Stabilization of Clay Subgrade Soils for Pavements Using Ground Granulated Blast Furnace Slag

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Abstract—About 20% of total land area in India is covered predominantly by Black Cotton soil. The BC soil is well known to exhibit typical character of high swell potential due to dramatic volume changes influenced by the moisture content and also it is known for its low shear strength. India is a developing country with remarkable development in Infrastructure. In this scenario, in Construction industry, Soil stabilization has gained serious attention becoming the major issue. In this project, the objective is to utilize GGBS; which is a locally available plentiful industrial by product, for stabilizing the BC soil. The main focus is to verify the suitability of GGBS as a soil stabilizer in the local construction industry for road, embankment and structural fills in a way beneficial to the environment by putting an industrial waste to good use as well as minimizing the amount of waste to be disposed to the environment. To evaluate the effectiveness of GGBS in improving properties of existing soil to meet specified engineering requirements, experimental investigations were undertaken on the index properties (Consistency Limits proposed by Atterberg, Specific gravity and Hydrometer analysis), compaction characteristics (MDD and OMC), strength characteristics (Swelling pressure, Direct shear and CBR). Tests were carried on the natural soil and also on treated soil. GGBS is added ranging from 0% to 40% of the amount of dry weight of natural soil. Test results indicate that Atterberg limits generally decreased, whereas specific gravity of stabilized soil increased with higher GGBS content. There was increase in the MDD observed and the OMC values decreased with the increase in GGBS content and at 20%, the optimum value for dry density is achieved. The CBR values increased with increasing GGBS content. The laboratory results obtained illustrate that at 20% optimum GGBS content, stabilization of the poor Black Cotton soil with GGBS satisfactorily meets the general specifications for subgrade materials.

Keywords: Expansive soil, GGBS, Compaction, CBR, Swelling Pressure.

I. INTRODUCTION

In the construction of earth structures such as embankments (highways, railways and canals), loose soil obtained from borrow pits compulsorily has to be compacted to increase its density and hence it's shear strength and also required to lower the compressibility. These operations make the project highly expensive which increases the cost of construction. From the late contemporary decades, we can make a note of rigorous studies conducted to find out all possible methods for reusing variety of wastes in construction industry. Till date, waste generated from construction, slag obtained from blast furnace, coal fly ash and bottom ash, are proven as suitable for use in several places as a substitute for aggregates in road embankments, pavement construction, laying of foundations and also in structural buildings. Slag from steel industry and mine-wastes are in most cases recycled to suit as secondary materials in buildings, road and geotechnical constructions. On the other perspective, steel plant and iron manufacturing industries all over the world contribute enormous quantity of GGBS every year. Environmentally safe disposal of GGBS is now demanding the exploration of innovative and cost effective methods of utilizing the GGBS in many fields. At present days there is a very big responsibility on a civil engineer to use industrial waste materials as soil stabilizers to avoid negative environmental impact.

A. JUSTIFICATION FOR THE STUDY

In this present study the black cotton soil with poor geotechnical parameters such as low safe bearing capacity, less shear strength, highly expansive nature and high swell potential is stabilized with GGBS and compacted to increase its density and thereby its shear strength and also to decrease its swell potential. The choice of using GGBS lies in the fact that it is locally generated industrial waste product. The major use of GGBS mostly is due to its slow cementitious properties that can be used as replacement to ordinary Portland cement (up to 60% OPC in the concrete mix) and which can also be used for stabilization of soils. The potential of using industrial by-product for soil stabilization so as to improve the geotechnical parameters of BC soils and their use in addition with cement and lime is enormous, but very little research has been done in order to verify the extent of suitability of using GGBS in stabilizing soil. When proper amount of GGBS is added to the soil, the phenomenon of stabilization takes place. Soil stabilization in broader sense is used in the construction of road, embankment and foundation. This study is focused in investigating the potential of GGBS as an additive to stabilize soils, to control the volume change, compressibility and swelling pressure of some expansive soils. The research is concentrated on the solutions for stabilization issues of a soil that is highly clayey and expansive.

B. AIM AND OBJECTIVES OF THE STUDY

This project aims at using GGBS in the stabilization of black cotton soil. The specific objectives of this study include:

- Determination of the properties which reflect engineering behavior of the black cotton soil as well as of GGBS.
- Determination of the index properties and the properties relating to strength of the Black cotton soil – GGBS mixtures;
- To evaluate the effect of optimum GGBS content on index properties and Atterberg limits that are LL, PL and PI of black cotton soil and GGBS mixtures.
- Determination of the optimum GGBS content on strength characteristics of the Black cotton soil - GGBS mixtures.

II. MATERIALS

Black Cotton Soil: Black Cotton soils are soils that have high clay content in them. In the present study, the BC soil is collected from district of Ballari, Karnataka. Due to the very typically variable volumetric behavior of these soils when subjected to various climatic conditions, the stages of construction activity and works of maintenance of the roads has not only resulted getting expensive, but also difficult. It is a soil having expansive nature. The Soil is procured from beneath the ground level at a 0.5m depth by means of open-excavation. Before using the soil, it was left to dry and later sieved through IS sieve of 425 micron size.

Ground-Granulated Blast-Furnace Slag (GGBS): The GGBS taken in this project is procured from Jindal Vijayanagara Steel Ltd, Toranagallu, from Bellary district of Karnataka.. The material may be classified as low compressible inorganic silt (ML). It is a byproduct obtained from the blast furnaces that are basically used in iron manufacturing. Considered as a waste disposal, it can be put into fruitful use as a construction material extending its application in the projects like road, pavement, railway ballast, landfills etc. The tabulation of physical properties of BC soil and GGBS is done in Table 1.

Table 1: Black Cotton Soil And GGBS properties

Soil Characteristics	Description	
	BC Soil	GGBS
Maximum dry density	1.6 g/cc	1.62 g/cc
Optimum moisture content	21.6%	21.7%
Specific gravity	2.72	2.82
Free swelling index	60%	0 %
Liquid limit	72%	34.5%
Plastic limit	43.12%	NA
Plasticity index	28.88%	NP
Shrinkage Limit	10.614%	NP

III. METHODOLOGY

To study about the soil stabilization, soil is mixed with GGBS. Later the engineering properties were determined. The experimental setup and the test procedure have been planned in a particular way that accounts all the aspects that are related, such as relative proportions are mixed at calculated values of O.M.C. Replacement of soil is done accordingly with the different proportions of GGBS.

The following tests are conducted for stabilizing Black Cotton Soil. These tests were conducted for the Black cotton soil with 0%, 10%, 20%, 30% and 40% GGBS addition respectively.

1. Atterberg's Limits
   - Liquid Limit (IS: 2720(PART-V)-1985) Using Cone Penetrometer method
   - Plastic Limit
   - Shrinkage Limit
2. Grain Size Distribution for BC Soil (IS: 2720(Part IV)-1975)
   - Wet Sieve Analysis (IS: 2720 (Part IV) - 1985)
   - Hydrometer Analysis (IS: 2720(Part IV)-1985)
3. Soil Compaction test (IS: 2720 (Part VII) - 1980) Using Light Compaction method
4. Swelling Pressure test (As Per IS : 2720 (Part Xl)) Using Constant Pressure method
5. Direct Shear Test (IS: 2720 (Part XIII)-1986)
6. California Bearing Ratio (CBR) Test (IS: 2720 (Part XVI)-1987).

IV. RESULTS AND DISCUSSIONS

1. ATTERBERG'S LIMITS (IS: 2720(PART V)-1985)

A. Liquid Limit

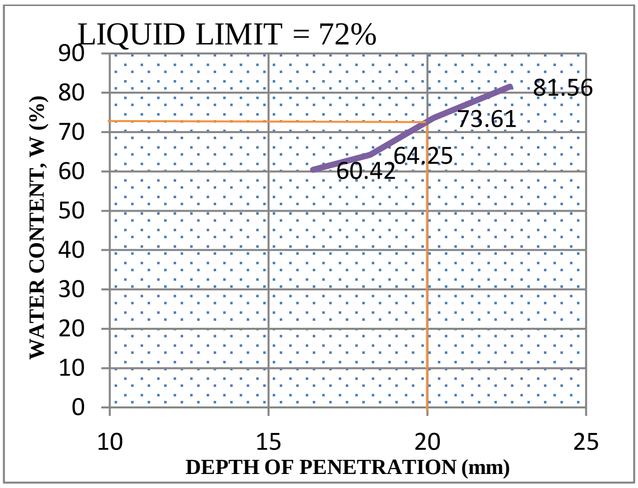


Fig 1: Liquid limit Curve for BC Soil

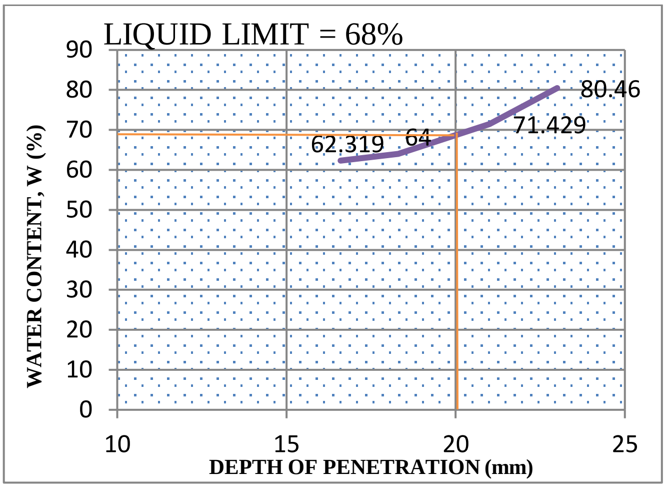


Fig 2: Liquid limit Curve for 90% Soil And 10% GGBS

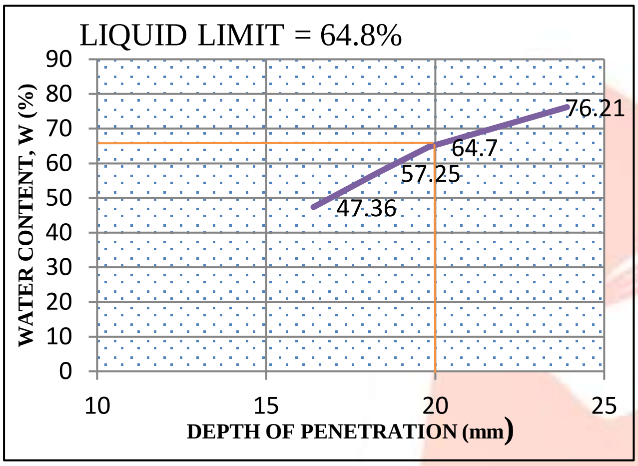


Fig 3: Liquid limit Curve for 80% Soil And 20% GGBS.

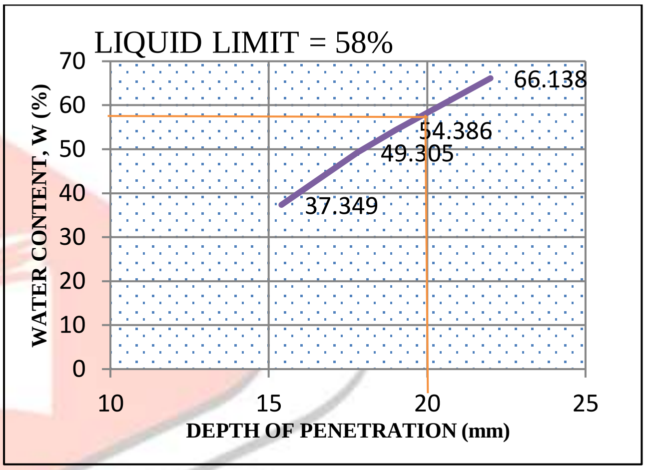


Fig 4: Liquid limit Curve for 70% Soil And 30% GGBS

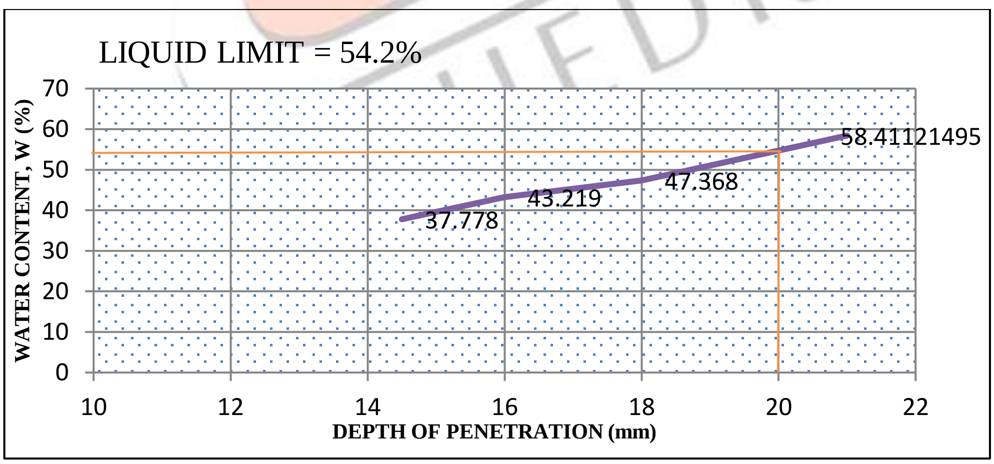


Fig 5: Liquid limit Curve for 60% Soil And 40% GGBS

Referring to above Liquid limit curves plotted for various % of GGBS addition to the BC soil, it can be inferred that, the liquid limit gradually decreases with the increase in % of GGBS. The LL reduced from 72% at 0% GGBS to 54.2% at 40% GGBS.

Table 2: Effect of GGBS on Atterberg Limits and Plasticity index

BC Soil + Fine GGBS	Liquid Limit (Wl) (%)	Plastic Limit (Wp) (%)	Plasticity Index (Ip) (%)	Shrinkage Limit (%)
100% + 0%	72	43.12	28.88	10.614
90% + 10%	68	37.99	30.01	9.629
80% + 20%	64.8	34.89	29.91	9.345
70% + 30%	58	33.61	24.39	9.173
60% + 40%	54.2	34.31	19.89	8.022

From the results tabulated in Table 2, it is observed that as the percentage of GGBS is increased, the Atterberg Limits gets decreased thereby the plasticity index also gets reduced. MORTH specifies that the plasticity index of soils to be used for embankments, sub grades, earthen shoulders and miscellaneous backfills should be below 25. Hence through GGBS stabilization, the MORTH specifications are attained.

Table 3: Soil Classification from Wet sieve analysis of Black Cotton Soil

% Of Gravel	0.6
% Of Sand Particles	7.9
% Of Silt And Clay	91.5
Soil Classification	
Indian Standard Soil Classification	CH

2. HYDROMETER ANALYSIS:

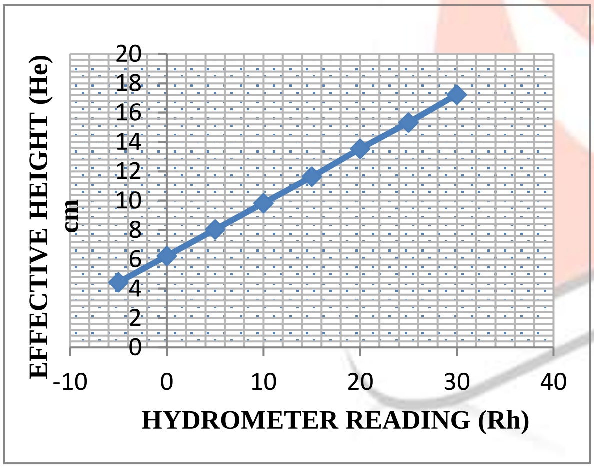


Fig 6: Calibration Curve for the Hydrometer

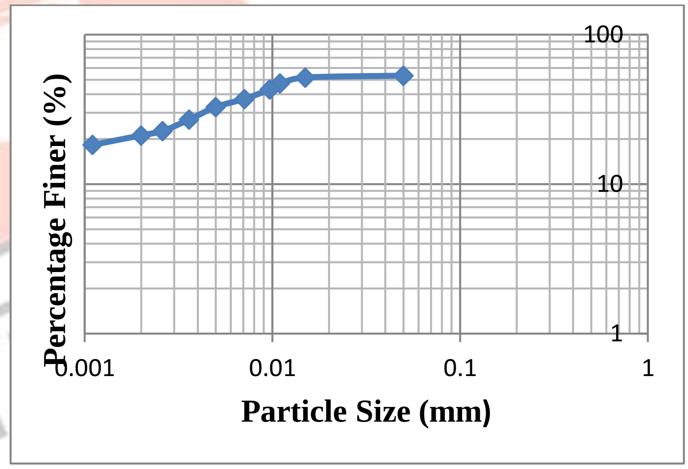
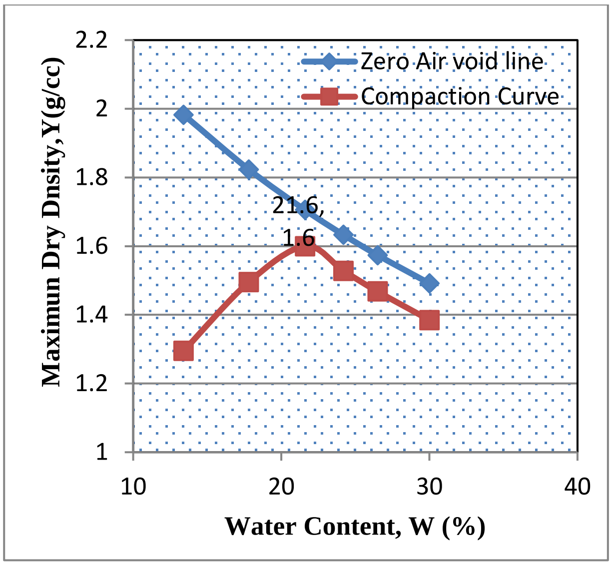


Fig: 7: Grain Size Distribution curve from Hydrometer Analysis

3. SOIL COMPACTION CHARACTERISTICS (OMC and MDD):

Table 4: Variation of OMC and MDD with different % OF GGBS

% GGBS	OMC (%)	MDD (g/cc)
0	21.6	1.6
10	19.6	1.665
20	18.4	1.704
30	17.2	1.7
40	17	1.686



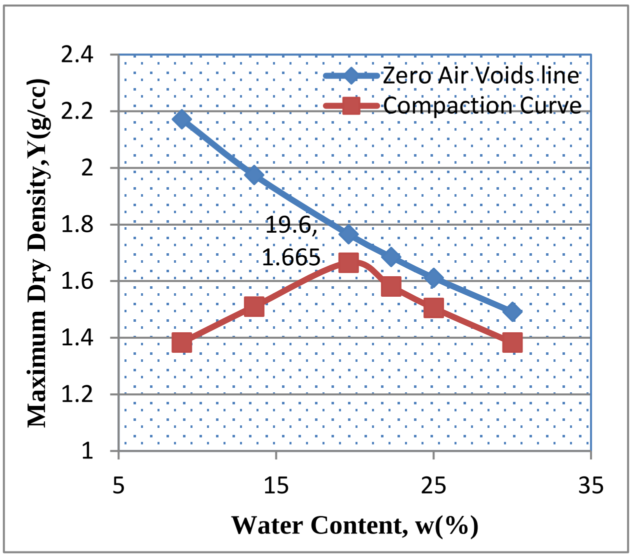
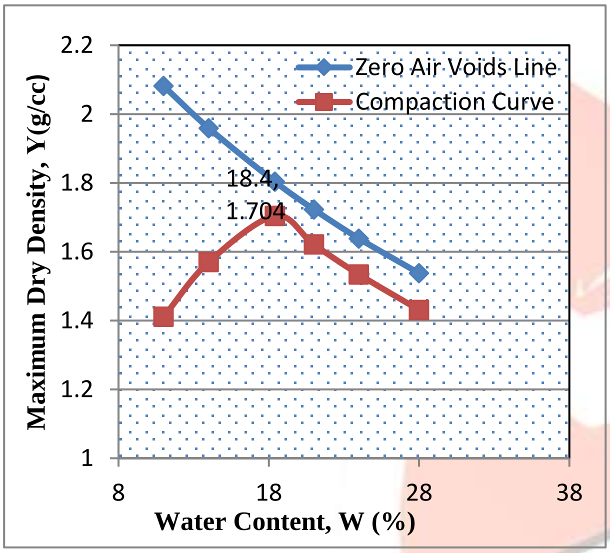


Fig 8: Compaction Curve for Black Cotton Soil

Fig 9: Compaction Curve for 90% BC SOIL + 10% GGBS



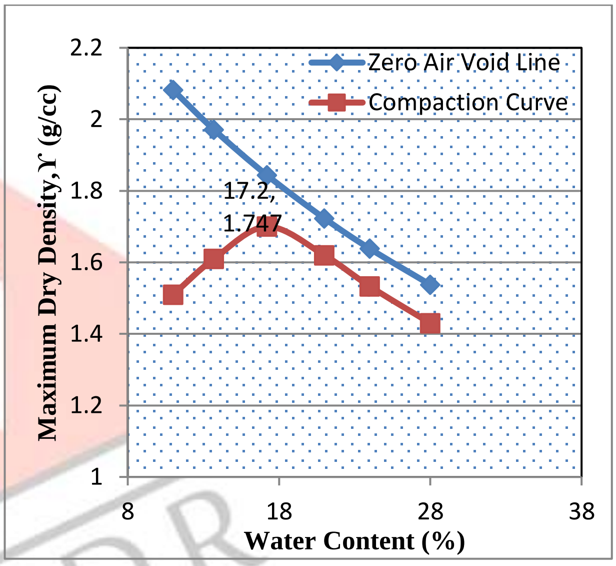


Fig 10: Compaction Curve for 80% BC SOIL + 20% GGBS

Fig 11: Compaction Curve for 70% BC SOIL + 30% GGBS

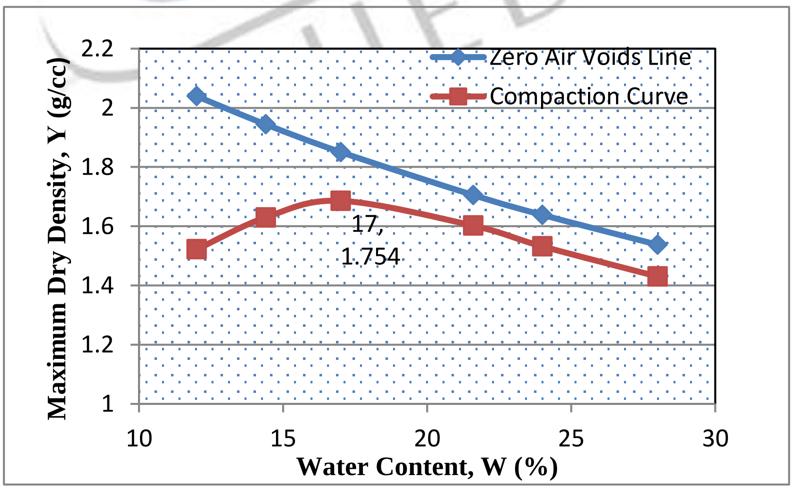


Fig 12: Compaction Curve for 60% BC SOIL + 40% GGBS

From the above Compaction test results, it is observed that Optimum moisture content(OMC) decreases gradually with the increasing GGBS content whereas the Maximum dry density(MDD) values, increased with increasing GGBS content, i.e., up to 20% GGBS and thereby on further addition, it decreased. Thus, the optimum GGBS percentage for achieving OMC and MDD is 20%.

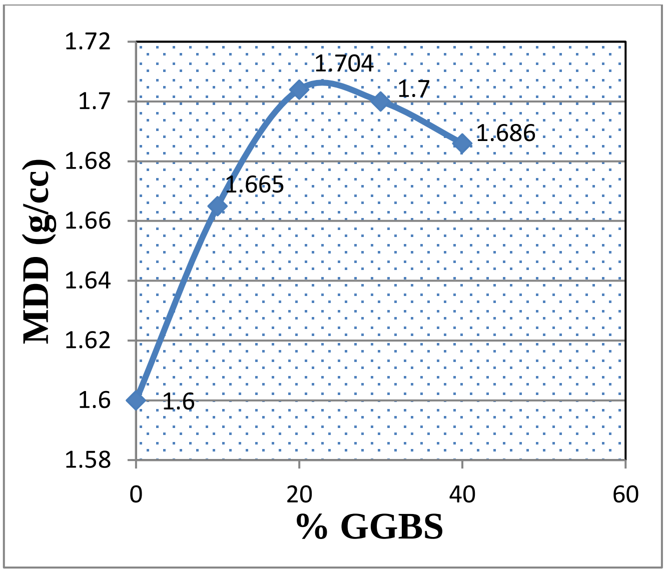


Fig 13: Variation of MDD with different % of GGBS

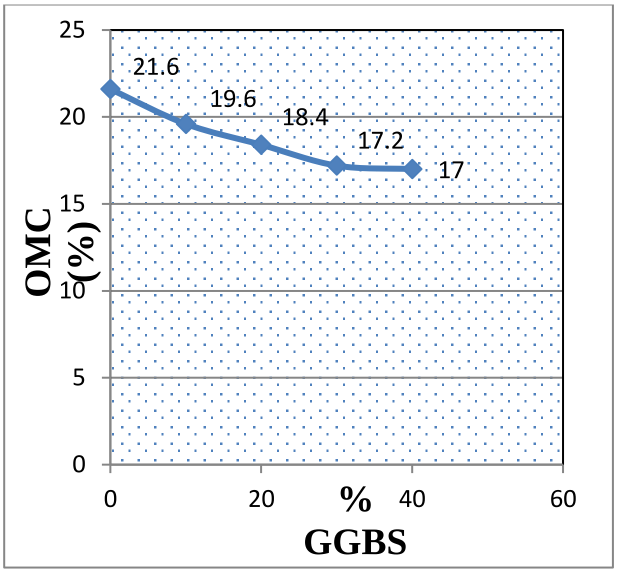


Fig 14: Variation of OMC with different % of GGBS

4. SWELLING PRESSURE:

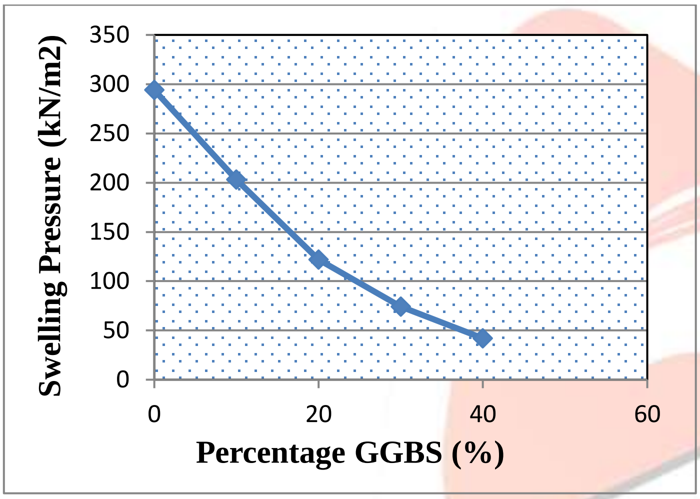


Fig 15: Effect of % of GGBS on Swelling Pressure of BC soil

Table 5: Effect of Different Percentages of GGBS on Swelling pressure of Black Cotton Soil

Soil Sample	Swelling Pressure (kN/m2)
100% BC Soil + 0% GGBS	294
90% BC Soil + 10% GGBS	203
80% BC Soil + 20% GGBS	122
70% BC Soil + 30% GGBS	74
60% BC Soil + 40% GGBS	42

From above results on swelling pressure test, it can be inferred that with the higher percentage of GGBS addition, the swelling potential reduces to a great marginal value. The swelling potential of expansive Black Cotton soil can be reduced up to 42 kN/m2 by using 40% GGBS. With the decrease in swelling Potential, stability will be improved in the soil.

5. DIRECT SHEAR:

Table 6: Variation of Cohesion (C) and Angle of internal friction (φ) with different % of GGBS

% GGBS	C (kN/m2)	φ (degree)
0	18.6333	19.69
10	16.6719	20.85
20	14.7105	21.75
30	8.8263	23.17
40	4.9035	23.74

Referring to Table 6, the direct shear test results indicate that higher percentage of GGBS content in the soil increases the angle of internal friction (φ) and decreases the Cohesion (C).

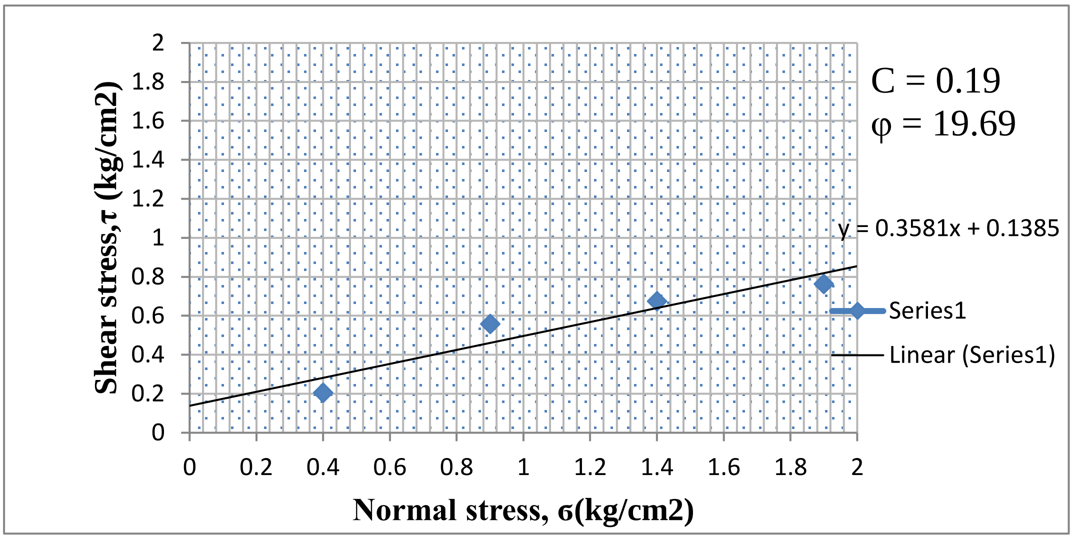


Fig 16: Failure plane for Black Cotton Soil

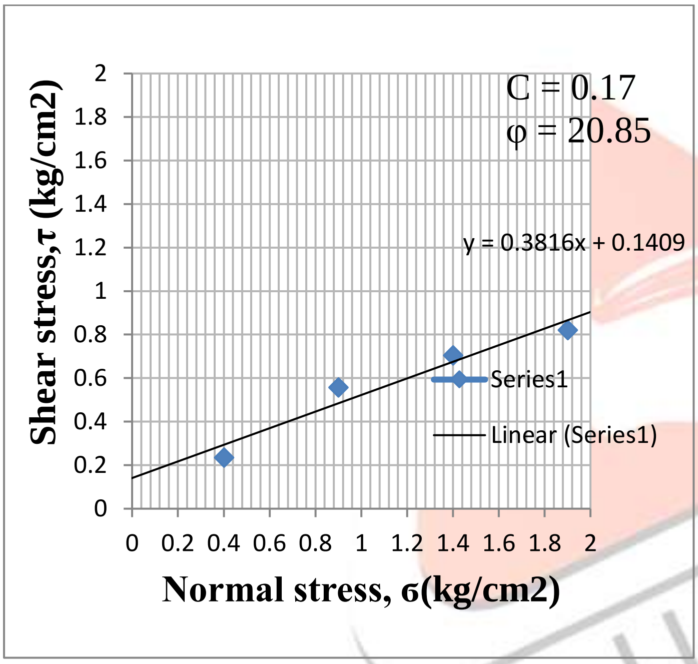


Fig 17: Failure plane for 90% BC SOIL + 10% GGBS

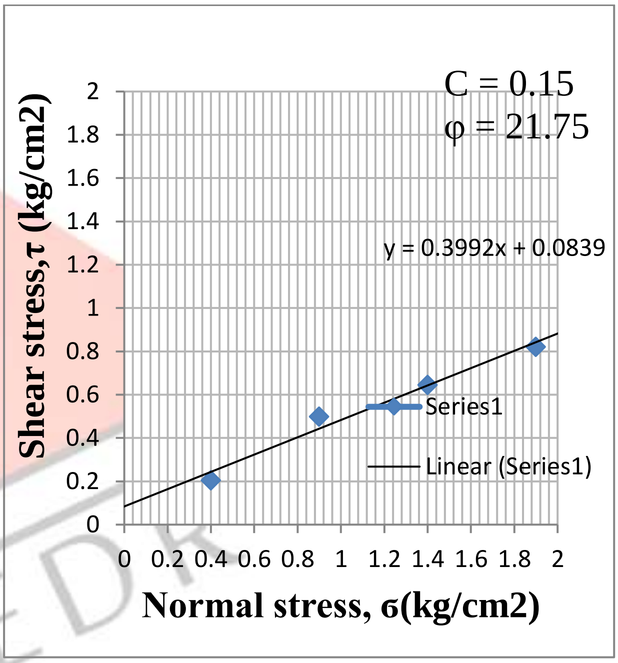


Fig 18: Failure plane for 80% BC SOIL + 20% GGBS

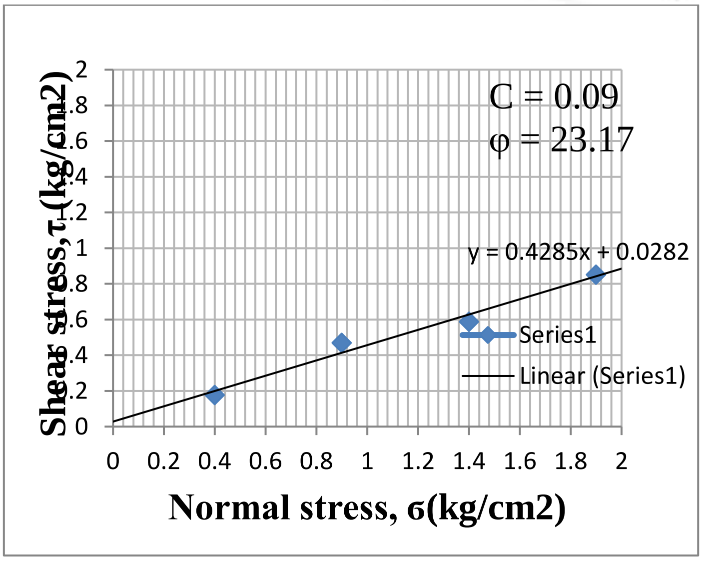


Fig 19: Failure plane for 70% BC SOIL + 30% GGBS

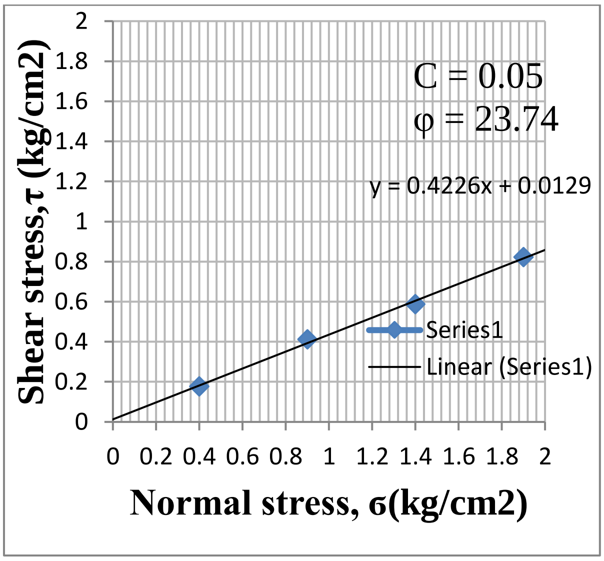


Fig 20: Failure plane for 60% BC SOIL + 40% GGBS

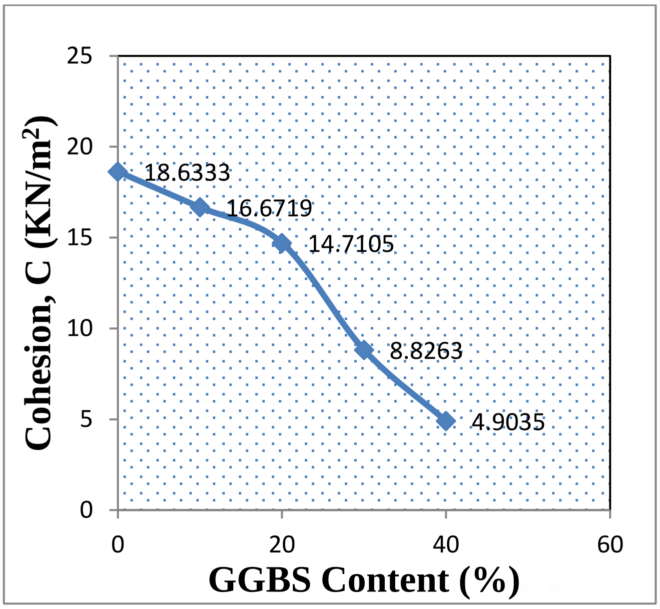


Fig 21: Variation of Cohesion (C) with different % of GGBS

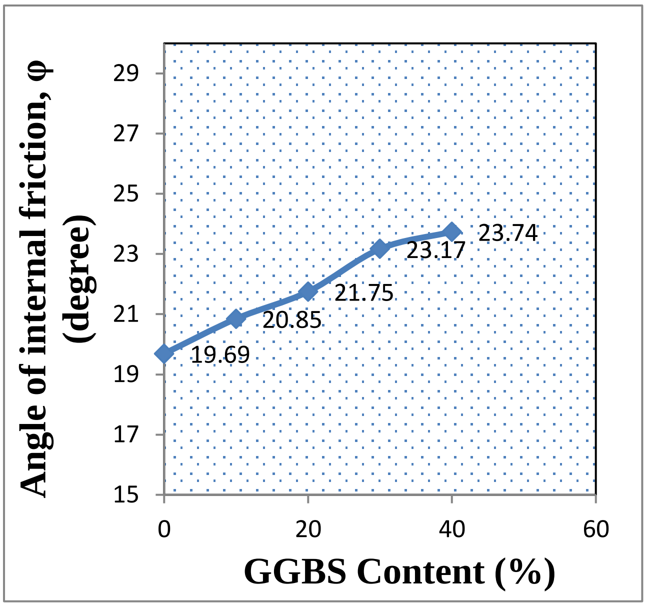


Fig 22: Variation of angle of internal friction (φ) with different % of GGBS

6. CALIFORNIA BEARING RATIO (CBR):

Table 7: Variation of CBR with different % OF GGBS

% GGBS	CBR (%) at 2.5mm Penetration
0	6.34
10	8.50
20	9.31
30	9.04
40	8.77

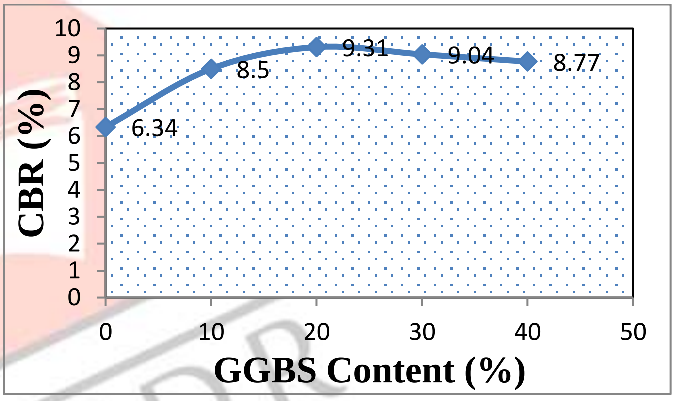


Fig 23: Variation of CBR with different % of GGBS

The CBR test results indicate progressive improvement in the CBR values with the increasing GGBS content up to 20% GGBS. A maximum value of CBR i.e., 9.31% is attained at 20% GGBS. On further increase in percentage of GGBS, the CBR values reduced.

Table 8: Variation of CBR with Cohesion (C) and angle of internal friction (φ)

CBR (%)	Cohesion, C (kN/m2)	Angle of internal Friction, φ (degrees)
6.34	18.6333	19.69
8.5	16.6719	20.85
9.31	14.7105	21.75
9.04	8.8263	23.17
8.77	4.9035	23.74

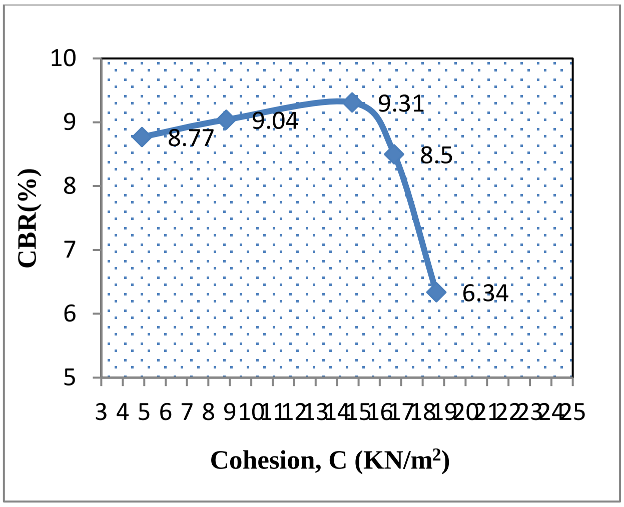


Fig 24: Variation of CBR with Cohesion (C)

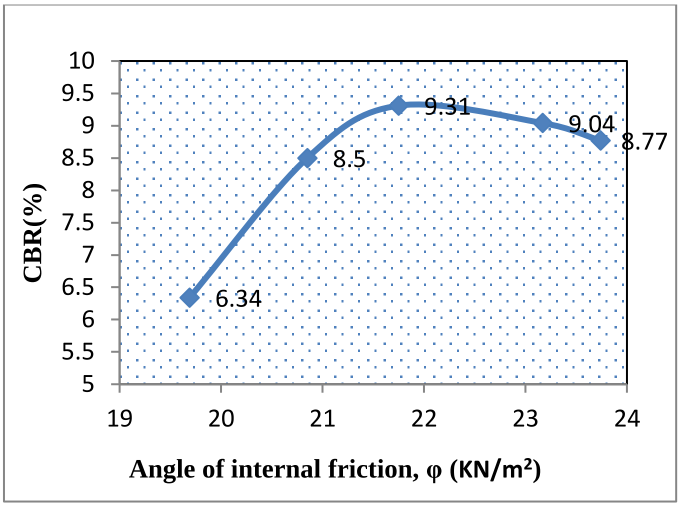


Fig 25: Variation of CBR with angle of internal friction (φ)

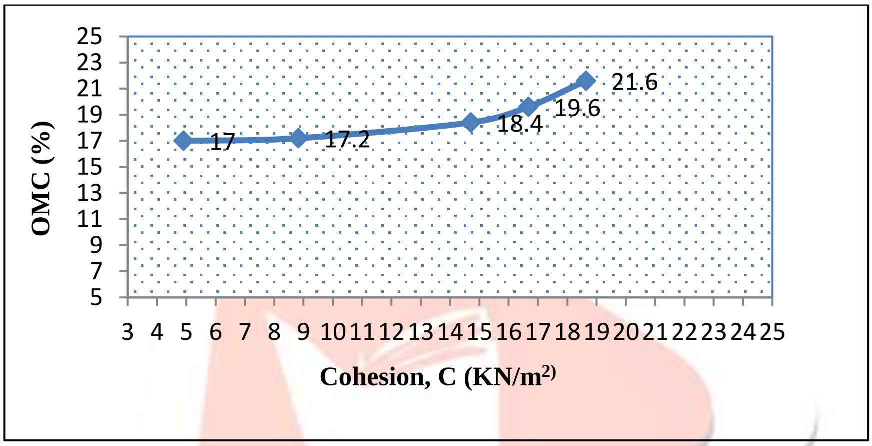


Fig 26: Variation of OMC with Cohesion (C)

From the above Fig 26, it can be inferred that with the increase in optimum moisture content of the soil sample, the cohesion also increases. The OMC values of 17%, 17.2%, 18.4%, 19.6% and 21.6% are for 0%, 10%, 20%, 30%, and 40%, respectively. Thus, it indicates that the binding property of the soil grains is improved with the GGBS addition.

V. CONCLUSIONS

Soil stabilization with the help of GGBS is found to be an effective way for enhancing the engineering performance of Black Cotton soil. Following inferences can be drawn while using ground granulated blast furnace slag as a stabilizer for black cotton soil.

The Concluding remarks from experimental results can be drawn as following:

1. Effect of GGBS on Atterberg Limits: With the increment of percentage of GGBS content, the liquid limit, the plastic limit and thus the plasticity index goes on decreasing, which makes the soil lesser plastic.
2. Effect of GGBS on Compaction characteristics: OMC decreased and MDD increased with the increasing percentage of GGBS proportion in the mixtures. Optimum Values of OMC (18.4%) and MDD (1.704 g/cc) is attained at 20% GGBS. However, beyond 20% GGBS, MDD gets reduced which indicates that, a maximum of 20% GGBS can be used for improving Compaction characteristics of BC soil.
3. Main cause for these results is the predominant effects of reduced clay content and increase in the resistance to friction respectively. Hence compactibility of soil increases and making the soil more dense and hard.
4. Effect of GGBS on Swelling pressure:Enormous reduction occurs in the swelling of the soil. This happens because the GGBS addition produces a large amount of calcium ions which accumulate in the double layer surrounding the surface of soil (clay) grains, thereby bringing down the capability of moisture attraction. Adding to this, the pozzolonic compounds even have the ability to bring closer the soil particles thereby improving its strength and decreasing the potential to swell.
5. Effect on shear strength parameters - Cohesion and angle of internal friction showed reduction and increment respectively. As the percentage of GGBS increases, C decreases and whereas φ increases considerably. This indicates that, through GGBS stabilization, soil becomes less cohesive and more resistant to shear stresses. Thus shear strength of the soil progressively improves with the increasing GGBS percentage.

6. Effect on CBR: The CBR value increases with the increasing percentage of GGBS up to 20% GGBS and thereby reduces on further addition above 20%. A maximum CBR value of 9.31% is attained at 20% GGBS. Thus it is concluded that the optimum GGBS content to attain maximum CBR is 20%. The initial increase in CBR indicates significant densification to have taken place among soil grains which may be due the cementitious compounds formation. Thus with the increasing GGBS content, the pavement thickness can be reduced.
7. From the graphs plotted between CBR and Cohesion and also between CBR and angle of frictional resistance, inference can be drawn that the shear strength increased with adding up of GGBS up to 20%. On further adding of GGBS, it results in decrease of the shear strength of Soil-GGBS mixture.
8. From the graph plotted between OMC and Cohesion, it is observed that, with the increase in OMC values, there was increase in Cohesion which indicates the binding properties to have been improved with the GGBS addition.
9. Further, the blended soil meets the requirements as per specifications given by MORTH of sub grade.

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