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Stabilisation of Black Cotton Soils Using Fly Ash, Hubballi-Dharwad Municipal Corporation Area, Karnataka, India

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STABILISATION OF BLACK COTTON SOILS USING FLY ASH,HUBBALLI-DHARWAD MUNICIPAL CORPORATION AREA, KARNATAKA, INDIA

Strictly as per the compliance and regulations of:

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Udayashankar D.Hakari [α] , S.C.Puranik [σ]

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I. Introduction

The black cotton soils possess low strength and undergo excessive volume changes, making their use in the constructions very difficult. The properties of the black cotton soils may be altered in many ways viz. mechanical, thermal, chemical and other means. Modification of black cotton soils by chemical admixtures is a common stabilisation method for such soils (Bell, 1993). Among various admixtures available lime, fly ash and cement are most widely and commonly used for the stabilisation of the black cotton soils. Fly ash contains siliceous and aluminous materials (pozzolans) and also certain amount of lime. When mixed with black cotton soils, it reacts chemically and forms cementitious compounds. The presence of free lime and inert particles in fly ash suggests that it can be used for stabilisation of expansive soils (Indraratna et.al., 1991).

The Hubballi-Dharwad Municipal Corporation (HDMC) area lies between 15 ° 18' 25" - 15° 30' 47" North latitudes and 74° 57' 37" - 75° 11' 0" East longitudes. Hubballi-Dharwad is a twin city in the state of Karnataka and is considered as second biggest city in the state and is the largest city corporation in the state next only to Bangalore. It is recognized as the commercial hub of the North Karnataka region with tremendous increase in the commercial and industrial activities taking place in the twin city at present. In order to provide a matching infrastructure for sustaining the growing economy, there has been a rapid change in the land use in the twin city. Most of these areas comprise of agricultural fields with the black cotton soil coverage. As a matter of fact, the construction of the buildings, roads and other structures on these expansive soils has become inevitable. The wide spread of the black cotton soil in the twin city of Hubballi-Dharwad has posed challenges and problems to the construction activities. However no work has so far been carried out with regards to the stabilisation of Hubballi-Dharwad black cotton soils and to study the effect of fly ash on these soils in improving their geotechnical properties. The possible use of fly ash for stabilizing these soils has been explored in this study.

The West Coast Paper Mills, Dandeli (Karwar dist, Karnataka), located at about 60 km. from Hubballi-Dharwad, generates huge quantity of fly ash and its disposal and management is posing serious problem. Considering the proximity of the source and availability aspects as well, the Dandeli fly ash (DFA) has been preferred and used for the stabilisation of the black cotton soils under study. Fig. 1 shows the location details of Dandeli and Hubballi-Dharwad.

Fig. 1 : Karnataka state map showing the location of Hubballi-Dharwad and Dandeli

II. Review of Earlier Work

A number of researchers have worked in developing different methods of soil stabilization, which are practical and economical. Amarjit Singh (1967) reported the use of fly ash and lime for stabilizing soils in road construction. Amos and Wright (1972) have studied the effect of mixing fly ash with black cotton soils. In the recent past, many researchers have carried out experimental and field studies for the stabilization of expansive soils using fly ash. Yudhbir and Honjo (1991) stated that the pozzolanic fly ashes can be advantageously made use of to improve the geotechnical properties of black cotton soils. Modification of black cotton soils by chemical admixtures is commonly adopted method for stabilizing the swell-shrink tendency of expansive soils (Bell, 1993). Sivapullaiah et.al.(1996) reported that the addition of fly ash decreased the liquid limit of black cotton soils and studied the effect of fly ash on the index properties of these soils from Karnataka, India. Bhoominadhan and Hari (1999) proposed the use of fly ash in construction works like brick making and soil stabilization. Cokca (2001) studied the effect of fly ash on expansive soils and he concluded that fly ash can be recommended as an effective stabilizing agent for the improvement of expansive soils. Pandian et.al.(2002) studied the effect of Raichur fly ash and Neyveli fly ash on the CBR characteristics of black cotton soils from Karnataka, India and reported the beneficial aspects of the fly ash-soil mixes in road construction. Phanikumar and Sharma (2004) presented the effect of fly ash on free swell index, swell potential, plasticity, compaction, strength characteristics of expansive soils and concluded that the fly ash improves the plasticity, compaction and strength characteristics of black cotton soils obtained from Andhra Pradesh, India.

The stabilization of black cotton soils with fly ash is thus well recorded and recognized in the literature; particularly in the past two decades.

III. Materials and Methods

The properties of the materials used and the details of the methods of testing are as follows.

a) Materials used

i *Black cotton soil*

Twenty natural black cotton soil samples were collected from different locations of Hubballi-Dharwad Municipal Corporation (HDMC) area were studied for their expansive characters. These samples have been identified for their swell potential and have been broadly grouped into three categories based on their degree of expansiveness and problematic nature as (i) Highly expansive and problematic group, (ii) Moderately expansive and problematic group and (iii) Least expansive and problematic group (Hakari and Puranik, 2010). In the present work, one sample from each of the above category has been considered for the stabilisation study. The location and the category of these samples are indicated below:

Sl.no.	Soil sample no.	Location	Category of soil
1	BC 8	Charanthimath Gardens, Dharwad.	Highly expansive and problematic soil
2	BC 10	Shalini Lay out, Gadag Road, Hubballi.	Moderately expansive and problematic soil
3	BC 11	Adjacent High Court, Dharwad.	Least expansive and problematic soil

About 200 kg. of the above black cotton soil samples were collected by open excavation from a depth of 1 meter from the natural ground level. The soil samples were air dried and pulverized to pass through IS 425 micron sieve before testing. The geotechnical properties of the above soils are given below at Table-1.

ii. *Fly ash*

The fly ash used in this work is procured from “The West Coast Paper Mills, Dandeli, Karwar District, Karnataka. It is located reasonably near at about 60 kms. from Hubballi-Dharwad twin city. The fly ash sample is designated as DFA (Dandeli Fly Ash). The DFA belongs to class-F category and its chemical composition and physical properties are given below in the Table-2 (a) and (b) respectively.

iii. *Black cotton soil and DFA mixes*

The black cotton soil samples were mixed with DFA on dry weight basis in varying percentages of 10%, 20%, 30%, 40%, 50% and 60%. The corresponding mixes have been designated as M-10, M-20, M-30, M-40, M-50 and M-60 respectively. M-0 indicates virgin soil sample. The finely blended mixes were then kept for oven drying for 24 hours and tests were conducted immediately after wet mixing with water in required quantity depending on the test. For the strength test, curing periods of 7, 14 and 28 days were considered.

Constituents	Percentage (%)
Silica ($Si O_2$)	57.00
Alumina ($Al_2 O_3$)	23.00
Ferric oxide ($Fe_2 O_3$)	8.32
Calcium oxide (CaO)	2.70
Magnesium oxide(MgO)	0.83
Titanium Oxide ($Ti O_2$)	0.23
Loss on ignition	7.92

Table 2 (a): Chemical composition of Dandeli Fly ash (DFA)

Sl.no.	Property	Value
1.	Specific gravity	2.07
2.	Grain size distribution:	
	Clay size	4.0 %
	Silt size	85.0 %
	Fine sand size	11.0 %
3.	Atterberg limits:	
	Liquid limit	59.0 %
	Plastic limit	Non-plastic
	Plasticity index	--
	Shrinkage limit	Varies with initial water content

Table 2 (b): Physical properties of Dandeli Fly ash (DFA)

b) *Tests conducted*

The tests for the determination of specific gravity, Atterberg limits, compaction parameters, unconfined compressive strength and California bearing ratio were conducted as per relevant I.S. codes.

IV. Materials and Methods

a) *Liquid limit*

The results indicating the effect of varying percentages of DFA on the liquid limits of selected black cotton soil samples are presented in Fig.2.

The liquid limit decreases with the addition of fly ash. The results show a considerable decrease in the liquid limit upto 30% increase in the fly ash percentage (i.e. M 30 mixes) and then after the decrease is observed to be marginal for further increase of fly ash percentage. The liquid limit of the black cotton soils is essentially controlled by the thickness of the diffused double layer and the shearing resistance at particle level. The addition of fly ash results in the decrease of liquid limit due to the effect of reduction in the diffused double layer thickness as well as due to the effect of dilution of clay content of the mix. The decrease of liquid limit becomes very marginal or nil beyond 50 – 60 % of fly ash. This is due to the increased dilution effect i.e. due to the increased percentage of coarser size particles in the mix because of the increased percentage of fly ash.

Category under which the soil is identified	Least expansive and problematic soils	Moderately expansive and problematic soils	Highly expansive and problematic soils
Soil sample no. →	BC 8	BC 10	BC 11
Properties ↓			
Plasticity characteristics :			
Liquid limit (%)	54.6	50.7	68.4
Plastic limit (%)	13.6	18.5	23.2
Plasticity index (%)	41.0	32.2	45.2
Shrinkage limit (%)	9.5	12.2	10.62
Compaction characteristics :			
Optimum moisture content (OMC) (%)	23.5	32.0	31.0
Maximum Dry Density (MDD) (gm/cm^3)	1.86	1.60	1.65
California Bearing Ratio (CBR) (%)	4.05	2.50	0.96
Strength characteristics :			
Unconfined compressive strength(UCS)(kN/m^2)	116.3	72.5	74.5

Table 1 : Geotechnical properties of the selected black cotton soil samples

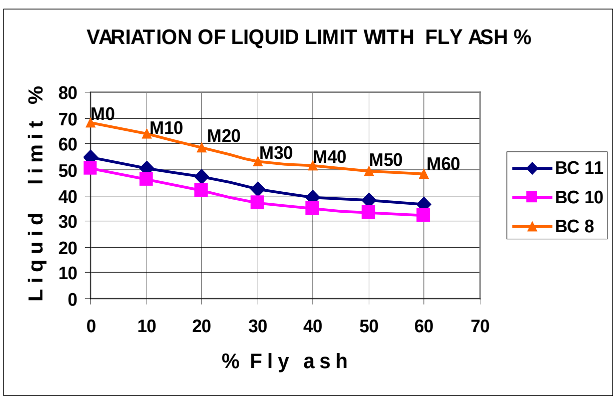

Fig. 2 : Variation of liquid limit with DFA percentages

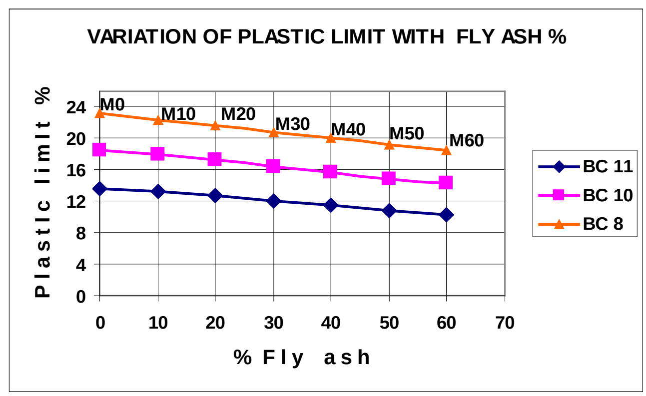

Fig. 3 : Variation of plastic limit with DFA percentages

b) Plastic limit

Fig.3 shows the variation of the plastic limit of the samples with DFA percentages. As can be seen from the graph, the addition of fly ash results in a steady decline in the plastic limit of the soils. The decrease of the plastic limit is observed to be more significant for the sample BC 8 as compared to the samples BC 10 and BC 11.

On addition of fly ash, the plastic limit of the soil may increase due to flocculation owing to the presence of free lime in the fly ash. But in the case of DFA, the free lime content is not sufficient enough as to increase the plastic limit and hence no such change is observed. Further increase in the addition of fly ash results in the decrease of plastic limit. This is because of the fact that as the quantity of fly ash in the mix increases, the amount of soil to be flocculated decreases and also the finer particles of fly ash may be incorporated in the voids of flocculated soil. This leads to the decrease in the water held in the pores leading to the decrease of the plastic limit.

c) Plasticity Index

The variation of plasticity index of the samples with the addition of different percentages of DFA is shown in the Fig.4. As seen from the graph, the addition of DFA decreases the plasticity index of the soil samples. The decrease is observed to be more with the increase in the quantities of fly ash up to 30% and then the trend of decrease is nominal with further increase in the percentages of fly ash.The effect on the liquid limit and plastic limit by the addition of fly ash is observed to reflect the trend of variation of plasticity index upon the addition of fly ash in increasing percentages.

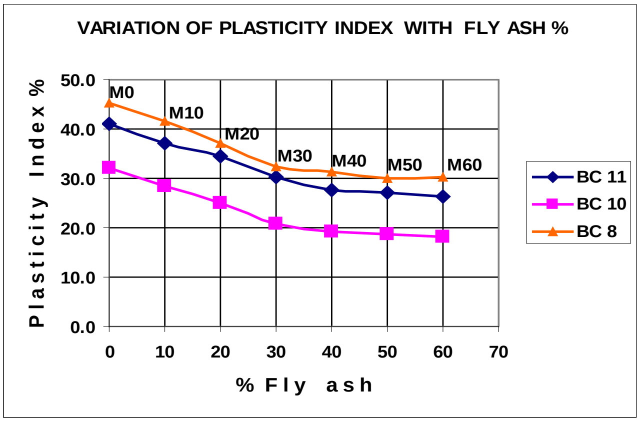

Fig.4 : Variation of plasticity index with DFA Percentages

d) Shrinkage limit

Fig.5 shows the variation of shrinkage limit in respect of the study samples BC 11, BC 10 and BC 8 upon the addition of DFA in increasing percentages It is seen that the shrinkage limits of the samples follow a steady increase with the addition of DFA in increasing percentages. The increase in the shrinkage limit with the addition of DFA is mainly due to the flocculation of clay particles caused by the free lime present in the DFA resulting in the reduction of friction between the particles; and also due to the substitution of finer particles of black cotton soil by relatively coarser fly ash particles.

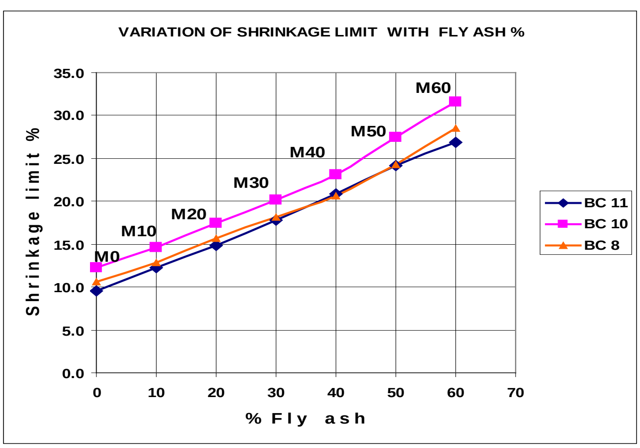

Fig.5 : Variation of shrinkage limit with DFA percentages

e) Compaction parameters – Optimum Moisture Content (OMC) and Maximum Dry Density (MDD)

Fig.s 6(a), (b) and (c) below show the variation of dry density-moisture content relationship for the varying percentages of DFA for the study samples BC 11, BC 10 and BC 8 respectively.

It is seen that density-moisture content relation is affected and varies upon the addition of DFA in increasing percentages; for all the three black cotton soil samples considered for the stabilisation study. It is observed from the Fig.6 that, the trend of increase in MDD and decrease in OMC with increasing percentages of DFA is observed up to 30 - 40% and the MDD is observed to decrease with further increase in the DFA percentages.

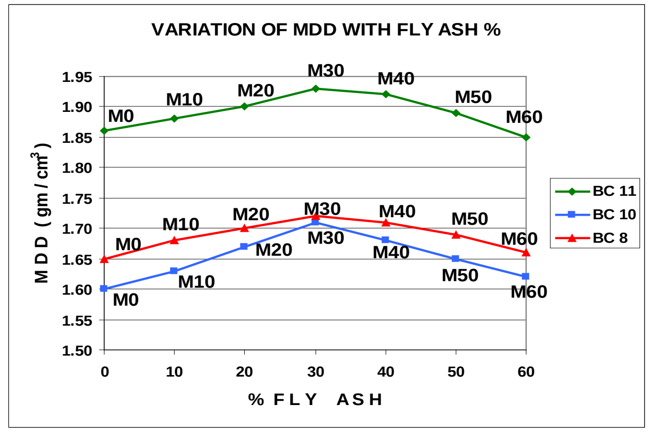

Fig.7(a): Variation of MDD with varying DFA Percentages

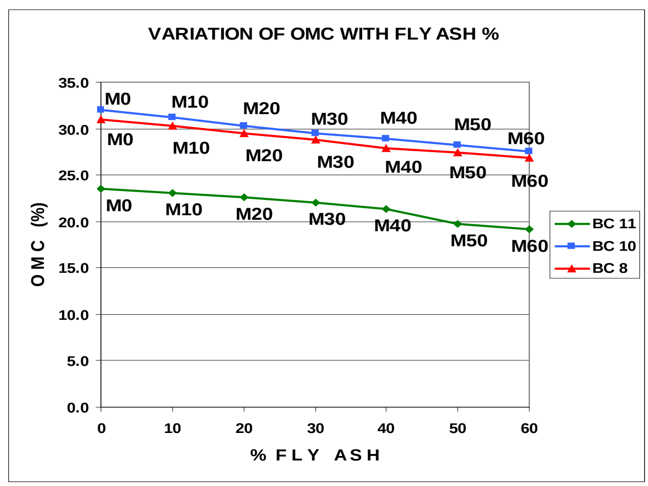

Fig.7(b): Variation of OMC with varying DFA Percentages

Fig.s 7(a) and (b) present the variation of MDD and corresponding OMC respectively for the soil samples BC 11, BC 10 and BC 8 with the varying percentage of DFA from 10% to 60%. Fig.s 7(a) and (b) indicate that, on addition of fly ash to the black cotton

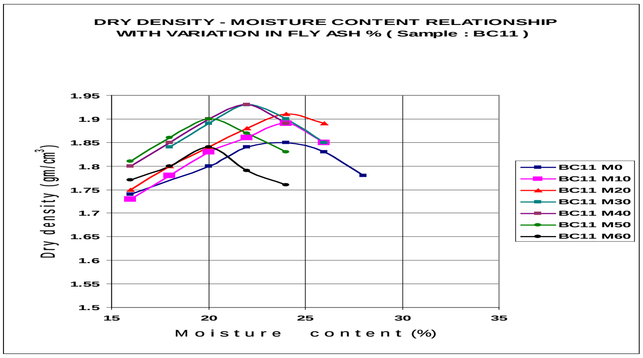

Fig.6(a): Variation of Moisture content – Dry density relationship of soil sample BC 11 with DFA percentages

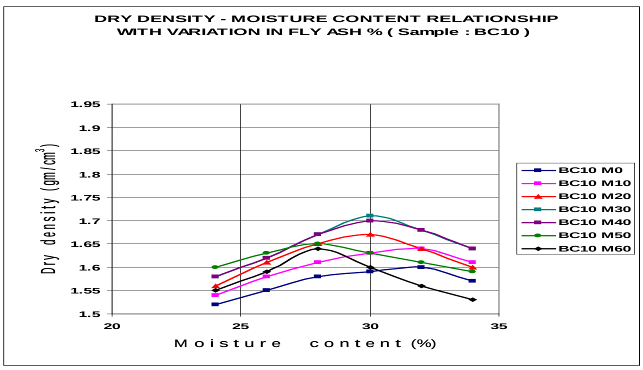

Fig.6(b): Variation of Moisture content – Dry density relationship of soil sample BC 10 with DFA percentages

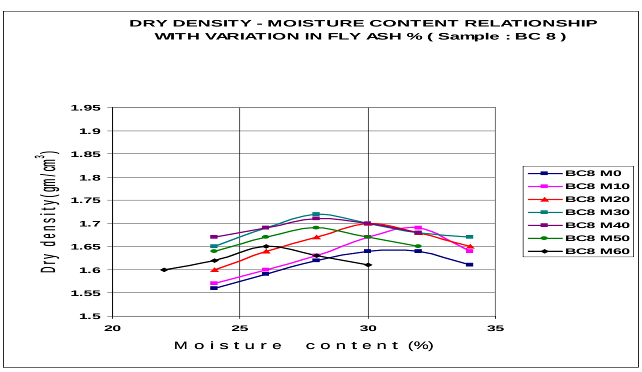

Fig.6(c): Variation of Moisture content – Dry density relationship of soil sample BC 8 with DFA percentages

Soil, the MDD increases and the OMC decreases. The MDD shows a gradual increase with the increase in the fly ash percentages up to 30-40% of fly ash. There after it exhibits a decreasing trend with further increase in the fly ash percentages. The OMC values corresponding to their respective MDD values show a steady decrease with the increasing fly ash percentages. The decreasing trend of OMC continues up to a certain fly ash percentage; here in the present study it is between 40 – 50%, and then after it appears to be stable with very marginal variation in its value.

The above observations in the variation of MDD and OMC values with the varying percentages of DFA suggest an optimum percentage of fly ash between 30 – 40% as suitable for addition to the study black cotton soil samples so as to obtain the best possible favourable changes in the compaction parameters for these soils i.e. to obtain a higher value of MDD and a lower value of OMC for any particular soil sample.

The behaviour of black cotton soil is controlled by diffused double layer. The addition of fly ash in small percentage results in the decrease of repulsive pressure of soil particles. This in turn reduces the resistance to compactive effort and the mix gets compacted to relatively higher densities. Though there will be flocculation due to free lime in the fly ash, this effect is dominated when the fly ash percentage is low. Hence a marginal increase in dry density is observed. Further addition of fly ash beyond 30-40% results in increased flocculation due to increased availability of free lime content of fly ash. This would increase the repulsive forces of soil particles, thereby increasing the resistance to compactive effort and hence the density of mix starts decreasing.

f) Strength characteristics – Unconfined Compressive Strength (U C S)

The effect of addition of fly ash to the black cotton soil samples BC 11, BC 10 and BC 8 on their UCS values along with the variation of UCS with increase in the curing period is presented respectively at Fig.8(a), (b) and (c) below.

The Fig.8(a), 8(b) and 8(c) exhibit that the UCS of the black cotton soil samples increases with the addition of DFA; suggesting an improvement taken in the strength characteristics of the black cotton soil + fly ash mixes. It is observed that, an increase in the values of UCS is gradual and relatively small for smaller curing periods of 7 days and 14 days. The improvement in the UCS is comparatively better for a longer curing period of 28 days; as can be seen from the graph pertaining to 28 days curing. For the same mix of any of the sample, at the relative increase in the UCS is thus observed maximum when a curing of 28 days is allowed.

It is seen that the strength increases on addition of small percentage of 10% or 20% of fly ash. Further increase in fly ash percentage shows no considerable increase in the strength. This is due to the probable disturbance of soil skeleton and consequent reduction in cohesion. The strength of soil is observed to improve considerably with curing time which is due to the pozzolanic reactivity of the free lime content of the fly ash.

g) California Bearing Ratio (C B R)

The variation of CBR (soaked condition) of the three black cotton soil samples with the addition of DFA in increasing percentages is shown in Fig.9. The CBR value of the soil increases with the addition of DFA up to a certain percentage of fly ash (30-40% here) and there after it starts decreasing for further addition of DFA.

The low CBR of the black cotton soil (as compared to the black cotton soil-fly ash mixes) is attributed to its inherent low strength which is due to the dominance of the clay fraction. Addition of fly ash to the black cotton soil increases gradually the CBR of the mix up to a peak value of addition of 30-40% of fly ash. This is due to the frictional resistance contributed from the DFA in addition to the cohesion from the black cotton soil. Further increase in the fly ash percentage causes a reduction in the CBR due to the reduction in the cohesion because of the decreasing b lack cotton soil content in spite of increase in strength due to increase in fly ash content. It is hence observed that, a suitable mix proportion (M30 for BC 11 and BC 8, M40 for BC 10 in the present study) optimizes the frictional contribution of fly ash and the cohesive contribution from black cotton soils; leading to the maximization (peak value) of the CBR.

V. Conclusions

Based on the results of the investigation, following conclusions are drawn.

i) Dandeli fly ash is used as a stabiliser for improving the geotechnical characteristics of Hubballi-Dharwad black cotton soils. Addition of Dandeli fly ash significantly improves the index properties, compaction and strength characteristics of black cotton soils understudy and the effects of fly ash treatment vary depending upon the quantity of fly ash , that is mixed with the study black cotton soil samples.

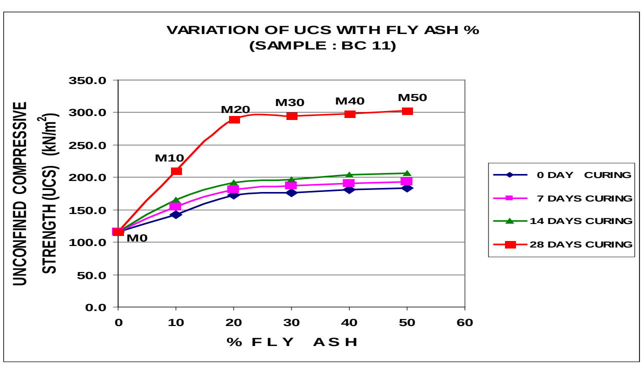

Fig.8(a): Variation of UCS with DFA percentages for different curing periods in respect of sample BC 11

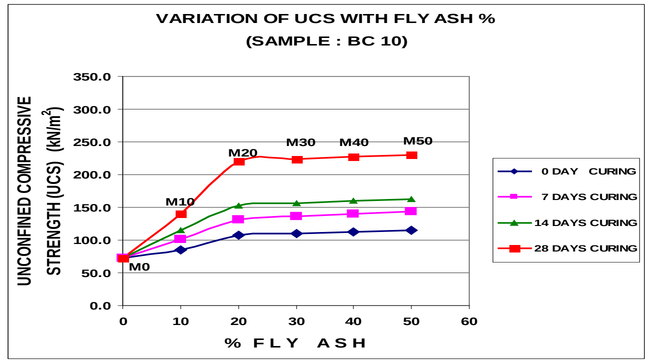

Fig.8(b): Variation of UCS with DFA percentages for different curing periods in respect of sample BC 10

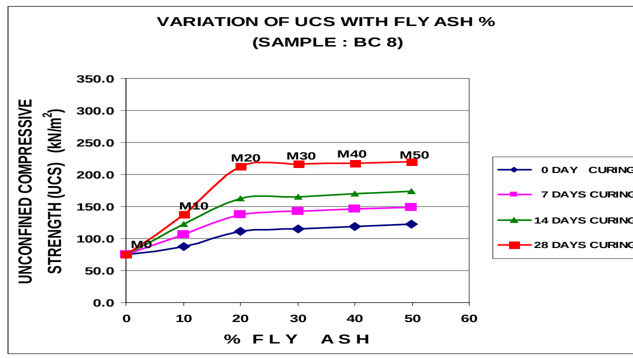

Fig. 8(c): Variation of UCS with DFA percentages for different curing periods in respect of sample BC 8

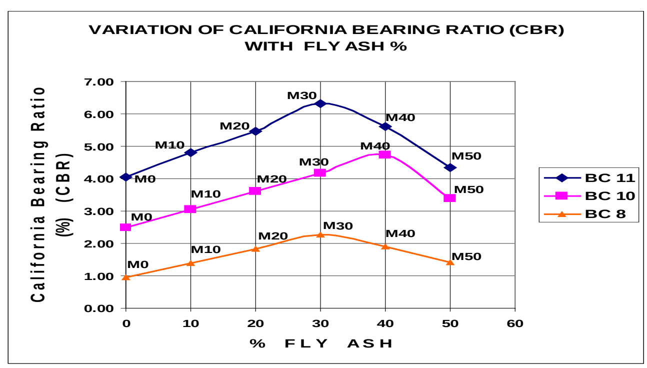

Fig.9: Variation of CBR with DFA percentage

ii) The liquid limit and plastic limit of the soils decrease with the addition of Dandeli fly ash which indicates a desirable change as the soil + fly ash mix can gain shear strength at an early stage than the virgin soil with the change in the water content. The relative decrease in the plasticity index of the soils is another favourable change since it increases the workability of these soils. The shrinkage limit of the soils increases with the addition of Dandeli fly ash, which facilitates in checking the volume change behaviour of the soils over a large variation in the moisture content as the season changes.

iii) Addition of Dandeli fly ash brings in an improvement in the compaction parameters of the study soils, by increasing the maximum dry density of soils

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with decrease in the corresponding values of optimum moisture content.

iv) The unconfined compressive strength of these soils increases upon the addition of Dandeli fly ash. The trend of improvement in the unconfined compressive strength is observed to be more pronounced with the curing of the soil + fly ash mix. A curing period of 28 days is observed to yield the maximum enhancement in the unconfined compressive strength.

v) The California bearing ratio of the study soils increase gradually with the addition of Dandeli fly ash up to a certain percentage of Dandeli fly ash, beyond which, further increase in Dandeli fly ash percentage is observed to cause a decreasing trend in the California bearing ratio values. The improvement in the California bearing ratio value of the black cotton soil upon the addition of Dandeli fly ash suggests that, it can be effectively used in bulk as sub-base material in combination with the study soils, for the road construction works.

vi) The study of variations of different parameters viz. liquid limit, plastic limit, plasticity index, shrinkage limit, maximum dry density, optimum moisture content, unconfined compressive strength and California bearing ratio with the addition of Dandeli fly ash suggest that, for each parameter of the study soil samples, there exists an optimum Dandeli fly ash percentage for mixing with the soil under consideration; at which the respective parameter attains its most desirable value from geotechnical point of view.

Table-3 lists such optimum Dandeli fly ash percentage recommended for different parameters of the study soils. Remarks made thereon in the table indicate the effect of addition of Dandeli fly ash beyond the optimum percentage on these parameters. The geotechnical properties of Hubballi-Dharwad black cotton soils can be favourably changed using the Dandeli fly ash and an optimum quantity between 30-40% can yield the best possible results.

Table 3 : Recommended DFA percentage for the stabilisation of the study soils

Soil parameters considered for assessment of stabilisation results	Optimum DFA %	Value of the parameter at optimum DFA %			Remarks
		BC 11	BC 10	BC 8	
Liquid limit (%)	30	42.3	37.3	53.1	The decrease in liquid limit is marginal with further increase of DFA beyond 30%.
Plastic limit (%)	20 – 30	12.7	17.2	21.6	Beyond 30% DFA the rate of decrease of plastic limit is relatively less as compared to the rate of decrease up to 30% DFA.
Plasticity index (%)	30	30.2	20.9	32.0	No considerable reduction in plasticity index value beyond 30% DFA.
Shrinkage limit (%)	30 – 40	17.8	20.2	18.1	Increase in shrinkage limit, though continuous with increase in DFA%; further increase in the shrinkage limit is not as effective and considerable beyond 40% DFA.
Maximum dry density (gm/cm^3) and Optimum moisture content (%)	30	1.93 and 22.0	1.71 and 29.5	1.72 and 28.8	The soil samples yield peak values of maximum dry density and corresponding values of optimum moisture content for addition of DFA at 30%.
Unconfined compressive strength (kN/m^3)	20 – 30	176.2 (0 day curing)	110.5 (0 day curing)	115.1 (0 day curing)	Unconfined compressive strength attains peak value at DFA % between 20 and 30, beyond which the increase in the strength is marginal. The trend is same for increased curing periods.
California bearing ratio (%)	30 – 40	6.32	4.17	2.28	California bearing ratio reaches peak value when the DFA% is between 30 and 40, beyond which it starts decreasing with further addition of DFA.

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