Improving the characteristics properties of sulfate infected BC soil using GGBFS and different fibres

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Abstract - *The stress resistant properties of soils can be improved in a variety of ways. For example, sheets, strips or rods of metal or polymeric materials can be placed in the soil to create a composite material. Researchers believe that there is a great potential of combined usage of monofibres and hybrid fibers as a stabilization materials in sulphate infected black cotton soil mix, making it stronger and durable. But not much progress has been made in this regard. The main objective of this research work is to investigate the index properties and stress resistant properties by adding stabilization materials like, GGBFS along with monofibres and hybrid fibres. The research is proposed to address the following problems. 1. Effect of replacement of sulphate infected BC soil by stabilization material such as ground granulated blast furnace slag (GGBFS) in different percentages like 0%, 5%, 10%, 15%, 20%, 25%, 30%, 35% and 40% and thereby determining the optimum dosage of stabilization materials. 2. Effect of addition of different monofibres such as Jute fibre (JF), Poly propylene fibre (PPF), Waste plastic fibre (WPF) and High density polyethelene fibre (HDPEF) on the properties of sulphate infected BC soils. 3. Effect of addition of different hybrid fibres such as (JF+WPF), (PPF+WPF) and (PPF+HDPEF) on the properties of sulphate infected BC soils. It is observed that the sulphate infected black cotton soil using GGBFS as stabilization material has shown improved index properties at 20% replacement level. Unsoaked CBR value, soaked CBR value, cohesion value from direct shear test and UCC test cohesion value, all show an increasing trend upto 20% replacement of black cotton soil by silicafume. After 20% replacement level, all the above values go on decreasing. It is observed that the sulphate infected black cotton soil using GGBFS as stabilization material along with monofibres has shown improved stress resistance properties when monofibres are added at 1.5% by volume fraction. From the results obtained, it may also be concluded that, the performance of HDPE fibres is better than polypropylene fibres, waste plastic fibres and jute fibres in enhancing the stress resistance properties of sulphate infected black cotton soil using silicafume as stabilization material.*

***Key Words*: GGBFS, Polypropylene fiberes, Sulfate infected BC soil, Stabilization, Stress resistant**

1. INTRODUCTION

Good quality soil is always essential for the construction of any civil engineering infrastructures. This is even true for roads and highways. Good quality sub-grade soils are necessary for durable roads. Sometimes such soils may not be available and the construction engineer or highway engineer is likely to face problem in the design and constructions. The sulphate infected black cotton soil exhibits low load bearing capacity and high swelling property and this may pose many problems on site. Volume changes of some soils resulting from changes in their water content may cause unappreciable movement of structure that are founded on such soils, resulting in heaving, shear failure, accessible settlement, cracking and breaking up. Among the problems of soils, the soil infected with sulphates pose peculiar problems on site. Unless the problems of sulphate bearing soils are not addressed properly, the durability of the structure will be in question. The sulphate attack on soil is usually accompanied by strength loss and large volume changes resulting in substantial heave in stabilized earth works. Many researchers have reported examples of detrimental effect of sulphate either naturally present in the ground or artificially added. Among the most commonly encountered naturally occurring sulphates in the earth's crust are calcium sulphate which occurs as gypsum (or selenite ($CaSO4.2H2O$)) [Veith 20]. Sulphate may be present within the soil already or may be produced from the oxidation of sulphide minerals. Sometimes industrial activities are responsible for the presence of sulphates in soils. As the concentration of sulphate in soils increase, its detrimental effects also increase. Many researchers have reported examples of detrimental effects of sulphates, either naturally present in the ground or artificially added when soils are modified or stabilized with lime and/or cement [Mitchell 17 and Hunter 11] in USA. The expansion in lime-stabilized clay in the presence of sulfates is believed to be partly caused by the growth of ettringite crystals formed on the clay particle surfaces [Mitchell 17]. There is a deliberate bias and focus towards the more 'troublesome'sulfate-bearing soils, Lower Oxford Clay (LOC). In addition, there is an interest in the utilization of wastepaper sludge ash (WSA) as a soil stabilizer. WSA is an industrial by-product of wastepaper recycling and re-processing, that is increasingly becoming abundant in UK as paper recycling rates increase [Kinuthia et al. 14]. So far, the progress in this regard has been minimal. But now with the implementation of government schemes like "Pradhan Mantri Gram Sadak Yojana (PMGSY)", NHDP Project, Golden Quadrilateral Project, North South East Corridor Project, the road constructions scenario has taken a big leap forward. However, fund constraint, lacks of good quality construction materials in the vicinity of the project considerably hamper the progress. One of the major costs involved in road construction is the transportation of materials. To minimize this cost, the locally available materials should be used, particularly the soil. But if the soil available locally is not of good quality, it causes a major problems for this soil has to be stabilized suitably.This document is template. We ask that authors follow some simple guidelines. In essence, we ask you to make your paper look exactly like this document. The easiest way to do this is simply to download the template, and replace(copy-paste) the content with your own material. Number the reference items consecutively in square brackets (e.g. [1]). However the authors name can be used along with the reference number in the running text. The order of reference in the running text should match with the list of references at the end of the paper.

2. Literature Review

During the last few decades, many researchers have studied the behaviour of sulphate infected black cotton soil. Stabilization of soils with hydraulic binders is essential to improve their engineering properties. Therefore, they can be used, in situ, in geotechnical applications such as sub-base layer with the required performances. Sulphates and sulfides are naturally present in the soils, mainly as gypsum CaSO4 · 2H2O or pyrite FeS2. Sulphates are widely recognised in altering soil stabilization, inducing considerable swellings. Le Borgne [10] describes the effects of 0.62 and 6.20 g of SO_2^{-4} · kg^{-1} (as gypsum) in silt treated with 1.5% of quicklime and 6% of cement CEMII. The effects are evaluated with various physical and mechanical tests. Xing et al. (2009) study the UCS of NaCl-rich soils (chloride concentrations from 1.54 to 16.00 g.kg−1), treated with 21% of cement CEMI 32.5: 8.00 g of chloride ·kg−1 decrease the UCS values about 20% compared with a soil with 1.54 of chloride ·kg−1. Parker [15] reported that sulfate attack of the lime stabilized capping layer of the new carriageways on the 7.5 km A10 Wadesmill bypass U.K. resulted in heave that left up to 25% of the carriageways buckled, cracked and ridged. Similarly, Wild et al. [21], researching on industrial kaolinite clay stabilized with various lime and gypsum contents, agreed with Mehta [16] that osmotic swelling would take place within the colloidal layer in regions of high sulfate concentration in close proximity to the developing ettringite rods at the clay particle surfaces. Research work by Kinuthia et al. [13] and Bai et al. [6] has established the principal crystalline components in WSA as typically calcium oxide (about 5 wt.% of which is free quicklime with traces of calcium hydroxide). The ash is highly alkaline (pH 11–12) probably as a result of the residual free CaO. Basu et al. [3] studied about the usage of jute-synthetic blended woven geotextile in construction of unpaved rural roads. Laboratory test results shows that, this woven geotextile can be suitable for use as a separation layer as well as a reinforcing material for construction of medium traffic-volume unpaved roads. The use of jute (z85%) in cross direction resulted in notable increase in modulus, breaking strength, CBR puncture resistance of the geotextiles as compared to 100% HDPEF geotextile. Bent and Broms [4] studied about the usage of geofabric in stabilizing very soft clay. The method has been used in Malaysia and Singapore to stabilize very soft clay in setting ponds with a shear strength of approximately 3kPa so that the area can be used for construction. They have observed that, Geo-fabric can be used to increase the bearing capacity of very soft clay so that the fill required for the preloading of the clay can be placed. Wild et al. [22] studied the lime stabilized sulphate bearing clay soils stabilized with ground granulated blast furnace slag (GGBFS) and have concluded that, partial substitution of lime with GGBFS gives improved 7 days and 28 days strengths for both kaolinite and Kimmeridge Clay, the maximum level of lime substitution is different for the two clay types. Bidula Bose [5] studied the geo-engineering properties of the virgin soil and fly ash treated soil and it was found that there was 55% increment in the CBR value when compared with the virgin soil. Anil and Sivapullaiah (2011) studied the effectiveness of fly ash with ground granulated blast furnace slag in the soil and it was found that the UCS of flyash-GGBFS mixture increases with the increase in the GGBFS content. And also it was observed that the strength increases with the curing period. Sahu [19] observed that, stabilized fly ash with optimum lime content shows maximum economy. Three combinations were tried, stabilized fly ash with 50% sand, optimum lime content and activators (optimum lime content+20% sand). The saving was 6.0, 25.3 and 20.3% respectively. It was seen that the rate of increase of CBR value of fly ash stabilized with lime is more than with sand.

From the above literature review, it appears that chlorides and sulphates have an influence on the properties of treated soils. However, no specific threshold concentrations could be defined to predict the stabilization disturbances in treated soils containing anions such as chlorides and/or sulfates. Hence, it is clear that only a few limited research works have been carried out on ground granulated blast furnace slag and waste paper ash (WSA) behaviour study on sulphate infected black cotton soil with fiberes

3. Experimental Investigation

Main objective of this experimental programme is to study the behavior of sulfate infected black cotton soil which is stabilized using GGBFS and different fiberes.

3.1 Preperation of Potassium Sulphate Solution and Soil Sample

Potassium sulphate (K2SO4) powder was used to raise the sulphate level in the soil. Potassium sulphate powder was mixed with the calculated amount of water and the solutions were prepared. In the study, potassium sulphate concentration 20000 ppm was used. A series of tests were first performed on compacted soil specimens without any admixture followed by additional tests.

Figure 1. Blending of artificial laboratory soil samples prior to compaction

3.2 Maximum dry density and optimum moisture content test

This test was conducted to know the MDD and OMC of the freshly prepared soil sample for soil mix and for different combinations as per IS: 2720-1974, Part-6. Each soil sample was prepared by initial dry mixing of raw soil about 3kg. Then water was added about 3% of weight of soil sample and mixed again until the water spreads all over the soil. The dry and wet mixing of soil-water was carried out in a non-porous metal tray in order to avoid water loss. The soil samples were subjected to this test and respective optimum moisture content and maximum dry densities of all combinations were determined. Determination of water content was carried out by the oven drying method.

3.3 California bearing ratio test

This test was conducted to know the CBR of the freshly prepared soil sample for soil mix and for different combinations as per IS : 2720-1987, Part-XVI.

The test is performed by measuring the pressure required to penetrate a soil sample with a plunger of standard area. The measured pressure is then divided by the pressure required to achieve an equal penetration on a standard material. It is the ratio of force per unit area required to penetrate a soil mass with standard circular piston at the rate of 1.25mm/min. to that required for the corresponding penetration of a standard material. During immersion, water will flow into the sample due to capillary action. If after the first 3 days in the tank there is still little or no water at the top of the specimen, then water is added to the top of the specimen for the remainder of the soaking period prior to testing for strength.

3.4 Direct shear test

This test was conducted to know the shear strength parameter of the soil for the soil mix and for different combinations as per IS: 2720-1986, Part-13. For each test three specimens samples were extracted after compacting the soil specimen in the standard proctor mould. The specimen samples were tested with different normal stresses i.e., 100 kpa, 200 kpa and 300 kpa in undrained conditions. The proving ring readings were noted at fixed interval of horizontal dial gauge readings to study the stress-displacement behavior of soil specimen. The stress-horizontal displacement curves were plotted to study the stress-displacement behavior of soil specimen. The shear strength parameters were also studied.

3.5 Unconfined compression shear test

This test was conducted to know the shear strength parameter of the soil for the soil mix and for different combinations as per IS: 2720-1973, Part-10. The shearing strength is commonly investigated by means of compression tests in which an axial load is applied to the specimen and increased until failure occurs. The unconfined compressive strength is the load per unit area at which unconfined cylindrical specimen of soil will fail in a simple compression test. If the unit axial compression force per unit area has not reached a maximum value up to 2 percent axial strain, unconfined compressive strength shall be considered the value obtained at 2 percent axial strength.

4. Experimental results of sulphate infected black cotton soil using GGBFS as stabilization material.

4.1 Index properties of sulphate infected black cotton soil using GGBFS as stabilization material.

Table 1. gives the index properties of black cotton soil using GGBFS as stabilization material in it. The variation of specific gravity, liquid limit, plastic limit, plasticity index, shrinkage limit and pH value of GGBFS based stabilization material are shown in figure 2 to figure 7.

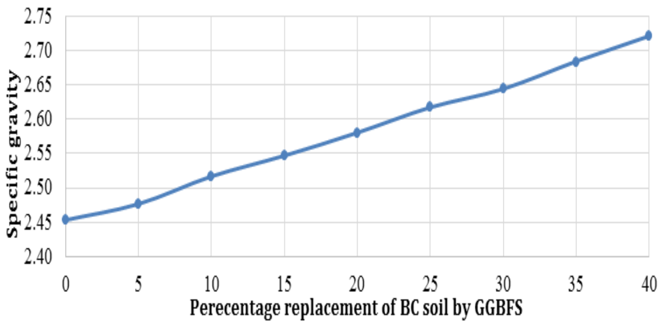

Figure 2. Variation of specific gravity for different percentage replacement of BC soil by GGBFS

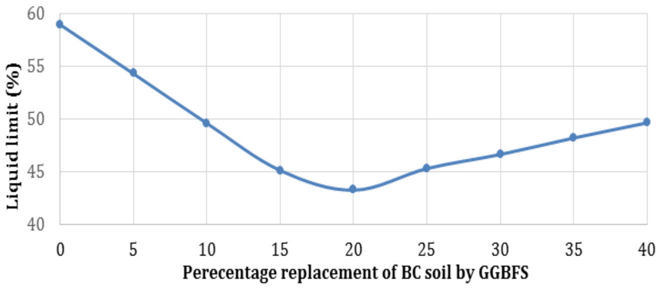

Figure 3. Variation of liquid limit for different percentage replacement of BC soil by GGBFS

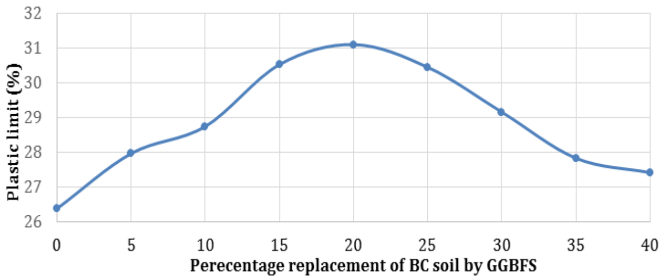

Figure 4. Variation of plastic limit for different percentage replacement of BC soil by GGBFS

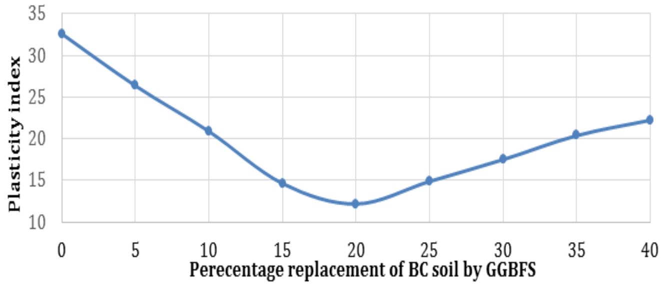

Figure 5. Variation of plasticity index for different percentage replacement of BC soil by GGBFS

Table 1- Index properties of sulphate infected B C soil using GGBFS as stabilization material

Percentage replacement of B C soil by GGBFS	Specific gravity	Average specific gravity	Liquid limit (%)	Average liquid limit (%)	Plastic limit (%)	Average plastic limit (%)	Plasticity index	Average plasticity index	Shrinkage limit (%)	Average shrinkage limit (%)
0	2.42	2.45	59.04	59.00	26.81	26.40	32.23	32.60	20.6	20.91
	2.46		59.12		26.45		32.67		21.28	
	2.48		58.85		25.94		32.91		20.84	
5	2.49	2.48	54.42	54.34	28.09	27.98	26.33	26.36	18.21	18.12
	2.46		54.38		27.88		26.5		18.06	
	2.5		54.21		27.96		26.25		18.08	
10	2.53	2.52	49.56	49.64	28.78	28.75	20.78	20.89	16.74	16.68
	2.54		49.65		28.63		21.02		16.78	
	2.49		49.72		28.84		20.88		16.52	
15	2.54	2.55	45.24	45.15	30.51	30.52	14.73	14.63	14.23	14.35
	2.57		45.02		30.37		14.65		14.33	
	2.53		45.18		30.68		14.5		14.48	
20	2.6	2.58	43.12	43.28	30.97	31.09	12.15	12.19	14.12	13.98
	2.57		43.25		31.32		11.93		13.86	
	2.56		43.48		30.98		12.5		13.95	
25	2.61	2.62	45.41	45.34	30.45	30.44	14.96	14.90	14.97	14.88
	2.63		45.32		30.52		14.8		14.85	
	2.62		45.28		30.34		14.94		14.81	
30	2.63	2.64	46.72	46.68	29.18	29.16	17.54	17.52	15.75	15.74
	2.65		46.26		29.04		17.22		15.67	
	2.63		47.05		29.25		17.8		15.81	
35	2.69	2.68	47.95	48.24	28.06	27.84	19.89	20.40	17.06	17.21
	2.68		48.28		27.92		20.36		17.45	
	2.67		48.48		27.54		20.94		17.12	
40	2.71	2.72	49.75	49.68	27.55	27.43	22.2	22.25	17.98	17.85
	2.73		49.69		27.29		22.4		17.92	
	2.71		49.61		27.45		22.16		17.64	

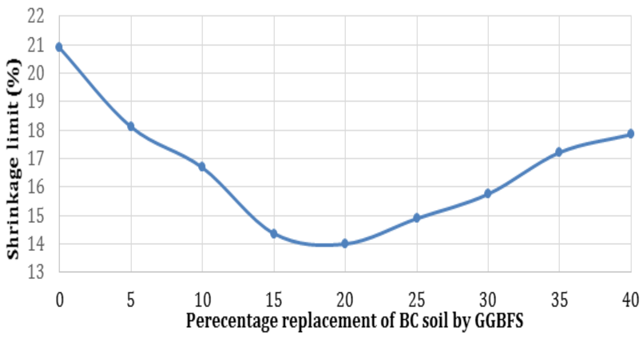

Figure 6. Variation of shrinkage limit for different percentage replacement of BC soil by GGBFS

It is observed that the sulphate infected black cotton soil using GGBFS as stabilization material has shown improved index properties at 20% replacement level. Table 1 and related graphs show the improvement in index properties for sulphate infected black cotton soil when treated with GGBFS as stabilization material with 20% replacement level.

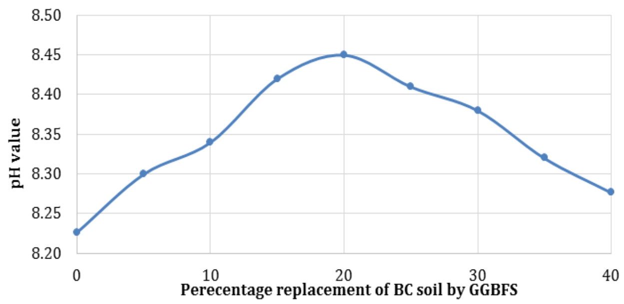

Figure 7. Variation of pH value for different percentage replacement of BC soil by GGBFS

Liquid limit and shrinkage limit values show a decreasing trend upto 20% replacement of black cotton soil by GGBFS. After 20% replacement level, liquid limit and shrinkage limit values go on increasing. The percentage decrease in liquid limit and shrinkage limit at 20% replacement level are found to be 26.64% and 33.15% respectively with respect to reference mix. Plastic limit shows an increasing trend upto 20% replacement of black cotton soil by silica fume. After 20% replacement level, plastic limit goes on decreasing. The percentage increase in plastic limit at 20% replacement level is found to be 15.09% with respect to reference mix. Plasticity index which is an effective parameter for controlling the swell potential of soil, is also less at 20% replacement level. The percentage decrease in plasticity index at 20% replacement level is found to be 62.61% with respect to reference mix. Higher the plasticity index, higher is the swell.

This may be attributed to the fact that at 20% replacement of black cotton soil by silica fume, an appropriate development of a cementitious matrix, resulting from the pozzolonic reactions forming calcium silicate hydrates (CSH), calcium aluminosilicate hydrates (CASH) and calcium aluminate hydrates (CAH) under the localized alkaline conditions within the soil matrix.

Thus, it may be concluded that the sulphate infected black cotton soil using GGBFS fume as stabilizing material shows improved index properties at 20% replacement level.

4.2 Stress resistance properties of sulphate infected B C soil using GGBFS as stabilization material.

Table 2 to table 3 gives the stress resistance properties of sulphate infected B C soil using GGBFS as stabilization material. The variation in MDD, OMC, unsoaked CBR, soaked CBR, cohesion, angle of shearing resistance (ϕ), UCC cohesion and UCC (α) are shown in figure 8 to figure 15.

Table 2. Stress resistance properties of sulphate infected B C soil using GGBFS as stabilization material.

Percentage replacement of B C soil by GGBFS	MDD (gm/cc)	Average MDD (gm/cc)	OMC (%)	Average OMC (%)	CBR (Unsoaked) (%)	Average CBR (Unsoaked) (%)	CBR (Soaked) (%)	Average CBR (Soaked) (%)
0	1.64	1.62	22.86	22.92	3.22	3.29	2.54	2.57
	1.61		22.98		3.34		2.56	
	1.6		22.93		3.32		2.61	
5	1.72	1.70	23.38	23.45	4.53	4.45	3.64	3.64
	1.68		23.51		4.42		3.72	
	1.71		23.46		4.39		3.55	
10	1.78	1.79	24.11	24.08	5.47	5.36	4.29	4.22
	1.77		24.15		5.28		4.12	
	1.81		23.97		5.32		4.25	
15	1.86	1.87	25.62	25.54	6.11	6.12	4.78	4.68

	1.85		25.43		6.17		4.52	
	1.91		25.56		6.08		4.75	
	1.88		25.87		6.95		4.92	
20	1.89	1.89	25.91	25.94	6.72	6.82	5.01	4.95
	1.9		26.03		6.79		4.93	
	1.86		26.81		6.28		4.55	
25	1.85	1.85	27.12	26.92	6.25	6.24	4.68	4.65
	1.83		26.84		6.2		4.72	
	1.8		27.54		5.69		4.26	
30	1.82	1.81	27.38	27.40	5.82	5.74	4.13	4.21
	1.81		27.28		5.71		4.23	
	1.76		28.02		4.92		3.78	
35	1.71	1.75	27.85	27.92	4.96	4.96	3.86	3.85
	1.78		27.89		4.99		3.92	
	1.74		28.84		4.75		3.61	
40	1.72	1.73	28.95	28.91	4.78	4.82	3.85	3.72
	1.73		28.94		4.92		3.69	

Table 3. Some more stress resistance properties of sulphate infected B C soil using GGBFS **as stabilization material.**

Percentage replacement of B C soil by GGBFS	Cohesion from direct shear test (kg/cm2)	Average cohesion (kg/cm2)	Angle of shearing resistance from direct shear test (ϕ)(degree)	Average angle of shearing resistance (ϕ) (degree)	UCC cohesion (kg/cm2)	Average UCC cohesion (kg/cm2)	UCC (α)	Average UCC (α)
	8.92		18.12		8.86		16.74	
0	9.28	9.10	18.65	18.36	9.08	8.90	16.58	16.75
	9.11		18.31		8.76		16.92	
	10.92		17.18		11.12		16.02	
5	10.75	10.82	17.28	17.24	11.14	11.21	16.18	16.15
	10.8		17.26		11.37		16.24	
	12.52		16.24		12.45		15.59	
10	12.28	12.34	16.12	16.22	12.34	12.35	15.52	15.64
	12.23		16.29		12.25		15.81	
	13.65		15.38		13.29		15.24	
15	13.75	13.75	15.31	15.35	13.34	13.38	15.21	15.37
	13.86		15.37		13.52		15.67	
	13.92		14.72		13.78		15.21	
20	13.86	13.95	14.55	14.65	13.92	13.85	15.08	15.14
	14.08		14.68		13.86		15.12	
	13.18		14.76		12.65		15.16	
25	13.34	13.26	14.81	14.81	12.85	12.72	15.31	15.28
	13.25		14.86		12.67		15.38	
	12.92		15.16		12.04		15.51	
30	12.76	12.85	15.04	15.11	11.98	11.95	15.48	15.47
	12.88		15.14		11.83		15.41	
	12.23		15.72		11.48		15.68	
35	12.18	12.25	15.62	15.63	11.51	11.51	15.61	15.62
	12.34		15.55		11.54		15.58	
	11.95		16.42		11.01		15.85	
40	11.75	11.86	16.27	16.35	11.11	11.02	15.82	15.85
	11.88		16.36		10.94		15.88	

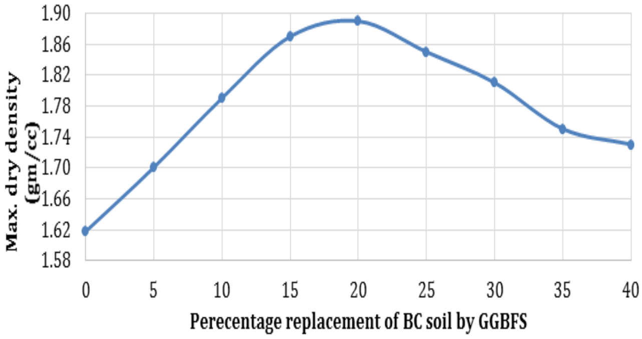

Figure 8. Variation of max. dry density for different percentage replacement of BC soil by GGBFS

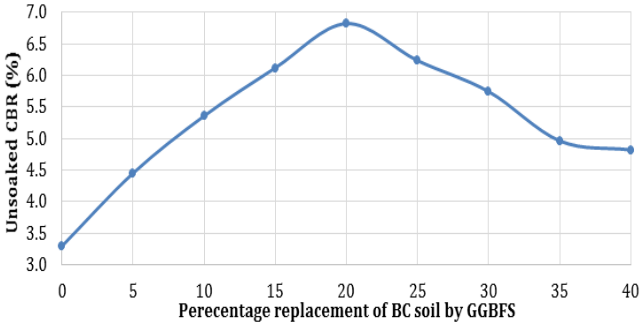

Figure 10. Variation of unsoked for different percentage replacement of BC soil by GGBFS

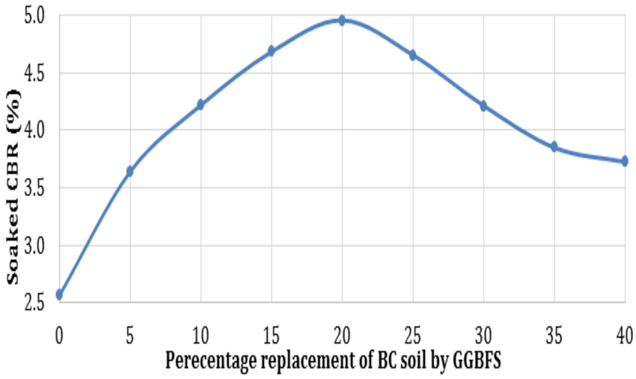

Figure 11. Variation of soked for different percentage replacement of BC soil by GGBFS

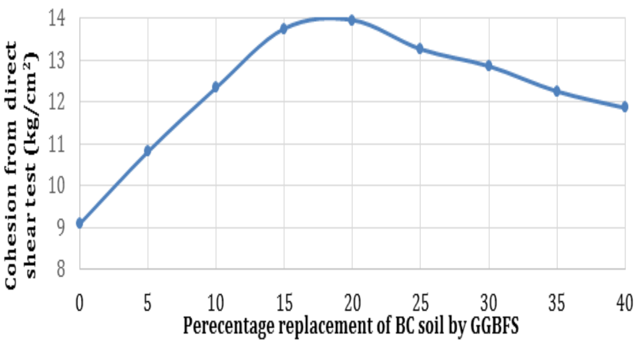

Figure 12. Variation of cohesion of direct shear test for different percentage replacement of BC soil by GGBFS

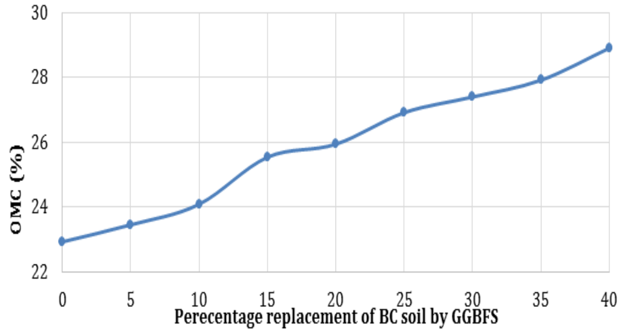

Figure 9. Variation of max. dry density for different percentage replacement of BC soil by GGBFS

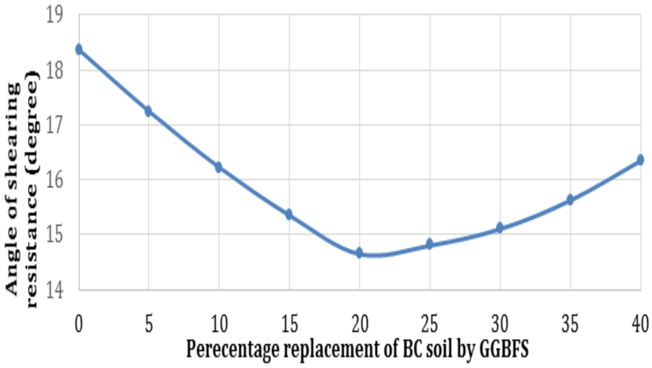

Figure 13. Variation of angle of shearing resistance of direct shear test for different percentage replacement of BC soil by GGBFS

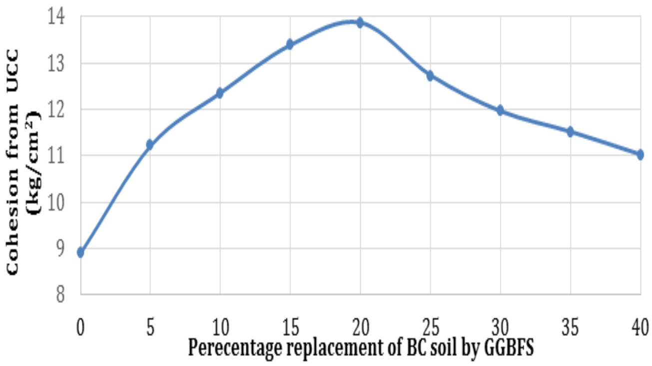

Figure 14. Variation of cohesion of UCC test for different percentage replacement of BC soil by GGBFS

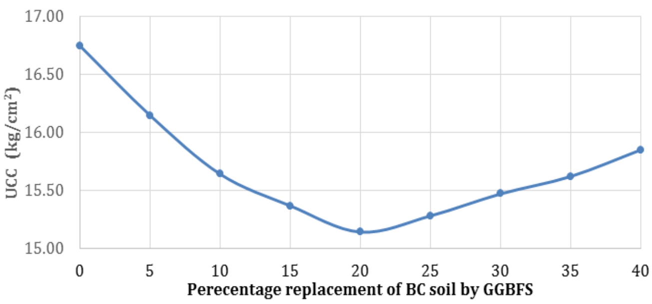

Figure 15. Variation of *angle of shearing resistance of UCC test* for different percentage replacement of BC soil by GGBFS

It is observed that the sulphate infected black cotton soil using GGBFS as stabilization material has shown improved stress resistance properties at 20% replacement level. Table 2 and table 3 and related graphs show the improvement in stress resistance properties for sulphate infected black cotton soil when treated with GGBFS as stabilization material with 20% replacement level.

Unsoaked CBR value, soaked CBR value, cohesion value from direct shear test and UCC test cohesion value, all show an increasing trend upto 20% replacement of black cotton soil by GGBFS. After 20% replacement level, all the above values go on decreasing. The percentage increase in unsoaked CBR value, soaked CBR value, cohesion value from direct shear test and UCC test cohesion value at 20% replacement level are found to be 51.83%, 48.18%, 34.74% and 35.76% respectively with respect to reference mix. Angle of shearing resistance Φ obtained by direct shear test and α value obtained by UCC test shows a decreasing trend upto 20% replacement of black cotton soil by silica fume. The percentage decrease in angle of shearing resistance Φ obtained by direct shear test and α value obtained by UCC test at 20% replacement level are found to be 20.21% and 09.59% respectively with respect to reference mix.

This may be due to the fact that at 20% replacement of black cotton soil by GGBFS, an appropriate colloidal product may be formed which consists of a complex calcium-sulpho-aluminate-silicate hydrate (C-A-S- S-H) on the surface of the clay plates. From this colloidal surface product, a crystalline compound commonly known as ettringite (C_3A-3C S-H32) nucleates. Ettringite is known to impart significant strength enhancement, due to its needle like crystal crystalline morphology.

Thus, it may be concluded that the sulphate infected black cotton soil using GGBFS as stabilizing material show improved stress resistance properties at 20% replacement level.

4.3 Stress resistance properties of sulphate infected B C soil using GGBFS as stabilization material along with monofibres.

Table 4 and table 5 gives the stress resistance properties of sulphate infected B C soil using GGBFS as stabilization material at 20% replacement level along with monofibres like HDPE, Polypropylene, waste plastic and jute fibres. The variation in unsoaked CBR value and soaked CBR value for different monofibres are shown in fig. 16 to fig. 23

Table 4 Stress resistance properties of sulphate infected B C soil using GGBFS as stabilization material along with monofibers like HDPE fibres and PPF fibres

Perecentage of fibres added by volume fraction	HDPE fibres				Polypropylene fibres			
	CBR (Unsoaked) (%)	Average CBR (Unsoaked) (%)	CBR (Soaked) (%)	Average CBR (Soaked) (%)	CBR (Unsoaked) (%)	Average CBR (Unsoaked) (%)	CBR (Soaked) (%)	Average CBR (Soaked) (%)
0.0	6.95	6.82	4.92	4.95	6.95	6.82	4.92	4.95
	6.72		5.01		6.72		5.01	
	6.79		4.93		6.79		4.93	
0.5	8.38	8.35	6.42	6.43	7.89	8.02	6.22	6.28
	8.26		6.52		8.05		6.26	
	8.41		6.34		8.12		6.35	
1.0	9.62	9.64	7.92	7.84	9.41	9.35	6.99	6.92
	9.56		7.88		9.38		6.92	
	9.74		7.72		9.25		6.86	
1.5	13.89	13.95	9.62	9.56	11.35	11.45	8.92	8.95
	14.05		9.58		11.68		9.02	
	13.92		9.48		11.31		8.92	
2.0	12.89	12.86	8.68	8.75	10.27	10.34	7.63	7.68
	12.92		8.71		10.42		7.69	
	12.77		8.87		10.34		7.71	

Table 5 Stress resistance properties of sulphate infected B C soil using GGBFS as stabilization material along with monofibers like WPF fibres and Jute fibres

Perecentage of fibres added by volume fraction	Waste plastic fibres				Jute fibres			
	CBR (Unsoaked) (%)	Average CBR (Unsoaked) (%)	CBR (Soaked) (%)	Average CBR (Soaked) (%)	CBR (Unsoaked) (%)	Average CBR (Unsoaked) (%)	CBR (Soaked) (%)	Average CBR (Soaked) (%)
0.0	6.95	6.82	4.92	4.95	6.95	6.82	4.92	4.95
	6.72		5.01		6.72		5.01	
	6.79		4.93		6.79		4.93	
0.5	7.92	7.85	5.91	5.86	7.22	7.24	5.51	5.46
	7.84		5.85		7.16		5.49	
	7.78		5.81		7.35		5.37	
1.0	9.08	9.10	6.35	6.45	7.83	7.85	5.92	5.82
	9.15		6.52		7.91		5.76	
	9.06		6.48		7.82		5.79	
1.5	10.29	10.35	8.35	8.24	8.62	8.52	7.31	7.28
	10.39		8.21		8.55		7.25	
	10.38		8.15		8.39		7.27	
2.0	9.31	9.25	7.78	7.65	7.92	7.85	6.72	6.75
	9.21		7.36		7.85		6.68	
	9.23		7.82		7.78		6.84	

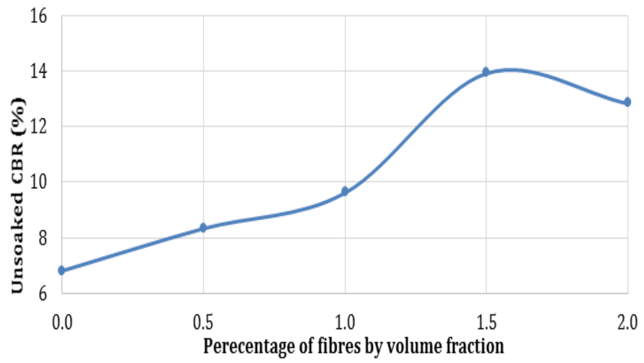

Figure 16. Variation of unsoaked CBR for different percentage of HDPE fibres when BC soil is replaced by GGBFS

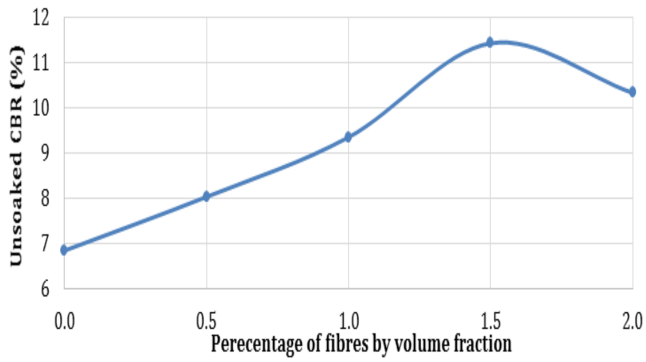

Figure 18. Variation of unsoaked CBR for different percentage of polypropylene fibres when BC soil is replaced by GGBFS

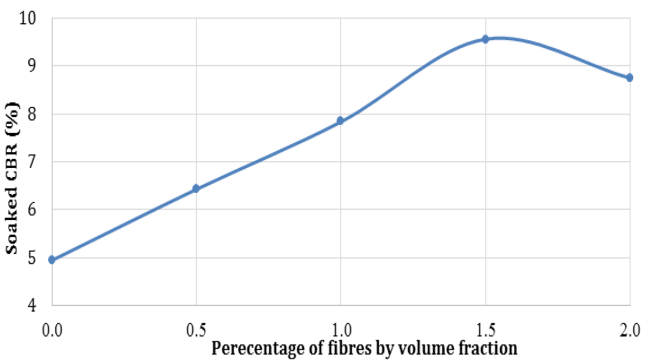

Figure 17. Variation of soaked CBR for different percentage of HDPE fibres when BC soil is replaced by GGBFS

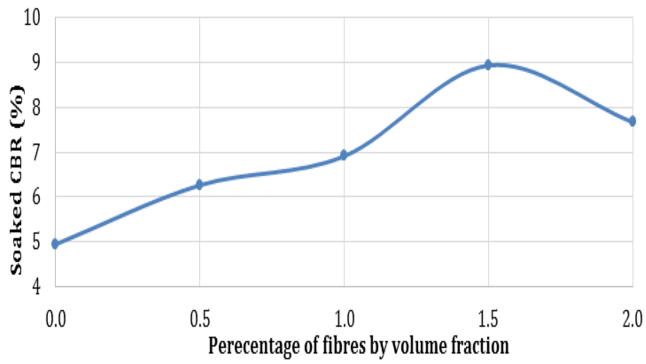

Figure 19. Variation of soaked CBR for different percentage of polypropylene fibres when BC soil is replaced by GGBFS

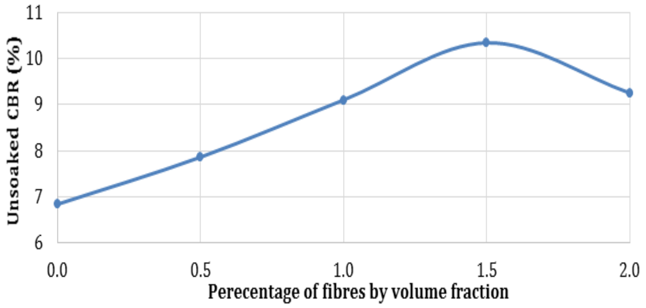

Figure 20. Variation of unsoaked CBR for different percentage of waste plastic fibres when BC soil is replaced by GGBFS

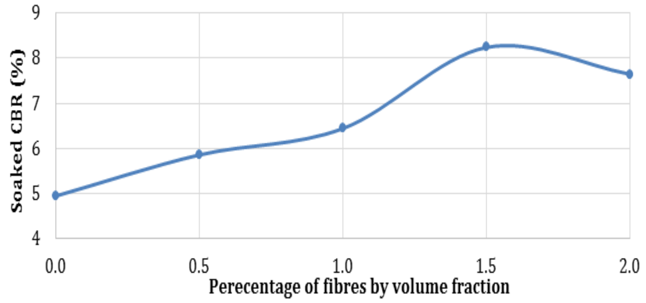

Figure 21. Variation of soaked CBR for different percentage of waste plastic fibres when BC soil is replaced by GGBFS

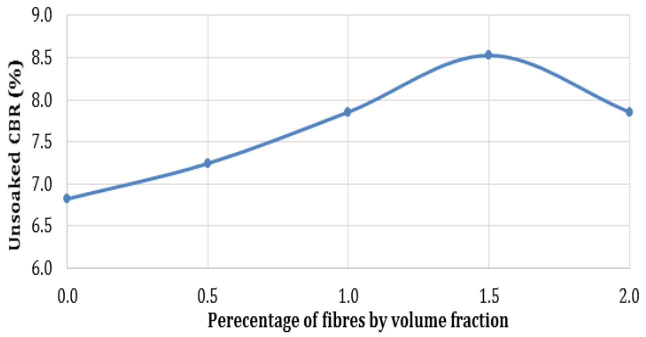

Figure 22. Variation of unsoaked CBR for different percentage of jute fibres when BC soil is replaced by GGBFS

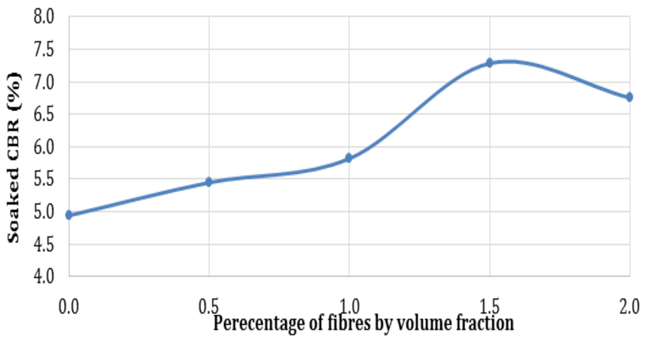

Figure 23. Variation of soaked CBR for different percentage of jute fibres when BC soil is replaced by GGBFS

It is observed that the sulphate infected black cotton soil using GGBFS as stabilization material along with monofibres has shown improved stress resistance properties when monofibres are added at 1.5% by volume fraction. Table 5.21 and related graphs show the improvement in stress resistance properties for sulphate infected black cotton soil when 20% block cotton soil is replaced by GGBFS and different monofibres are used. Various monofibres such as HDPE fibres, Polypropylene fibres, waste plastic fibres and jute fibres all have shown good results at 1.5% dosage level. Unsoaked CBR value and soaked CBR value have shown an increasing trend upto 1.5% addition of fibres. The percentage increase in unsoaked CBR value for various monofibres such as HDPE fibres, polypropylene fibres, waste plastic fibres and jute fibres, at 1.5% dosage are found to be 51.12%, 40.42%, 34.09% and 19.95% respectively with respect to reference mix. The percentage increase in soaked CBR value for various monofibres such as HDPE fibres, polypropylene fibres, waste plastic fibres and jute fibres, at 1.5% dosage are found to be 48.17%, 44.66%, 39.89% and 31.93% respectively with respect to reference mix.

Thus, it is clearly seen that addition of monofibres have dramatically increased the stress resistance properties of sulphate infected black cotton soil treated with GGBFS.

This may be attributed to the fact that the addition of fibres to the soil increase the interfacial bond, thereby increasing the friction between soil and fibres. This renders it difficult for soil particles that surround fibres to change in position from one point to another and thereby improving the bond force between soil particles. When local cracks appears in the soil, fibres across the crack will take on the tension in the soil, which effectively impedes further development of cracks and improves the resistance of the soil to the force applied. Thus, the crack can be prevented by bridging effect of fibres. Further, the cementitious matrix produced from the pozzolonic reaction by the stabilizing material, may cover around the fibre surface may improve the interfacial bond and may increase the friction co-efficient between soil and fibres.

Thus, it may be concluded that the addition of monofibres such as HDPE fibres, polypropylene fibres, waste plastic fibres and jute fibres to sulphate infected black cotton soil using GGBFS as stabilizing material significantly enhance the stress resistance properties.

From the results obtained, it may also be concluded that, the performance of HDPE fibres is better than polypropylene fibres, waste plastic fibres and jute fibres in enhancing the stress resistance properties of sulphate infected black cotton soil using GGBFS as stabilization material.

4.4 Stress resistance properties of sulphate infected B C soil using GGBFS as stabilization material along with hybrid fibres.

Table 6 and table 7 gives the stress resistance properties of sulphate infected B C soil using GGBFS as stabilization material at 20% replacement level along with hybrid fibres like (PPF+HDPEF), (PPF+WPF) and (JF+WPF). The variation in unsoaked CBR value and soaked CBR value for different hybrid fibre combinations are shown in fig. 24 to fig. 29.

Table 6. Stress resistance properties of sulphate infected B C soil using GGBFS as stabilization material along with hybrid fibers like (PPF+HDPEF) & (PPF+WPF)

Perecentage of hybrid fibres added by volume fraction	(PPF + HDPEF)				(PPF + WPF)				(JF + WPF)			
	CBR (Unsoaked) (%)	Average CBR (Unsoaked) (%)	CBR (Soaked) (%)	Average CBR (Soaked) (%)	CBR (Unsoaked) (%)	Average CBR (Unsoaked) (%)	CBR (soaked) (%)	Average CBR (soaked) (%)	CBR (Unsoaked) (%)	Average CBR (Unsoaked) (%)	CBR (soaked) (%)	Average CBR (soaked (%)
	6.95		4.92		6.95		4.92		6.95		4.92	
0.0	6.72	6.82	5.01	4.95	6.72	6.82	5.01	4.95	6.72	6.82	5.01	4.95
	6.79		4.93		6.79		4.93		6.79		4.93	
	9.91		7.75		8.32		6.71		8.16		6.21	
0.5	9.78	9.85	7.88	7.85	8.56	8.46	6.85	6.84	8.34	8.26	6.27	6.21
	9.86		7.92		8.49		6.97		8.28		6.15	
	11.89		9.42		10.45		7.58		8.89		6.95	
1.0	12.05	11.95	9.29	9.32	10.38	10.40	7.48	7.56	8.97	8.95	6.86	6.94
	11.92		9.26		10.36		7.62		8.99		7.01	
	13.62		10.49		11.86		9.3		11.06		8.48	
1.5	13.56	13.54	10.48	10.42	11.65	11.82	9.35	9.34	10.83	10.92	8.65	8.56
	13.44		10.29		11.95		9.38		10.87		8.54	
	12.72		9.71		11.04		9.04		9.78		7.92	
2.0	12.67	12.68	9.58	9.65	10.76	10.92	8.96	9.04	9.86	9.84	7.72	7.81
	12.65		9.66		10.95		9.12		9.88		7.79	

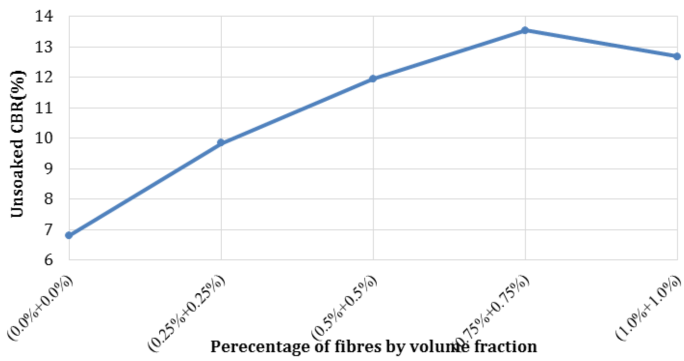

Figure 24. Variation of unsoaked CBR for different percentage of (PPF + HDPEF) when BC soil is replaced by GGBFS.

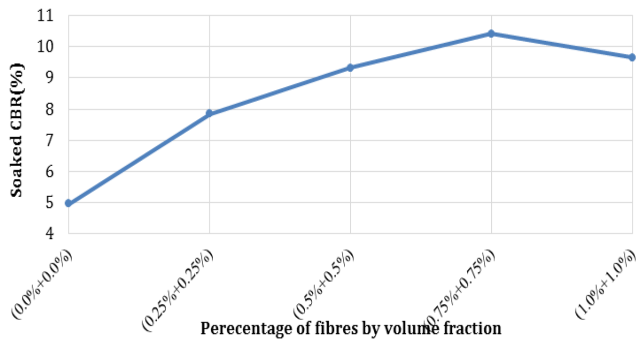

Figure 25. Variation of soaked CBR for different percentage of (PPF + HDPEF) when BC soil is replaced by GGBFS.

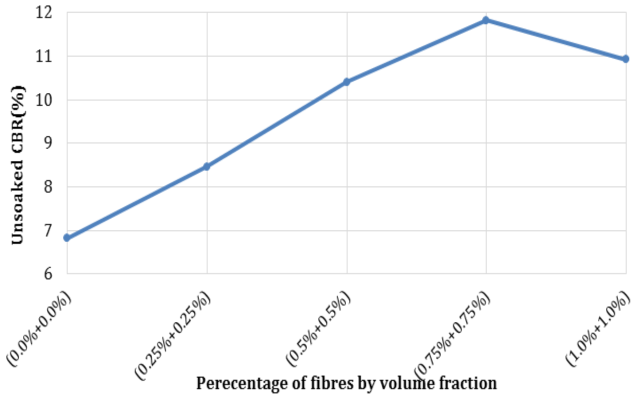

Figure 26. Variation of unsoaked CBR for different percentage of (PPF + WPF) when BC soil is replaced by GGBFS.

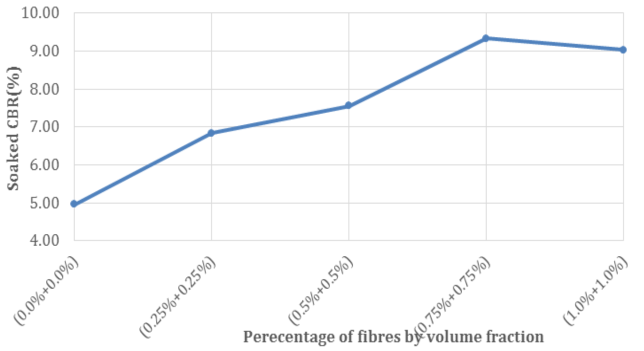

Figure 27. Variation of soaked CBR for different percentage of (PPF + WPF) when BC soil is replaced by GGBFS.

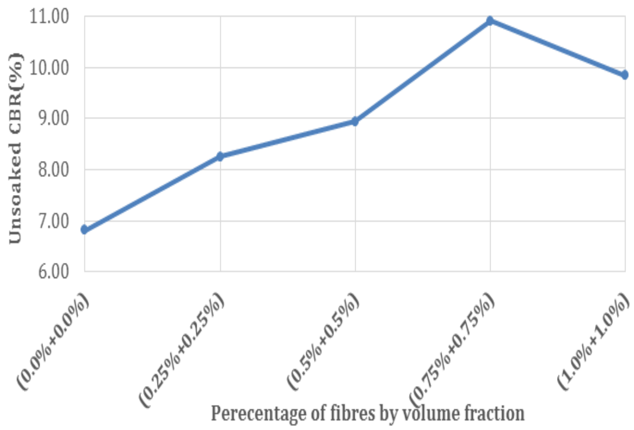

Figure 28 Variation of unsoaked CBR for different percentage of (JF + WPF) when BC soil is replaced by GGBFS

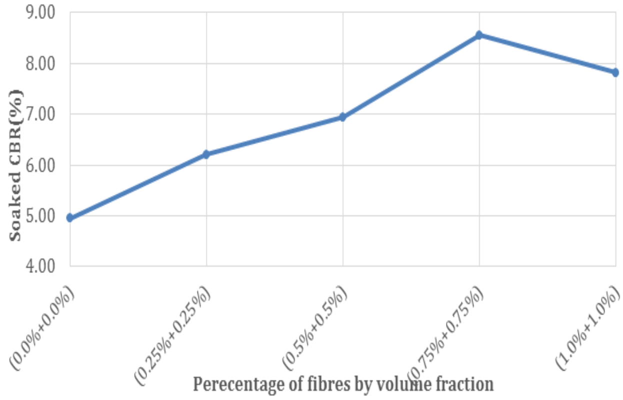

Figure 29 Variation of soaked CBR for different percentage of (JF + WPF) when BC soil is replaced by GGBFS

It is observed that the sulphate infected black cotton soil using GGBFS as stabilization material along with hybrid fibres has shown improved stress resistance properties when hybrid fibres are added at (0.75%+0.75%) by volume fraction. Table 6 and table 7 and related graphs show the improvement in stress resistance properties for sulphate infected black cotton soil when 20% block cotton soil is replaced by GGBFS and different combination of hybrid fibres are used. Various hybrid fibre combination such as (PPF+HDPEF), (PPF+WPF), and (JF+WPF) all have shown good results at (0.75%+0.75%) dosage level. Unsoaked CBR value and soaked CBR value have shown an increasing trend upto (0.75%+0.75%) addition of fibres. The percentage increase in unsoaked CBR value for various combination of hybrid fibres such as (PPF+HDPEF), (PPF+WPF), and (JF+WPF) at (0.75%+0.75%) dosage are found to be 49.62%, 42.32% and 37.53% respectively with respect to reference mix. The percentage increase in soaked CBR value for various combination of hybrid fibres such as (PPF+HDPEF), (PPF+WPF), and (JF+WPF) at (0.75%+0.75%) dosage are found to be 52.48%, 46.97% and 42.11% respectively with respect to reference mix.

Thus, it is clearly seen that addition of hybrid fibres have significantly increased the stress resistance properties of sulphate infected black cotton soil treated with GGBFS.

This may be attributed to the fact that the addition of hybrid fibres to the soil increases the interfacial bond, thereby increasing the friction between soil and fibres. This renders it difficult for soil particles that surround fibres to change in position from one point to another and thereby improving the bond force between soil particles. When local cracks appears in the soil, fibres across the crack will take on the tension in the soil, which effectively impedes further development of cracks and improves the resistance of the soil to the force applied. Thus, the crack can be prevented by bridging effect of fibres. Further, the cementitious matrix produced from the pozzolonic reaction by the stabilizing material, may cover around the fibre surface may improve the interfacial bond and may increase the friction co-efficient between soil and fibres. Further more, the hybrid fibres will act synergistically and play their role in bridging the small cracks and large cracks.

Thus, it may be concluded that the addition of hybrid fibres such as (PPF+HDPEF), (PPF+WPF), and (JF+WPF) to sulphate infected black cotton soil using GGBFS significantly enhance the stress resistance properties.

From the results obtained, it may also be concluded that, the performance hybrid fibre combination (PPF+HDPEF) is better than (PPF+WPF) and (JF+WPF) in enhancing the stress resistance properties of sulphate infected black cotton soil using GGBFS as stabilization material.

5. CONCLUSIONS

Following conclusions may be drawn from the study.

1. The sulphate infected black cotton soil using GGBFS as stabilizing material shows improved index properties at 20% replacement level.

2. The sulphate infected black cotton soil using GGBFS as stabilizing material show improved stress resistance properties at 20% replacement level.

3. The addition of monofibres such as HDPE fibres, polypropylene fibres, waste plastic fibres and jute fibres to sulphate infected black cotton soil using GGBFS as stabilizing material significantly enhance the stress resistance properties.

4. The performance of HDPE fibres is better than polypropylene fibres, waste plastic fibres and jute fibres in enhancing the stress resistance properties of sulphate infected black cotton soil using GGBFS as stabilization material.

5. The addition of hybrid fibres such as (PPF+HDPEF), (PPF+WPF), and (JF+WPF) to sulphate infected black cotton soil using GGBFS significantly enhance the stress resistance properties.

6. The performance of hybrid fibre combination (PPF+HDPEF) is better than (PPF+WPF) and (JF+WPF) in enhancing the stress resistance properties of sulphate infected black cotton soil using GGBFS as stabilization material.

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