BCS + 40% GGBS	30	Moderate	Marginal

The variation of FSI with GGBS is presented below in Fig. 1, which shows about 70% reduction in FSI with the addition of 40% GGBS.

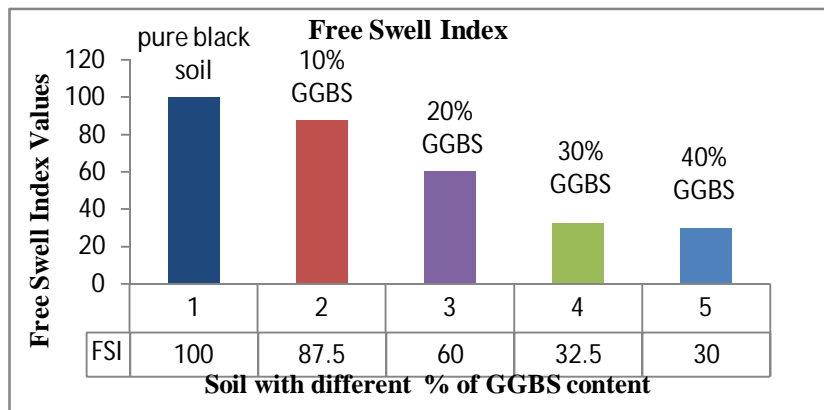


Fig. 1 Variation of FSI with different percentages of GGBS

The cause of decrease in FSI value is partly due to removal of soil particles by non-swelling GGBS which has very high concentration of silica and also due to replacement of limited monovalent cations present in clay micelles with multivalent cations like Ca^{+2} , Fe^{+2} present in GGBS. Due to decrease in size of micelle the swelling tendency of soil decreases.

Effect of GGBS on Plasticity Characteristics of Black Cotton Soil

In this research an attempt has been made to understand the effect of GGBS on the plasticity characteristics of black cotton soil.

Table 6 Variation in Atterberg's Limits with different percentages of GGBS

MIXTURE DESIGNATION	LIQUID LIMIT $w_l(\%)$	PLASTIC LIMIT $w_p(\%)$	PLASTICITY INDEX, $I_p(\%)$	SOIL TYPE Acc. to IS: 1498-1970
100% BCS + 0% GGBS	72.8	31.57	41.23	CH
90% BCS + 10% GGBS	66	32.92	33.08	MH
80% BCS + 20% GGBS	64.2	33.15	31.05	MH
70% BCS + 30% GGBS	60	33.69	26.31	MH
60% BCS + 40% GGBS	54	34.07	19.93	MH

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This shows that the addition of GGBS significantly effects liquid limit, plastic limit and plasticity index of the soil. Fig.2 shows the variation of Atterberg's Limits with different percentages of GGBS.

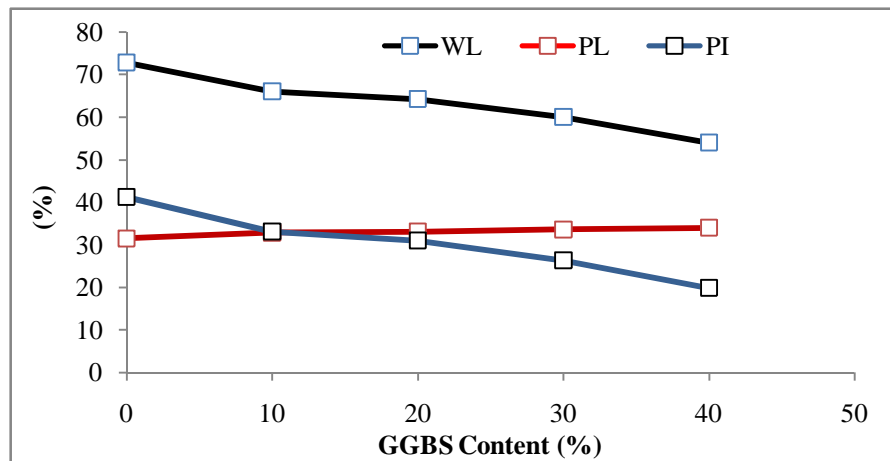


Fig. 2 Atterberg's Limit of Mixtures with GGBS (LL: Liquid Limit, PL: Plastic Limit, PI: Plasticity Index)

The maximum water content at which the interaction between the clay micelle is lost shows the liquid limit attainment. With the addition of GGBS, which is itself non plastic this interaction is lost earlier. Plastic limit is the minimum water content at which soil can be deformed without crumbling. It indicates the ease with which soil particle moves. This research shows GGBS addition reduces the ease of relative particle movement. Plasticity index is the indication of water assimilation capacity. It is the range at which soil can bind water and still behaves as plastic solid. For the soils with the same value of liquid limit, greater the plasticity index, greater is the dry strength and toughness at plastic limit, but the permeability and rate of volume change decrease while the compressibility remains the same.

Effect of GGBS on Compaction Characteristics of Black Cotton Soil

Compaction tests were carried for soil and soil-GGBS composites to find out the effect of the GGBS on the optimum moisture contents and maximum dry densities.

Table 7 Variation in OMC and MDD with different percentages of GGBS

MIXTURE DESIGNATION	MDD (in kN/m ³)	OMC (in %)
100% BCS + 0% GGBS	14.72	28
90% BCS + 10% GGBS	15.30	26
80% BCS + 20% GGBS	15.59	24.5
70% BCS + 30% GGBS	16.38	24
60% BCS + 40% GGBS	16.97	23.5

This study shows that there exist a relationship between MDD, OMC and GGBS content, with the percent increase in GGBS content the OMC has decreased but MDD has increased. Results from the compaction tests are presented in fig. 3.

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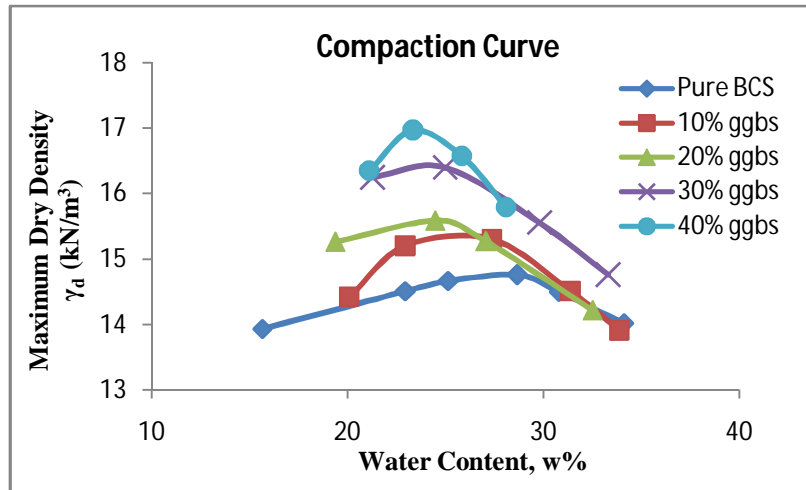


Fig. 3 Variation of FSI with different percentages of GGBS

Compactibility of the mix is increasing with the increase in GGBS content hence better compaction is achieved with the same compactive effort. Increase in maximum dry density is primarily due to higher specific gravity of GGBS and also due to alteration in gradation and chemical composition of GGBS.

Effect of GGBS on CBR Characteristics of Black Cotton Soil

Soaked CBR tests were conducted on untreated BCS and treated BCS with different percentages of GGBS at their OMC and MDD determined by light compaction tests. In this test a surcharge weight of 25N was placed over the sample compacted and the sample mould assembly transferred to soaking tank which is filled with water for 96 hours soaking period. The amount of swelling is measure by a dial gauge fitted with magnetic stand placed over the sample. The readings in dial gauge are taken at regular interval of time and final dial gauge reading after 96hrs is also noted. After 96hrs soaking period whole of the assembly transferred to strain controlled loading frame as per IS:2720 (Part-16)1987 and penetration corresponding to load is noted down which is presented in fig. 4.

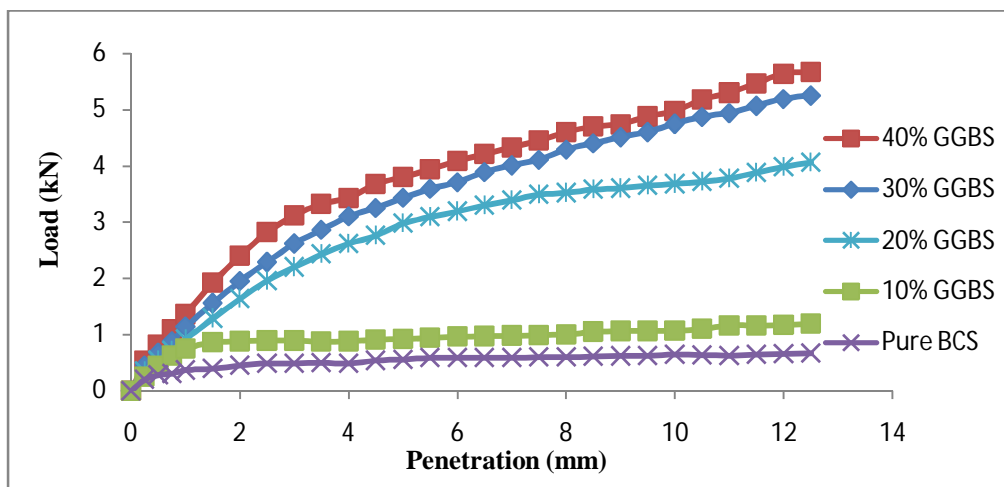


Fig. 4 Effect of GGBS on load penetration curves

This shows that with increase in GGBS content the CBR characteristics is improving many folds. The CBR value is

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determined corresponding to 2.5 and 5mm penetration levels. The greater of these values is considered as CBR. Variation in CBR characteristics with GGBS content is presented in table 8.

Table 8 Variation in CBR characteristics with GGBS content

MIXTURE DESIGNATION	CBR @ 2.5 mm (%)	CBR @ 5 mm (%)	CBR VALUE (%)
100% BCS + 0% GGBS	3.65	2.78	3.65
90% BCS + 10% GGBS	6.62	4.56	6.62
80% BCS + 20% GGBS	14.58	14.47	14.58
70% BCS + 30% GGBS	17.04	17.01	17.04
60% BCS + 40% GGBS	20.98	18.84	20.98

The increase in CBR value is due to better compaction and stabilisation occurred due to GGBS addition which means that pavement thickness required for safe transmission of wheel load decreases thus saving in cost of construction is achieved by using soil stabilized at 40 % GGBS as subgrade and sub base material.

Effect of GGBS on Unconfined Compressive Strength of Black Cotton Soil

The primary purpose of this test is to determine the unconfined compressive strength, which is then used to calculate the unconsolidated undrained shear strength of the clay under unconfined conditions. In this test, the unconfined compressive strength is taken as the maximum load attained per unit area, or the load per unit area at 20% axial strain, whichever occurs first during the performance of a test. The fig. 5 shows the plot for Black Cotton Soil tested on 0th day.

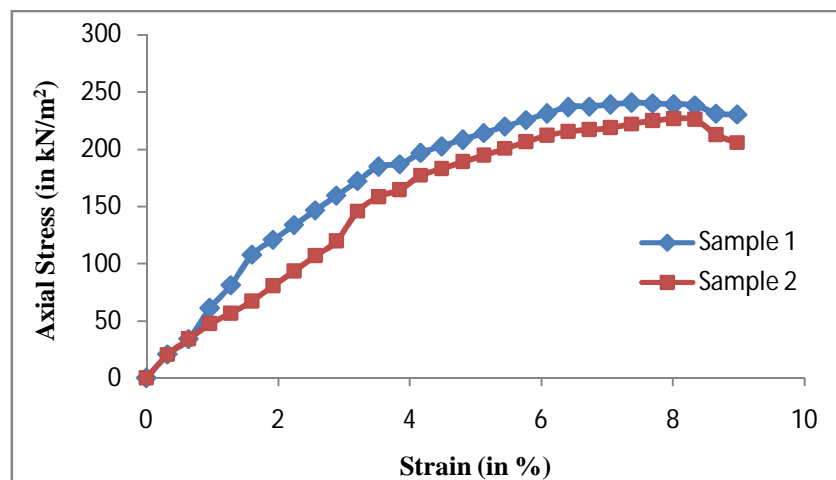


Fig. 5 UCS result on 0th day for pure Black Cotton Soil

For UCS two samples (sample 1 and sample 2) were tested and the average value of the two is reported as unconfined compressive strength at that GGBS content. This test is conducted on 0th, 7th and after 28th days of curing and thus the effect of curing period is also analysed on the unconfined compressive strength of soil. The result of UCS test is presented in table 9.

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Table 9 shows UCS result on 0th, 7th and 28th day at different GGBS content

MIXTURE DESIGNATION	UCS at 0 th DAY (in kN/m ²)	UCS at 7 th DAY (in kN/m ²)	UCS at 28 th DAY (in kN/m ²)
100% BCS + 0% GGBS	233.77	299.01	367.47
90% BCS + 10% GGBS	236.01	316.93	384.65
80% BCS + 20% GGBS	258.1	353.45	455.56
70% BCS + 30% GGBS	298.75	421.98	516.08
60% BCS + 40% GGBS	305.2	475.52	626.1

The overall variation in UCS with GGBS content and also the effect of curing period on UCS is shown in fig. 6.

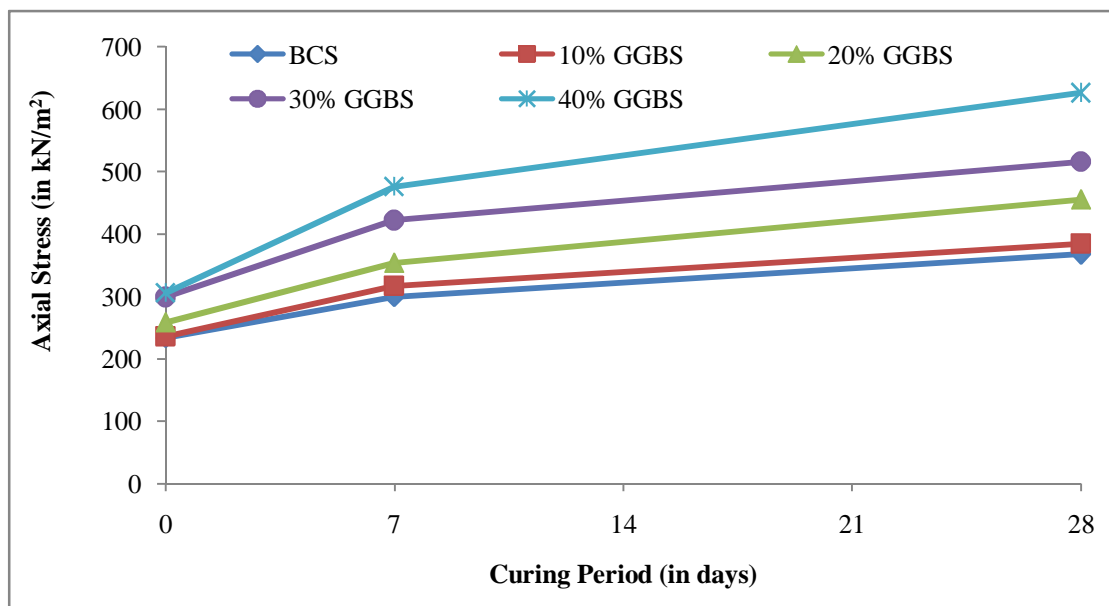


Fig. 6 Overall variation in UCS with Curing period

On 0th day the increase in UCS from 233.77 kN/m² to 305.2 kN/m² is primarily due to better compaction and also due to immediate formation of cemented product by GGBS and water. This test shows that rate of gain of strength in initial days is faster which reduced afterwards. The gain in strength in pure Black Cotton Soil is basically due to the thixotropic effect whereas in soil stabilised with different percentages of GGBS the silica and alumina that exist in the soil minerals and in GGBS become soluble and free when pH exceeds 12.4 and the released soluble silica and alumina and the calcium ions from hydration of GGBS creates cementitious materials such as Calcium Silicate Hydrates (C-S-H) and Calcium Aluminate Hydrates (C-A-H) which is responsible for its strength gain. These pozzolanic reactions are time dependent and are function of temperature, calcium quantity, pH value and the percentage of silica and alumina.

V. CONCLUSION

This experimental study was based on the soil procured from Ahwalwadi, (Pune) Maharashtra, which is known for its expansive soil. This study on the native soil has shown remarkable improvements in its geotechnical properties with the

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incorporation of GGBS, brought from Lafarge India ltd, Jojobera Cement Plant Jamshedpur in powdered form. Key components of the study are summarized below.

- [1] Free swelling index has reduced drastically about 70% with the incorporation upto 40% GGBS. Thus bringing its degree of severity from severe to marginal.
- [2] This study shows that with the increase of GGBS percentage optimum moisture content goes on decreasing while maximum dry density goes on increasing, hence compatibility of soil increases and thus making the soil more dense and hard. With the increase in GGBS content in the soil MDD has increased upto approximately 15% whereas the OMC decrease is observed to be 16%. As a result of increase in MDD the optimum void ratio and porosity have gone down.
- [3] Soaked CBR value after 4 days of curing observed to be increasing with increase in percentage of GGBS. The value of CBR for BCS was 3.65 which increased to 20.98 with the incorporation of 40% GGBS which means the increase in CBR is more than 450% when compared with BCS alone, which shows densification of soil takes place and thus making it more suitable for pavement construction.
- [4] On comparing the Unconfined Compressive Strength of BCS with soil treated with 40% GGBS the overall increase in UCS at 28 days of curing is found to be 70% which is encouraging. Increase in unconfined compressive strength confirms that stability of the soil increases with GGBS content.

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