EVALUATION OF FLY ASH AND GROUND GRANULATED BLAST FURNACE SLAG ON CONSISTENCY LIMITS OF BLACK COTTON SOIL

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Abstract: Black cotton soil (BCS) is a class of expansive soil which is unsuitable as pavement material due to its swelling and shrinkage characteristics. The sample site location is on the north west of South Africa. The approach that is adopted when such material are encountered is to remove the soil and replaced with quality materials. Cost of replacement is very high and stabilization of the soil is another alternative method of construction. Ground granulated blast furnace slag (GGBFS) is a by-product in the manufacturing of steel while fly ash (FA), a residue generated in combustion of coal is industrial waste that is readily available in the country. To sustain the environment by reducing the material to land fill sites, this paper examines the effect of FA and GGBFS respectively on consistency limits of BCS. Consistency limit is an indicator of clay behaviour and its evaluation provides basic mechanical data about the soil. Samples of the soil were obtained at a depth of 0.5m below the subgrade level. Sampling and tests of the soil was done according to South Africa standards to characterize BCS, FA and GGBFS. The percentages of FA and GGBFS were varied from 1 - 14% and 1 - 9% in steps of 1% respectively. Particle size distribution, Atterberg limit, standard proctor and California bearing ratio tests were conducted on the stabilized soil. The particle size distribution of BCS showed that 77% is clayey and silt; according to American Association of State Highway and Transportation official classify the soil as A-7-6(15) while the material falls outside G7-G8 envelope according to standard methods of testing road construction materials (TMH 1), making it unsuitable as subgrade material. Liquid limit (LL) and plastic index (PI) values of the virgin soil are 58% and 30% respectively. It was observed that PI decreases while LL increases as the percentage of the stabilizers increases; this could be attributed to cation exchange reaction that resulted in an increase inter-particle distribution. There was about 43%, 40% reduction in the value of PI for FA and GGBFS at 12% and 8% respectively when compared with the control. The maximum dry density (MDD) and optimum moisture density (OMC) of the virgin material are 1704 kg/m^3 and 15.3% respectively. MDD and OMC for FA & GGBFS modified BCS increases as the percentages of the stabilizers increases. Both the maximum dry density and optimum moisture content increases for FA, GGBFS from 1 – 12% and 1 – 6% respectively and then decreased. Increase in OMC is necessary for dissociation of admixtures with Ca^{2+} and OH^- ions to supply more Ca^{2+} for the cation exchange reaction. The stabilizers have significantly improved the index properties of the soil.

Keywords*:* black cotton soil; consistency limits; fly ash; ground granulated blast furnace slag; stabilization

INTRODUCTION

Black cotton soil lies predominately on the North West of South Africa and also in some isolated areas in the country. Black cotton soils (BCS) are inorganic clays of medium to high compressibility characterized by high shrinkage and swelling properties. Due to its high swelling and shrinkage characteristics, BCS has been a challenge to the highway engineers. This type of clay is very expansive and causes significant damages and problems. The usual approach when such soil is encountered, is to remove the soil, and replaces it with stronger materials likes crushed rock. The high cost of replacement causes highway contractors to explore alternative methods of highway construction on soft sub grades. One of such approach is to modify the engineering properties using various stabilizing agents to improve its performance. Harichane et al. [1] reported the effect of using lime, natural pozzolana and their combinations on the geotechnical characteristics of soft soils. It was concluded that the maximum dry density of lime stabilized soils decrease with the increase in lime content, in contrast with natural pozzolana stabilized soils. The combination lime-natural pozzolana increased the maximum dry density for the grey soil and decreased that of the red soil. Consistency limits (Atterberg limits) have been repeatedly shown to be useful indicators of clay behaviour [2, 3]. Evaluation of consistency limits provides some very basic mechanical data about a particular soil. The liquid limit and plasticity index are mainly influenced by clay minerals' ability to interact with liquids [4]. Akbulut et al. [5] studied the effect of surfactants on clays' contact angles and consistency limits; the experimental results indicated that surfactant modified clay consistency limits (liquid and plastic limits) changed significantly compared to those of natural clay. RBI grade 81 and sodium silicate was used to modified engineering properties of BCS, the result showed that liquid limit decreases as the admixture content increases whereas reverse trend was observed with plastic limit as it increases with the increase of admixture, results in net reduction of plasticity index [6]. Noorina and Yadav [7] studied the influence of blast furnace slag on consistency limits of BCS; it was reported that the liquid limit decreases with increase in the amount of blast furnace slag. The report concluded that the addition of blast furnace slag improves the index properties of BCS. Naderia and Naeini [8] examined the effects of plasticity index and waterborne polymer on strength of clayey soils, it was concluded that plasticity index (PI) has significant effect on the strength; an increase in PI causes a reduction in strength. Tests were conducted to study the effect of lime on Atterberg's limit, maximum dry density, optimum moisture content, shear strength and durability of quarry dust stabilized expansive soil mixes. The results shows that addition of quarry dust decreases the liquid limits, plastic limit and plasticity index while it increase the shrinkage limit of the expansive soil [9]. This paper presents the study on the evaluation of Fly Ash (FA) and Ground Granulated Blast Furnace Slag (GGBFS) respectively on consistency limits of Black Cotton soil.

EXPERIMENTAL PROGRAM

Materials

Black cotton soil lies predominately on the North West and Eastern parts of the country and in other parts of the country like; Kwa-Zulu Natal Province and Mpumalanga Province. The soil from Mpumalanga and North West areas of South Africa was the focus of this research. Samples were obtained from the N4 (North West near Brits) because the road lies on black cotton soil at depth of 0.5m below the subgrade. Representative soil samples were placed in plastic bags and transferred to the laboratory for analysis and assessment to determine the properties of the stabilized soil. Fly Ash and Ground granulated blast furnace slag was obtained commercially and stored in an air tight bags.

Testing Procedure

Sampling guidelines stipulated in the testing methods for highways and materials in South Africa [10-12] was used to characterize BCS, GGBFS and FA respectively. Table 1 shows the summary of the index property of BCS and the properties of GGBFS and FA used in this research. The percentages of FA and GGBFS were varied from 1 - 14% and 1 - 9% in steps of 1% was blended to stabilize BCS respectively. A series of laboratory test were conducted on the stabilized soil consisting of standard compaction, Atterberg limit and California bearing ratio (CBR) to find the optimum in accordance to standard specifications.

ANALYSIS OF TEST RESULTS

Consistency Limits

The summary of the engineering properties of BCS and the characteristics of FA and GGBFS are presented in Table 1. The particle size distribution of BCS shows that it composed of 77% clay and silt thus classifying the material as fine graded. BCS falls outside the G7 - G8 grading envelope which makes the material unsuitable as subgrade material in its virgin state and is classified according to American Association of Highway and Transportation officials (AASHTO) as A – 7 - 6 category. The results of liquid limit (LL) and plastic index (PI) on BCS with different percentages of FA and GGBFS conducted in accordance with the THM1 (1986) are shown in figures 1 and 2. Liquid limit and plastic index values of the virgin soil are 58% and 30% respectively, making the soil to be highly plastic. It was observed that PI decreases as the percentage of the stabilizers increases. There was about 43%, 40% reduction in the value of PI for FA and GGBFS at 12% and 8% respectively when compared with the control. Liquid limit was in contrast in that as the percentage of the stabilizers increases, it also increases. Generally, BCS reduces its plasticity with increased amount of FA and GGBFS due to cation exchange reaction that resulted in increased inter-particle attraction.

The linear shrinkage of virgin BCS is 13, the variation of LS with FA and GGBFS shows a reduction as the percentage of stabilizers increase up to a point and then increases with increase in stabilizer.

Table 1: Engineering properties of BCS and Characteristics of FA and GGBFS

BCS	(%)	FA	(%)	GGBFS	(%)
Liquid limit	58	Reactive CaO	< 10	LOI	0.42
Plastic limit	30	Chloride	< 0.1	SiO_2	38.9
Linear shrinkage	13	SO_4^{2-}	< 2.5	Al_2O_3	13.6
Gravel (> 2.36 mm)	7.0	F/CaO	< 1 max	Fe	0.61
Sand (> 0.425mm)	16.0	H_2O req.	< 95	CaO	37.1
Silt & clay	77.0	Soundness	< 10	MgO	8.67
Classification	Fine	Activity index 28d	> 75	K_2O	1.03
	A-7-6(15)	Activity index 90d	> 85	TiO_2	0.76
Specific gravity	2.58	Reactive SiO_2	> 25	MnO	0.78
OMC	15.3	Particle density	2-2.4g/cm^3	SO_3	0.63
MDD	1704 kg/m^3			Free H_2O	0.39
CBR @ 100, 98, 95 & 93%	3, 3, 2 & 2			Sulphide	0.98

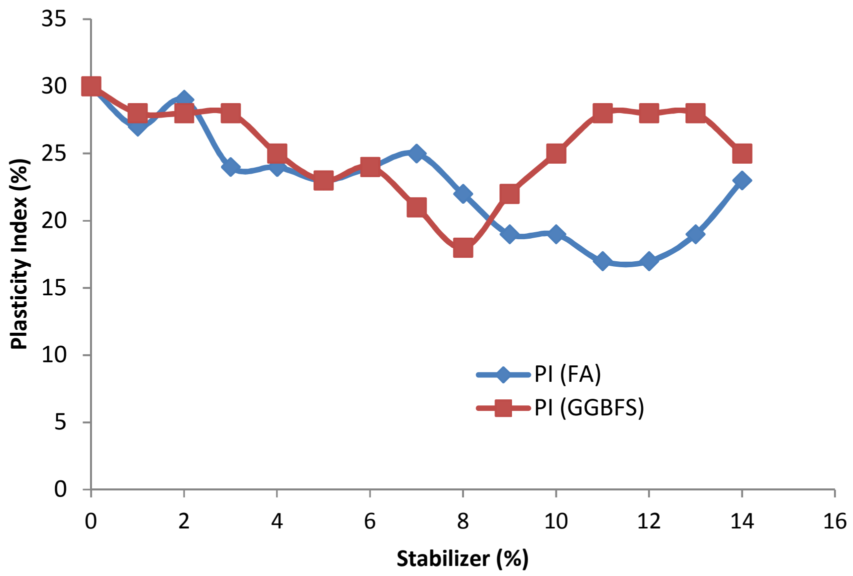

Figure 1: Plastic Index with percentages of Stabilizers

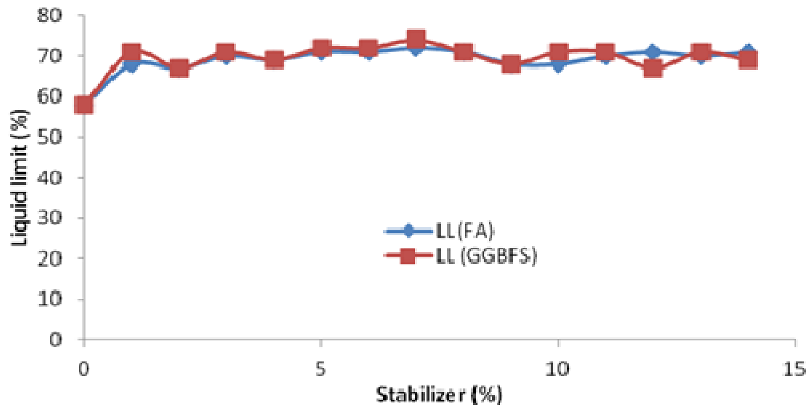

Figure 2: Liquid limits with percentage of Stabilizers

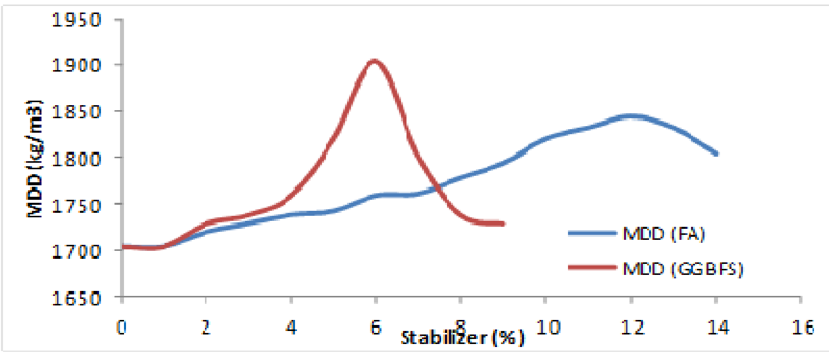

Figure 3: Variation of MDD with FA and GGBFS

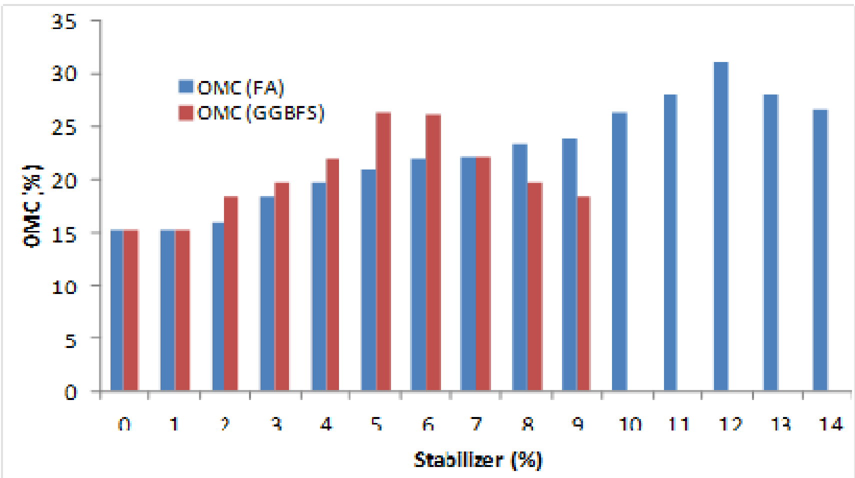

Figure 4: Variation of OMC with FA & GGBFS

Compaction Characteristics

The maximum dry density (MDD) and optimum moisture content (OMC) of the virgin BCS are 1704 kg/m^3 and 15.3% respectively. The variations of MDD and OMC with the percentage of stabilizers are shown in figures 3 and 4. MDD and OMC for both FA and GGFBS modified BCS increases as the percentage of modifiers increases. It is observed that the trend increases in MDD and OMC for FA, GGBFS from 1 – 12% and 1 - 6% respectively and then decreases afterwards. This result agreed with previous researches [13-17] that water is required for dissociation of admixtures with Ca^{2+} and OH^- ions to supply more Ca^{2+} for the cation exchange reaction. Also, it could be due to the increasing surface area caused by the higher amount of the additives, which required more water for lubrication of the entire matrix.

CONCLUSION

This study evaluated the use of fly ash and ground granulated blast furnace slag respectively on the consistency limit of black cotton stabilized soil obtained from Mpumalanga Province, South Africa. Black cotton soil was mixed with varying proportions of fly ash and ground granulated blast furnace slag (1 – 14% dry weight of soil). The soil mixtures were subject to sieve analysis, standard compaction, Atterberg limit and California bearing ratio tests. The results indicated that the addition of fly ash and ground granulated blast furnace slag enhances the consistent limit of black cotton soil by reducing the amount of clay size particles through flocculation and agglomeration of the clay particles. Moreover, the reduction in plasticity index (43%, 40%) of the stabilized soil for fly ash and ground granulated blast furnace slag was achieved at 12% and 8% respectively. Maximum dry density and optimum moisture density increases from 1704 kg/m^3, 15.3% with increase percentages of FA, GGBFS (1 – 12%, 1 – 6%) to 1844 kg/m3; 1905 kg/m^3, 31%; 36% respectively before decreasing. It can be concluded that the index properties of the study soil was significantly improved, hence fly ash and ground granulated blast furnace slags offers the potential for stabilization of black cotton soil for highway construction.

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