Experimental Study on the Suitability of Basalt Fiber Reinforced Red Soil for Highway Construction

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Abstract: **Heavy structures such as highways, bridges, highway embankments need good foundation soil. The use of natural or man-made fibers in sub grade soils is one of soil improvement technology for heavy projects. Basalt fibers is a naturally obtained inorganic fibers material which has wide use in many industries. Now-a-days the use of basalt fibers in concrete or soil was increased due to its excellent mechanical and environmental friendly properties. On other hand Telangana has a highest red soil deposit which has sand as major composition. Therefore, in this study an attempt is made to find the suitability of locally obtained red soil with the addition of basalt fibers for highway construction. The stabilized soil (soil+basalt) sample is tested for understanding the polypropylene characteristics through resilient and California bearing ratio (CBR) properties. Different percentages of basalt fibers (0%, 0.2%, 0.4%, 0. 6%, 0.8%, 1%, 1.2% and 1.4%) by weight of raw soil is added to the conventional red soil. Stabilized soil was subjected to California bearing ratio (CBR) and proctor compaction test along with preliminary tests. The experimental results shows that the addition of basalt fiber effectively increasing the strength of the soil. Adding of basalt fiber around 0.8% (by soil weight) can significantly enhance the strength of sub grade soil and efficiently improves in the design of pavement structure for highways.**

Index Terms: **Sub grade, Basalt fiber, CBR, MDD.**

I. INTRODUCTION

Soil stabilization is defined as changing the engineering properties of the soil. It is one of the methods of ground improvement. Stabilization of soil is mainly used in the pavements, roads and foundation construction. It modifies the engineering properties of the soil in terms of durability, volume stability, and strength. Nowadays different types of latest modern techniques are used in the former projects. Micro reinforcement within the soil is one of the effective and reliable techniques in the ground improvement techniques. Mostly such modification by reinforcement of fibers is first and foremost feasible in engineered fillings, embankments and pavement sub grade where surface mixing is uncomplicated and enhancement of geotechnical properties are needed (Jamei et al., 2012). In reinforcement, there are many advantages in randomly distributed fibers when compared to the conventional reinforcement using geogrids, geotextiles, geosynthetics, etc.

In nowadays, various fibers are developed and used in the industrial, construction, highway engineering. Basalt is a natural material, origins from volcanic rock. It is used in many civil engineering purposes. Basalt fibers are environmentally safe, possess high stability, nontoxic and insulating characteristics. Basalt fiber has high tensile strength when compared to the carbon fibers, E-glass fibers and provide good resistance against chemical corrosion and impact load (Deák & Czigány, 2009, Kumbhar, 2014).

1.1 Study Background

Researchers and engineers were been experimenting on foundation soils to enhance its properties so that it will assist the structure for being strong, durable, functional throughout its design life.

Dorigato & Pegoretti, (2012) found that the basalt fiber offers great resistance to salt and water corrosion and moderate resistance to acid corrosion. Ndepete & Sert, (2016) experimented on silty soil considered 6mm, 12mm, and 24mm long basalt fiber. The results show that unconsolidated undrained triaxial tests of 24mm long fibers mixed soil show maximum improvement in strength at 1.5% optimum fiber content. Ayothiraman & Singh, (2017) observed the improvement in geotechnical properties of clay soil by the addition of basalt and polypropylene fiber content. Devi, (2016) found that the improvement in MDD and UCS properties of soil is due to interfacial force in the form of fiber soil column and fiber soil net. Ramachandran et al., (2019) conducted an experiment on red soil by mixing basalt fiber and GGBS. The author observed the effective increase in compaction and shear strength of the red soil. Mishra & Babu, (2017) carried an experimental investigation on red soil and found effective improvement in the geotechnical properties by addition of plastic fiber. Ma et al., (2018) considered different proportions of basalt fiber and fly ash in the soil which exhibited the improvement in compaction characteristics of natural soil.

It was observed from the literature that on the addition of basalt fiber the geotechnical properties of soil were enhanced and very few experimental investigations were observed on red soil with the addition of basalt fiber. Therefore, this study aims in finding the experimental results on sub grade red soil by mixing 0%, 0.2%, 0.4%, 0.6%, 0.8%, 1% , 1.2% and 1.4% of basalt fiber (by weight of soil) and to observe the effect in pavement design due to the change in sub grade strength.

II. MATERIALS AND METHODS

The materials used in the experiment are Red soil and Basalt fiber

Red soil

The soil sample of a suitable quantity was collected from the local site (Nalgonda District). The soil surface layer on the natural ground was removed up to a depth of 0.15 - 0.2m and then the soil for the experiment was excavated and transported to the laboratory. The soil was exposed to the atmosphere for air drying and sieved from the IS sieve size of 4.74mm (see Fig 1).

Figure 1 Red soil sample

The preliminary tests such as sieve analysis, atterberg limit and proctor compaction tests were conducted on the conventional soil sample as per IS 2720. The properties of the soil sample collected are shown in table1. Based on the preliminary test results the soil is classified as silty sand (SM) according to the unified soil classification system (ASTM D-2487).

Table 1 represents the Geotechnical properties of the soil sample.

Sand %	53
Gravel %	42.54
Clay %	5.73
LL %	36
PL %	18
OMC %	11.6
MDD (g/cc)	1.96
Soil classification	SM

Basalt Fiber

Basalt fiber is a new construction material in modern civil engineering. It is made from the extremely fine fiber of basalt. Basalt originates from the volcanic magma and flood volcanoes, very hot fluid under the earth’s crust, solidified in the open air. It is golden brown in color as shown in Fig 2 (Kumbhar, 2014). Table 2 shows the physical and mechanical properties of basalt fiber of 12 mm long used in the study. The required quantity of basalt fiber was purchased from the local market.

Table 2 Properties of the basalt fiber used in this Study

Basalt Fiber Property	Value
Colour	Golden brown
Density	2.65 g/cm^3
Nominal length	12mm
Nominal diameter	13mm
Tensile strength	1235 MPa
Elasticity modulus	93.4 GPa
Specific gravity	2.7

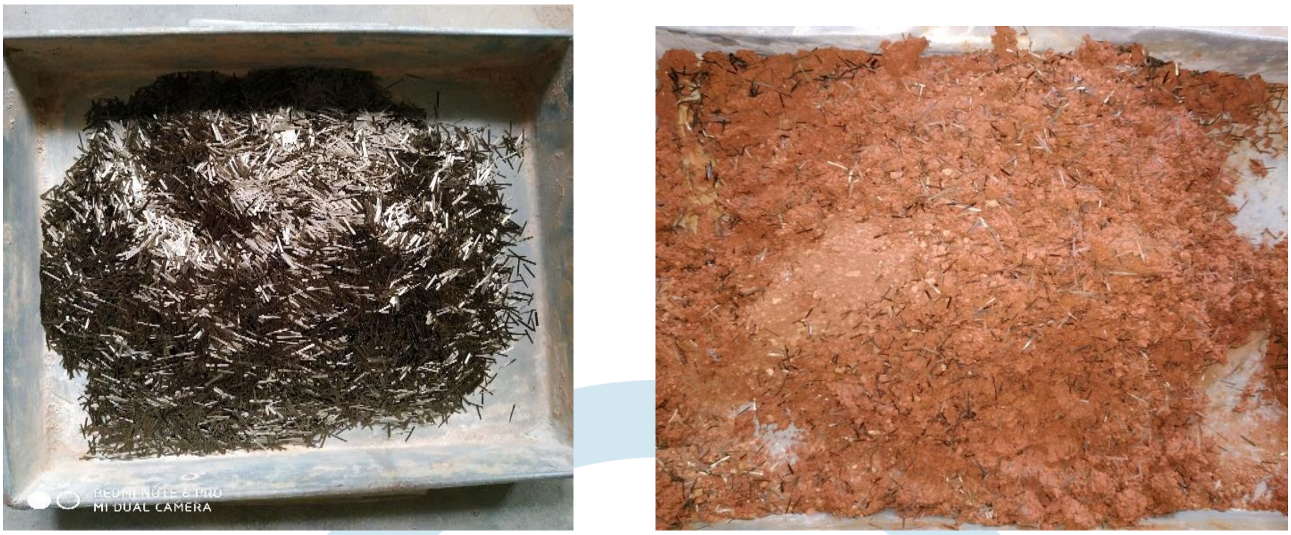

Figure 2 Chopped Basalt Fiber of 12mm long

2.1 Tests on Stabilized Soil

The stabilized soil (soil+ basalt fiber) is subjected to CBR and Procter compaction test in varying proportions (0.2%, 0.4%, 0.6%, 0.8%, 1%, 1.2% and 1.4%) of basalt fiber after the preliminary tests.

Proctor Compaction Test

This test shows the compaction characteristics of conventional soil and proportioned soil with varying moisture content. The soil sample passing through 4.75 mm IS sieve was mixed with a moisture content of 4%, 6%, 8%, 10%, and 12% and compacted in the mould capacity of internal diameter 10.2 cm with a hammer weighing about 2.5 kg.

California Bearing Ratio (CBR)

The CBR Test is conducted to the soil sample as per the IS 2720 (PART 16-1979). This test used for the assessment of the sub grade strength of pavement which ultimately influences the structural design features of the pavement. The varying proportioned basalt fiber added soil sample is mixed with OMC and placed in the CBR mould and then subjected to penetration. The load corresponding to 2.5mm and 5mm penetration were considered for the computation of CBR and CBR value at 2.5mm was reported in the document.

2.2 Design of Pavement

A simple typical approach as mentioned in IRC 37:2018 was used for designing the flexible pavement in order to observe the effect of stabilized soil (soil + basalt fiber) over pavement design features. IRC 37:2018 recommended material properties were used for the typical design of pavement structural layers.

Table 3 Recommended material properties (IRC 37:2018)

Material/layer Type	Resilient Modulus (MPa)	Poisson's ratio
Bituminous layer with VG 30	2000	0.35
Unbound granular layer	$Mr_{Granu} = 0.2\ (h)^{0.45} * Mr_{subgrade}$	0.35
Sub grade	$Mr_{sg} = 10*CBR$ (CBR < or = 5%) $Mr_{sg} = 17.6*CBR^{0.64}$ (CBR > 5%)	0.35

III. RESULTS AND DISCUSSION

The maximum dry density (MDD) of 1.96 g/cc for unreinforced/conventional soil was obtained at 8% optimum moisture content (OMC). Further experiments (proctor compaction test and CBR) were conducted on stabilized soil (soil + basalt fiber) whose results were provided in table 4. The results are exhibited against the basalt fiber proportions and also the OMC obtained for the corresponding basalt fiber reinforced soil sample.

The results show that the addition of 0.2% basalt fiber increased the CBR value twice that of unreinforced soil. Thereafter the CBR value increased at decreasing rate up to basalt fiber of 1.2%, after that it is slightly decreased with the further addition of basalt fiber percentage (shown in table4 and fig 3). The maximum dry density increased from 1.96 to 2.4 g/cc for the basalt fiber up to 0.8% due to the high specific gravity of basalt fiber, in a further increase in fiber content decreased the MDD of stabilized soil (shown in table4 and fig 3).

Table 4 Experimental results of basalt reinforced red soil

Basalt Fiber (%)	CBR (%)	MDD (g/cc)	OMC (%)
0	4.5	1.96	8
0.2	9.4	1.97	6
0.4	14.8	1.99	8
0.6	18.4	2.2	10
0.8	19.6	2.4	12
1	20.4	2.1	10
1.2	20.6	1.98	8
1.4	20.5	1.95	10

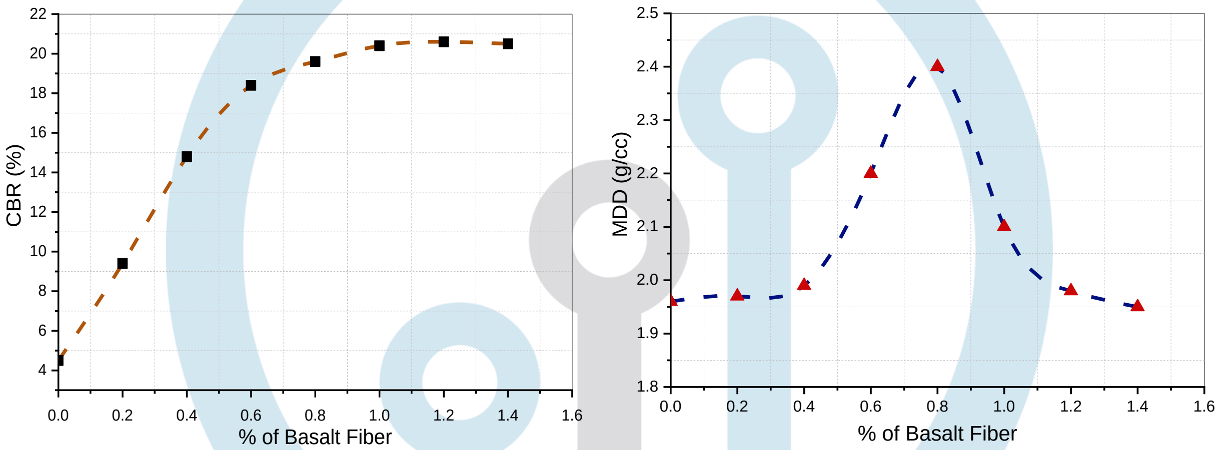

Figure 3 Graphs showing the trend in CBR and MDD against basalt fiber content

3.1 Design of Pavement

The strains in the pavement were computed using IITPAVE as per guidelines given by the IRC 37:2018 (see table 5). The typically recommended values were considered as shown in table 3 and the thickness of bituminous and unbound granular layers was kept to a minimum as 80mm and 500mm respectively. The maximum vertical and tensile strains which were critical in the design of a flexible pavement were computed and compared to observe the effect of basalt fiber content in the soil.

Table 5 Results of Strains obtained from IITPAVE

Basalt Fiber (%)	CBR (%)	$Mr_{sub\ grade}$ (MPa)	$Mr_{granular\ layer}$ (MPa)	Max Vertical Strains (ε_v)	Max Tensile strain (ε_t)
0	4.5	45	147.50	0.0005672	0.0004278
0.2	9.4	73.84	242.04	0.0003616	0.0003119
0.4	14.8	98.74	323.63	0.0002771	0.0002538
0.6	18.4	113.50	372.02	0.0002438	0.0002285
0.8	19.6	118.18	387.37	0.0002349	0.0002214
1.0	20.4	121.25	397.41	0.0002295	0.0002171
1.2	20.6	122.01	399.90	0.0002282	0.0002160
1.4	20.5	121.63	398.66	0.0002288	0.0002165

The table 5 shows that the increase in the proportion of basalt fiber increased the resilient modulus of sub grade and unbound granular layer up to fiber content of 1.2%, after that it was reduced but the reduction was very little. Similarly with the increase in fiber content the maximum vertical and tensile strains were decreased. The strains were reduced to half with the addition of basalt fiber of 0.4 to 1.2% (see table 5 and fig 4).

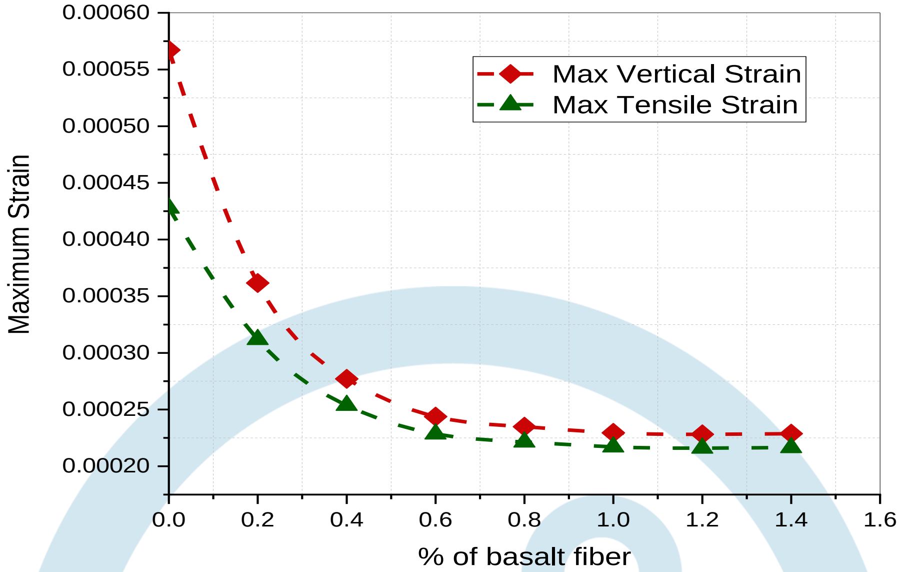

Figure 4 Curves of maximum strains in pavement against basalt fiber content

IV. CONCLUSIONS

The construction of highways demands high strength foundation soil. Among various techniques available for the improvement of sub grade soil, reinforcing the soil with fibers is widely adopted. Basalt fiber which is obtained naturally can enhance the strength of soil to a higher extent and also it is eco-friendly. Therefore this study aimed in observing the strength properties of locally available red soil with the addition of basalt fiber and also its effect on pavement design.

It is found that the addition of basalt fiber effectively increased the strength of the soil. The MDD was increased with an increase in fiber content up to 0.8% i.e. 1.96 to 2.4 g/cc due to the high specific gravity of basalt fiber. After that, it was reduced in a further increase of fiber.

The CBR of conventional soil was increased twice with the initial addition of basalt fiber of 0.2% and up to 0.8% of fiber CBR value was increased at a higher rate, thereafter CBR increased at decreasing rate in a further increase in fiber content.

Resilient modulus values of sub grade and unbound granular layer computed based on IRC 37:2018 guidelines were also shown an increase and the maximum vertical and tensile strains reduced to half and more than half for fiber content 0.4 to 1.2% which shows the greater resistance of pavement layer for fatigue and rutting failure.

The basalt fiber content around 0.8% by weight of the soil can effectively enhance the sub grade soil strength and efficiently improves the structural design of pavement for highways.

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