

## SOIL STABILISATION WITH WASTE MATERIALS BASED BINDER

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**ABSTRACT:** This paper describes a laboratory trial to study the effectiveness of a waste-based binder to stabilize expansive soils. The proposed binders viz., Fly ash and/or Ground granulated Blast furnace slag (GGBS) were mixed with the expansive soil along with a small amount of lime to increase soil pH and enable pozzolanic reactions. The geotechnical characteristics of the various combinations of samples were investigated through the compaction tests, unconfined compression tests etc. It was found that the addition of GGBS with and without fly ash and lime has significant influence on the geotechnical characteristics of the soil.

### INTRODUCTION

Expansive soils are those soils which show major volume changes due to change in the moisture content causing major damage to property. These soils contain minerals such as montmorillonite clays that are capable of absorbing water. When they absorb water they increase in volume. The more water they absorb the more their volume. Although mechanical compaction, dewatering and earth reinforcement have been found to improve the strength of the soils, other methods like stabilization using admixtures are more advantageous. The different admixtures available are lime, cement, fly ash, blast furnace slag etc. The stabilization of expansive soils with Cement and lime is well documented [13, 3]. Cement stabilization nowadays is less appreciated because of the increasing cost of cement and environmental concerns related to its production. India being the second largest producer of cement has a very heavy impact on the CO<sub>2</sub> emissions. One can imagine from the fact that approximately one tone of CO<sub>2</sub> is produced during the production of one tone of cement. On the other hand lime also contributes CO<sub>2</sub> to the world climate during its production. Moreover lime is not suitable for soils which contain sulfates as the presence of sulfates can increase the swelling due to the formation of swelling minerals such as ettringite and thaumasite [10]. With this growing evidence the requirement to find alternatives to Cement and lime has been made more pressing in recent years. The focus is on the use of the industrial materials like Fly ash and Ground Granulated Blast Furnace Slag (GGBS). Fly ash is a byproduct from burning pulverized coal in electric power generating plants. GGBS is manufactured from blast furnace slag, a by-product from the manufacture of iron. GGBS is obtained by quenching molten iron blast furnace slag immediately in water or stream, to produce a glassy granular product that is then dried and ground into a fine powder. It is an excellent binder to produce high performance cement and concrete. As industrial waste materials have little or no production cost, using these materials in the field of Geotechnical Engineering saves construction cost. The beneficial use of these industrial

waste materials is not only the promising solutions to reduce the disposal problem but also reduces the demand of cement thereby reducing the CO<sub>2</sub> emissions.

### Scope and present work

The main objective of the paper is to investigate the potential of using industrial materials in the field of Geotechnical engineering. A lot of research has been done on fly ash for the stabilization of expansive soils. Cokca [2] has studied the effect of fly ash on the properties of expansive soil prepared in the laboratory using kaolinite and bentonite. He has recommended that fly ashes can be used as effective stabilizing agents for improvement of expansive soils. Pandian [7] conducted laboratory CBR tests on the stabilized fly ash-soil mixtures and found that fly is an effective admixture for improving the soil quality. Sridharan [11] has studied the effect of fly ash on the unconfined compressive strength of Black Cotton soils found in India which is typically an expansive soil. They have suggested that the strength of BC soil is altered by significantly by two distinct mechanisms namely pozzolanic reactions which increase the strength and the reduction in cohesive strength of clayey soils by the silty nature of the fly ash particles. Nalbantoglu [5] investigated the effect of Class C fly ash on expansive soil and shown that there is an improvement in the plasticity characteristics of the expansive soil with the addition of fly ash. But many fly ashes often improve their strength with lime but may not meet the requirements. Hence the strength of fly ash mixture often needs to be enhanced for its better utilization in geotechnical and environmental applications. Also only few studies have been done to check the effectiveness of GGBS in Black cotton Soils (BC soils). Hence to study the effect of GGBS on BC soils laboratory compaction and strength tests has been done on the stabilized GGBS-BC soil mixtures. Hence research work presented on this paper is mainly concentrated on the stabilization of BC soil with GGBS and enhancing the cementitious properties of Fly ash with GGBS.

**MATERIALS USED**

**Black Cotton Soil**

The BC soil was obtained from Belgaum district of Karnataka state in India. It is an expansive soil which contains montmorillonite as the major mineral. Soil is collected from a depth of 1 m below the natural ground level by open excavation. The soil was dried and sieved through 425 micron IS sieve before its use in experimental studies.

**Ground Granulated Blast Furnace Slag (GGBS)**

The GGBS used is collected from the concrete industry which they use it for partial replacement of cement in the manufacture of concrete.

**Fly ash**

The Fly ash used in the experimental studies is collected from the Raichur Thermal Power plant which is in Raichur district of Karnataka state, India.

The physical properties of BC soil, GGBS, Fly ash used in the study are listed in Table 1. Grain size analysis of BC soil, GGBS and Fly ash are shown in Table 2.

**Table 1** Physical property of BC soil, Fly ash and GGBS

Properties	BC soil	Fly ash	GGBS
Specific gravity	2.61	2.01	2.83
Liquid limit: %	76	31.34	31.5
Plastic limit: %	35	NP	NP
Plasticity index: %	41	NP	NP
Shrinkage limit: %	10	-	-
Modified Free swell index:cm <sup>3</sup> /g	4.22	0	0
OMC: %	33	22	26
MDD (kN/m <sup>3</sup> )	13.56	12.83	12.74

**Table 2** Grain size analysis

Constituent	BC soil	GGBS	Fly ash
Clay content (%)	40	0.7	1.33
Silt content (%)	54	23	
Fine sand content (%)	6	76.3	96.67
Soil classification	CH	-	-

**METHODOLOGY**

**Compaction studies**

The unit weight of GGBS-soil mixture is an important parameter because it controls the strength, compressibility, and permeability. Densification improves engineering properties [8]. Mini Compaction tests designed by

Sridharan [12] were performed on the GGBS-BC soil mixtures at different GGBS-soil ratios. A premeasured amount of GGBS, measured as percent of dry soil by weight, was mixed thoroughly to produce a homogenous GGBS-soil mixture. Water was added slowly during mixing. The samples were then compacted in 38.1 mm diameter moulds. The compaction tests were done on BC soil alone, GGBS alone and on the soil-GGBS mixtures in weight proportions of 4:1, 3:2 and 2:3.

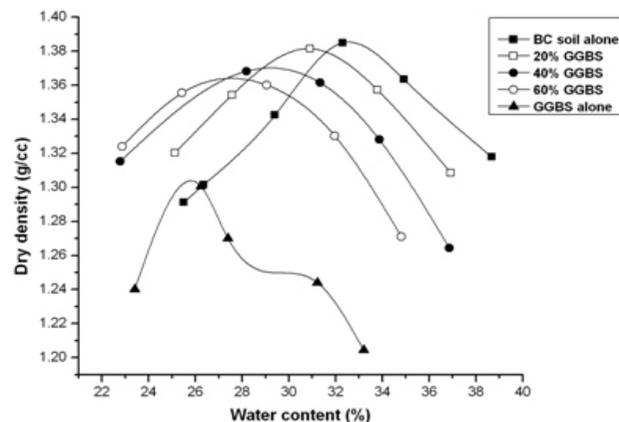
**Unconfined Compressive Strength (UCS)**

Compressive strength is one of the most important geotechnical properties that a material like GGBS must possess when being considered for the stabilization of soils. The unconfined compressive strength (UCS) varies with the GGBS-soil mixing ratio and water content. Hence the UCS test was done on the soil-GGBS mixtures in different proportions. The samples for UCS test of height 7.6 cm and diameter 3.8 cm were prepared by statically compacting the mixtures in the mould to their respective maximum dry density at corresponding optimum water content. The samples were then cured for different time periods in desiccators. UCS test conducted on Fly ash alone showed that the strength achieved is very less even for the 28 days curing period. So an attempt to enhance its strength characteristics UCS testing was done for the different Fly-GGBS mixtures. The unconfined compressive strength test as per the standard method [1] was then done on the cured samples at the end of the required curing period. A constant strain rate of 0.061 cm/min was maintained for all the samples.

**RESULTS AND DISCUSSIONS**

**Compaction Characteristics**

The results of the dry unit weight as a function of GGBS-soil mixtures and moisture contents are shown in Fig. 1.



**Fig. 1** Moisture density relationship of GGBS-soil mixtures

Table 3 summarizes the optimum moisture content (OMC) and maximum dry density (MDD) of the different GGBS-

soil mixtures.

It is interesting to note that both OMC and MDD decrease with increase in the GGBS content. Generally addition of silt or sand to fine grained soil decreases OMC and increases MDD. Similarly Fly ash addition has been reported to decrease the optimum moisture content and increase maximum dry density [9].

**Table 3** Summary of GGBS- Soil mixture (OMC and MDD)

GGBS-Soil Mixture	OMC (%)	MDD (gm/cc)
BC soil alone	33.00	1.386
20% GGBS	31.00	1.382
40% GGBS	29.00	1.370
60% GGBS	27.50	1.364
GGBS alone	26.00	1.316

The decrease in OMC is obviously due to the addition of GGBS which is relatively coarser relative to BC soil. Addition of coarser particles reduces the water holding capacity due to the reduction of the clay content. The decrease in MDD, in spite of increase in OMC, is due to the predominant effect of high frictional resistance offered by relatively coarser GGBS due to size and surface texture resisting the compactive effort effectively.

## Unconfined Compressive Strength

### (i) Soil-GGBS Mixtures

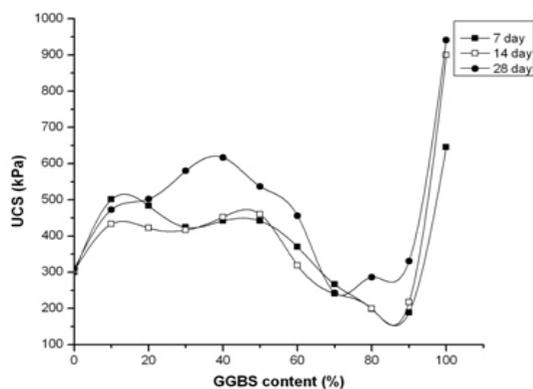
The variation of the unconfined compressive strength test with GGBS content for different curing periods has been shown in the Fig 2. From the figure it can be seen that the unconfined compressive strength (UCS) of BC soil increases with the addition of small amount of about GGBS which remains constant up about 40% addition of GGBS. With further addition of GGBS the UCS decreases continuously and reaches lowest value with the addition of 90% of GGBS.

The variations in strength can be explained by the following factors:

1. Reduction in cohesion of the soil due to addition of coarser materials
2. Increase in strength of soil due to cementation by pozzolanic compounds produced
3. The effect of compaction parameters as the soil GGBS mixtures are compacted to their respective optimum conditions.
4. Occupation of GGBS particles by finer soil particles.

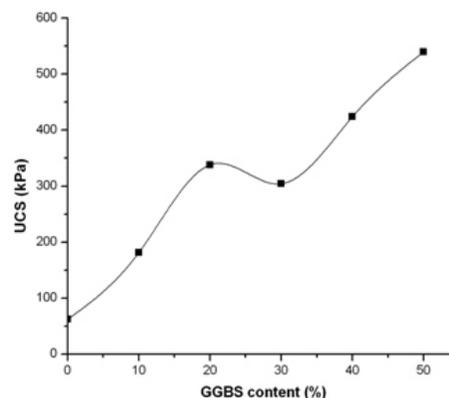
The reduction in cohesion of soil is least with the addition of 10% of GGBS because of soil particle cohesion is disturbance is minimum which however increases with increasing GGBS content. With increase in GGBS content the available pozzolanic material i.e. GGBS increases but the available water for pozzolanic reactions becomes less

due to decrease water content. Further the moulding densities are also lower with increasing GGBS content. It is clear from Table 3 that the both the moulding water and density are lower for soil GGBS mixtures. With GGBS content higher than 40% all the effect of decreased moulding water content and density dominate and the strength decrease. Thus the effect of pozzolanic reactions is nullified by lower densities and water contents. The 28 day curing period shows higher strength which means that the UCS increases with higher curing periods.



**Fig. 2** Variation of UCS of BC soil with GGBS content

### (ii) Fly ash-GGBS Mixtures



**Fig. 3** Variation of UCS of Fly ash with GGBS content

The variation of UCS of Fly ash with different GGBS content but without lime is shown in Fig 3. It can be seen from the figure that the gain in strength of the Fly ash-GGBS mixtures is extremely good for the 7 day curing period. The strength increased from 62 kPa to 540 kPa with addition of 50% of GGBS. The relationship found between the unconfined compressive strength of the Fly ash with GGBS content is linear with a discontinuity in between 20 to 30 % of the GGBS content. The discontinuity may be due to the disturbance caused to development of soil matrix and also by unfavourable gradation of Fly ash-GGBS mixtures.

Fig 4.shows the variation of UCS of Fly ash with different percentages of GGBS at lime content of 2 and 4 % for 7 day curing period. It can be seen from the figure that with the addition of lime has further improved the UCS of the Fly ash GGBS mixtures. One interesting point can be noticed from this figure that the discontinuity which occurs in the variation of UCS strength with GGBS content (between 20% and 30% GGBS content without lime is eliminated with the addition of lime.

It means the disturbance is balanced by the formation of further pozzolanic compounds in the presence of lime. Further the strength achieved is higher at still lower GGBS content. The relationship between the strength variations of Fly ash-GGBS mixtures is almost linear.

Increase in strength of Fly ash with addition of GGBS can be explained with two reasons: Firstly, the formation of compounds (C-S-H gel) possessing cementing properties in the presence of highly reactive siliceous and aluminous materials and water and secondly addition of GGBS to Fly ash makes the mix well graded which in turn increases the compacted density and hence the mechanical strength of the compacted mixture.

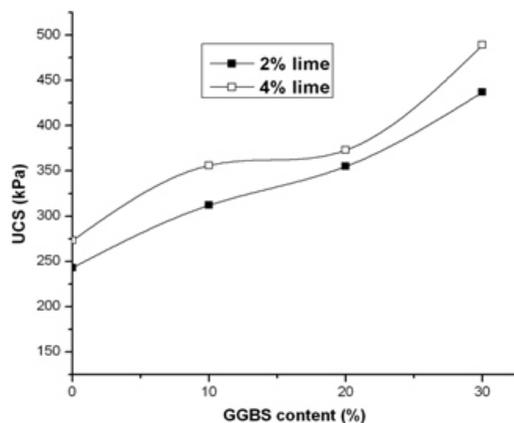


Fig. 3 Variation of UCS of Fly ash with GGBS content along with lime

## CONCLUSIONS

Based on the findings of the present investigation, the following conclusions can be drawn:

1. Both OMC and MDD decreased with the addition of GGBS to the BC soil. This is due to predominant effects of reduced clay content and increased frictional resisting respectively.
2. It is observed that the strength of the soil-GGBS mixtures increase with curing period.
3. The UCS of the Fly ash-GGBS mixture increases with the increase in the GGBS content.
4. Almost a linear relationship is found between the unconfined compressive strength of the Fly ash-GGBS mixture and the GGBS content with a discontinuity between 20 to 30% of the GGBS content.

5. Enhancing the cementitious properties of Fly ash without the addition of lime is a good signal for the increase in utilization rate of the industrial wastes.
6. The reduction in strength in the Fly ash-GGBS mixtures is overcome by addition of lime.

Based on the results of this research, it appears that BC soil is effectively stabilised with the addition of GGBS. Fly ash-GGBS mixtures are suitable for use in highway embankments and it can provide fill materials of comparable strength to most soils.

## REFERENCES

1. ASTM (1989) Standard test method for unconfined compressive strength of cohesive soil. Designation D2166-85. *Annual book of ASTM standards*, ASTM, Philadelphia, 4(08), 253-257.
2. Çokca, E. (2001) Use of class C fly ashes for the Stabilization – of an expansive soil, *Journal of Geotechnical and Geoenvironmental Engineering*, 127, 568-573.
3. Du, Y., Li, S., Hayashi, S., (1999). "Swelling-shrinkage properties and soil improvement of compacted expansive soil", Ning-Liang Highway, China. *Engineering Geology*, 53 (3-4), 351-358.
4. Hughes, P.N., Glendinning, S., Manning, D. A. C. and White, M.L. (2011), *Symposium at Queen's University Belfast*, 20<sup>th</sup> May, 2011.
5. Nalbantoglu, Z., (2004). "Effectiveness of Class C fly ash as an expansive soil stabilizer". *Construction and Building Materials* 18 (6), 377-381.
6. Nelson, J. D., and Miller, D. J. (1992). *Expansive soils*, Wiley, New York.
7. Pandian, N.S. and K.C. Krishna. (2002). "The Pozzolanic Effect of Fly Ash on the CBR Behaviour of Black Cotton Soil". *J. of Testing and Evaluation*, ASTM, 31(6), 479-485.
8. Pandian N.S. (2004), "Fly ash characterization with reference to geotechnical applications", *Journal of Indian Institute of Science*, Nov-Dec, 84, 189-216.
9. Phani kumar, B. R., and Sharma, R. S. (2004). "Volume Change Behavior of Fly Ash-Stabilized Clays." *Journal of Materials in Civil Engineering*, 19, 67-74
10. Rajasekaran, G. (2005), "Sulphate attack and ettringite formation in the lime and cement stabilized marine clays". *Journal of Ocean Engineering*, 32, 1133-1159.
11. Sridharan, A., Prashanth, J.P., and Sivapullaiah, P.V. (1997). "Effect of fly ash on the unconfined strength of black cotton soil". *Ground Improvement*, 1, 169-175.
12. Sridharan, A., and Sivapullaiah, P. V. (2005). "Mini Compaction Test Apparatus for Fine Grained Soils". *ASTM Journal of Testing and Evaluation*, 28, 240-246.
13. Yong, R.N., Ouhadi, V.R., Mohamed, A.M.O., (1996). "Physicochemical evaluation of failure of stabilized marl soil". *49th Can Geotech Conf Frontiers in Geotechnology*, Vol. 2, 769-776.