Investigation of Engineering Behavior of Soil, Polypropylene Fibers and Fly Ash -Mixtures for Road Construction

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***Abstract*—Fly ash is a waste produced mostly from the burning of coal in thermal power stations, which contributes to environmental pollution. Also, a number of studies have been conducted to investigate the influence of randomly oriented fibers on the engineering behavior of coarse grained and fine grained soils. The influence of randomly oriented polypropylene fibers on the engineering behavior of soil fly ash mixtures has not been reported so as much detail as in the case of the soils. The purpose of this investigation was to identify and quantify the influence of fiber variables (content and length) on performance of fiber reinforced soil- fly ash specimens. A series of laboratory unconfined compression strength tests and California bearing ratio tests were carried. Polypropylene fibers with different fiber length (6mm, 12mm and 24 mm) were used as reinforcement. Soil -fly ash specimens were compacted at maximum dry density with low percentage of reinforcement (0 to 1.50 % of weight).Four primary conclusions were obtained from this investigation. First, inclusion of randomly distributed fibers significantly improved the unconfined compressive strength of soil fly ash mixtures. Second, increase in fiber length reduced the contribution to peak compressive strength while increased the contribution to strain energy absorption capacity in all soil fly ash mixtures. Third, an optimum dosage rate of fibers was identified as 1.00 % by dry weight of soil- fly ash, for all soil fly ash mixtures. Fourth, a maximum performance was achieved with fiber length of 12mm as reinforcement of soil fly ash specimens**

***Index Terms-* CBR, Fly Ash, Polypropylene fibers, UCS**

I. INTRODUCTION

Coal burning electric utilities annually produce million tons of fly ash as a waste byproduct and the environmentally acceptable disposal of this material has become an increasing concern. Efforts have always been made by the researchers to make pertinent use of fly ash in road constructions in the localities which exists in the vicinity of thermal power stations. Quality construction materials are not readily available in many locations and are costly to transport over long distance. Hence, over the last few years, environmental and economic issues have stimulated interest in development of alternative materials that can fulfill design specifications. The established techniques of soil / fly ash stabilization by adding cement, lime and reinforcement in form of discrete fibers cause significant modification and improvement in engineering behavior of soils/ fly ash. Fibers are simply added and mixed randomly with soil or fly ash.

A review of the literature revealed that various laboratory investigations have been conducted independently either on fly ash / lime stabilization of soil or fiber reinforced soil. Studies concerning fly ash and 'lime utilization for soil stabilization have been conducted in the past years by many investigators like Mitchell and Katti (1981), Maher et al (1993), Consoli et al (2001). The physical and chemical mechanisms of both short and long term reactions involved in lime stabilization of the soils or soil fly ash mixtures have been extensively described in literature by Ingles and Metcalf (1972), Brown (1996). Edil *et al* (2006) indicated the effectiveness of fly ashes for stabilization of fine grained soils. However, the comprehensive work is required to comprehend the influence of discrete polypropylene fibers inclusion on engineering behavior of soil-fly ash mixture. One of the most promising approaches in this area is use of fly ash as a replacement to the conventional weak earth material and fiber as reinforcement will solve two problems with one effort i.e. elimination of solid waste problem on one hand and provision of a needed construction material on other. Also, this will help in achieving sustainable development of natural resources.

The results of direct shear tests performed on sand specimens by Gray and Ohashi (1983) indicated increased shear strength and ductility, and reduced post peak strength loss due to the inclusion of discrete fibers. The study also indicated that shear strength is directly proportional to fiber area ratio and length of fiber up to certain limit. These results were supported by number of researchers using consolidated drained triaxial tests like Gray and Al-Refeai (1986), Gray and Maher (1989), Al-Refeai (1991), Michaowski and Zhao (1996), Ranjan *et al* (1996), Michaowski and Cermak (2003). Maher and Ho (1994) indicated that increase in strength and toughness of kaolinite fiber composite was a function of fiber length and content, and the water content. It was indicated that the contribution of fibers to peak compressive strength was reduced, and ductility increased, with increasing fiber length. Consoli *et al* (1998) indicated that inclusion of fiber glass in silty sand effectively improves peak strength. Consoli et *al* (2002) indicated that due to inclusion of polyethylene terephthalate fiber in fines and improves both peak and ultimate strength which is dependent on fiber content. Kumar S. and Tabor E. (2003) studied the strength behavior of silty clay with nylon fiber for varying degree of compaction. The effect of polymer fiber inclusion on plain fly ash was studied by Chakraborty and Dasgupta (1996) by conducting triaxial tests. The fiber content ranging from 0 to 4 % by weight of fly ash was used with constant fiber aspect ratio of 30. The study indicates increase in friction angle. The study on soil fly ash mixture reinforced with 1% polyester fibers (20 mm length) was conducted by Kaniraj and Havanagi (2001), which indicated the combined effect of fly ash and fiber on soil. Kaniraj and Gayatri (2003) indicated that 1% polyester fibers (6 mm length) increased strength of raw fly ash and change their brittle failure into ductile one. Dhariwal, Ashok (2003) carried out performance studies on California bearing ratio values of fly ash reinforced with jute and non woven geo fibers. Keeping, in view the gaps in available literature and limited studies on behavior of fiber reinforced soil fly ash mixtures; the study was undertaken to identify and quantify the influence of fiber variables (content and length) on the engineering behavior of soil-fly ash mixtures.

II. Experimental Programme

Materials used

Locally available soil used in the soil fly ash mixtures was silt. The grain size distribution curve indicated that soil was primarily fine grained with approximately 85% silt size, 11.00% fine sand and 4.00 % clay size particles. The specific gravity of soil solids was 2.66. Fresh fly ash samples were collected from Tuticorin Thermal Power Station, Tuticorin (Tamil Nadu), India. The chemical composition and physical properties of fly ash are shown in Table 1. The fly ash is classified as Class F fly ash as per ASTM C618 (ASTM1993).

The polypropylene fibers RP6, RP12 and RP24 were used. Polypropylene fibers are hydrophobic, non corrosive and resistant to alkalis, chemicals and chlorides.

TABLE 1: Chemical Composition and Physical Properties of Fly Ash

Chemical composition	
Silicon dioxide SiO_2	1.30
Aluminium oxide Al_2O_3	25.70
Ferric oxide, Fe_2O_3	5.30
Calcium Oxide, CaO	5.60
Potassium Oxide , K_2O	0.60
Sodium Oxide, Na_2O	0.40
Magnesium Oxide, MgO	2.10

Physical Properties	
Specific Gravity	2.16
Loss on ignition (%)	1.90
Moisture (%)	0.30

Sample Proportions

The general expression for the total dry weight W of a soil fly ash fiber mixture is

$$W = W\text{s} + W\text{f} + W\text{ps} \quad (1)$$

Where Ws, Wf and Wps are weights of soil, fly ash and polypropylene fibers respectively. The proportions of soil, fly ash and fibers in soil fly ash mixture are defined as the ratio of their respective dry weight to the combined dry weight of soil fly ash. Thus, above equation can be written as

$$W = (P\text{s+Pf+Nps}) (\text{Ws+Wf}) \quad (2)$$

Where Ps= proportion of soil = Ws/(Ws+Wf)

Pf= proportion of fly ash = Wf/(Ws+Wf) and

Nps=Polypropylene fiber content =Wps/(Ws+Wf).

The sum of Ps and Pf is unity. The different values adopted in the present study for Ps were 0.00, 0.50 and 1.00; Pf were 1, 0.50 and 0.00 and Nps were 0.005, 0.01 and 0.015.

Sample Preparation

The samples were prepared by dry blending of soil and fly ash, with required amount of water obtained from standard proctor test. In preparation of fiber reinforced samples, the fibers were added to moist mixture of soil fly ash. The samples were mixed manually with proper care to get homogeneous mix.

Tests Conducted

Compaction Tests

The compaction tests on un-reinforced and reinforced soil fly ash mixes were conducted in accordance with Indian Standards Specifications (Bureau of Indian Standards (BIS) 1980 I.S.2720 (7)).

Unconfined Compression Strength Tests

Test Specimens of size 38 mm x 76 mm were prepared using mould by compacting samples in the three layers at maximum dry unit weight and optimum moisture content determined by conducting Standard Proctor Test. Unconfined Compression Strength tests were conducted in accordance with Indian Standards Specifications (Bureau of Indian Standards (BIS) 1973 I.S.2720 (10)).

California Bearing Ratio (CBR) Tests

CBR tests was conducted on specimens prepared using a cylindrical mould of 150 mm diameter and 175 mm height. The specimens were prepared by compacting samples in five layers at maximum dry unit weight and optimum moisture content determined by conducting Standard Proctor Test. The tests were conducted in accordance with Indian Standards Specifications (Bureau of Indian Standards, BIS) 1979 I.S.2720 (16)).

III. Test Results And Discussions

Observations from standard proctor tests, unconfined compression tests and California bearing ratio tests have been analyzed to study the effect of polypropylene fibers on engineering behavior of soil fly ash mixtures.

Moisture Density Relationship Standard proctor tests were carried out on un-reinforced and reinforced soil-fly ash mixes. In the case of soil- fly ash – fiber mixture, the dry weight of total mixture (W) was taken as per Equation (1). The moisture density relationship obtained from standard proctor tests showed that increasing fiber content from 0.00 % to 1.50 % by dry weight of soil fly ash and fiber length from 6mm to 24 mm had significant effect on the magnitude of either maximum dry density(MDD) and optimum moisture content (OMC)of soil fly ash mixture. The variation in MDD and OMC of different soil-fly ash-fiber mixtures with fiber content are shown in Fig.1 and Fig.2 respectively.

MDD showed increase of 1.20 % to 8.40 % and 1.01 % to 2.45 % in fly ash and soil fly ash mixtures respectively, due the addition of fibers. MDD of soil decreases by 0.27 % to 5.41 % due to addition of fibers. The decrease in OMC varies from 3.53 % to 20.35 % and 6.32 % to 8.54 % in fly ash and soil fly ash mixtures respectively ,whereas increases by 0.85 % to 6.72 % in soil.

Maher and Ho (1994) indicated that variation in OMC as a function of increasing fiber content was between 24 and 25.5 % respectively; with no noticeable change in MDD of Kaolinite fiber composite. It was also indicated that with increasing fiber length from 6.4 mm to 25.4 mm; no noticeable change was observed in moisture density relationship.

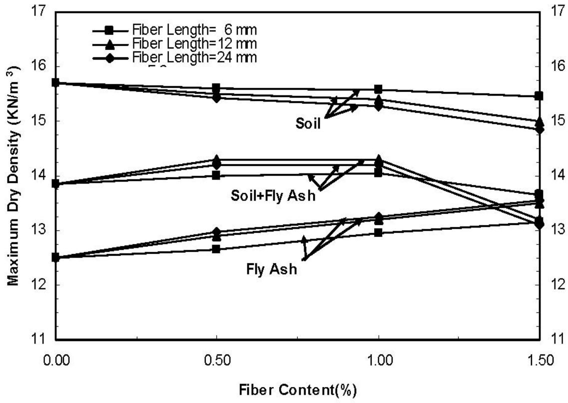

Figure 1: Variation of maximum dry density (MDD) with fiber content

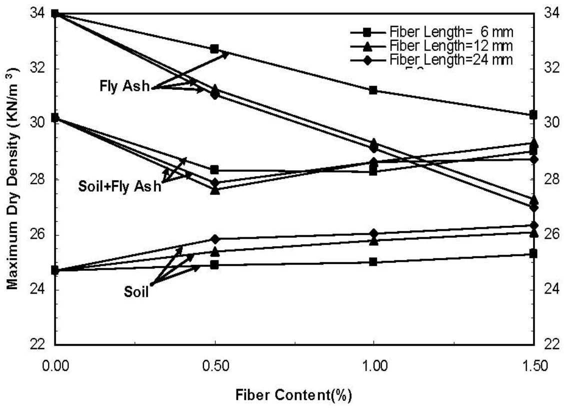

Figure 2: Variation of optimum moisture content (OMC) with fiber content

Unconfined Compression Tests

The effect of fiber inclusion on the unconfined compressive strength (UCS) and stress –strain relationship of soil-fly ash specimens was determined as a function of fiber content and length. Primarily, the tests were performed on un-reinforced soil-fly ash to establish base UCS so that relative gain in UCS due to addition of polypropylene fibers could be estimated. Fig.3 shows the stress strain response of soil fly ash mixtures without polypropylene fibers. As expected the stress strain relationship showed that without reinforcement, the soil –fly ash behavior was rigid and brittle. A distinct failure axial stress was reached at an axial strain of 2.3 %, 2.80 % and 3.4 % in soil, soil fly ash and fly ash respectively.

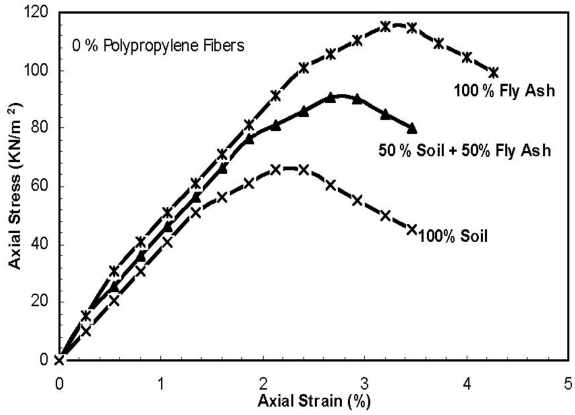

Figure 3: Stress strain response of un-reinforced soil-fly ash mixtures

Fiber inclusion affected the stress strain relationship of soil fly ash mixtures showing increase in the peak compressive strength, reducing the post peak reduction in compression resistance, and increasing the absorbed strain energy capacity or ductility. Typical stress strain relationships for soil fly ash mixture reinforced with 12 mm polypropylene fiber are presented in fig.4.

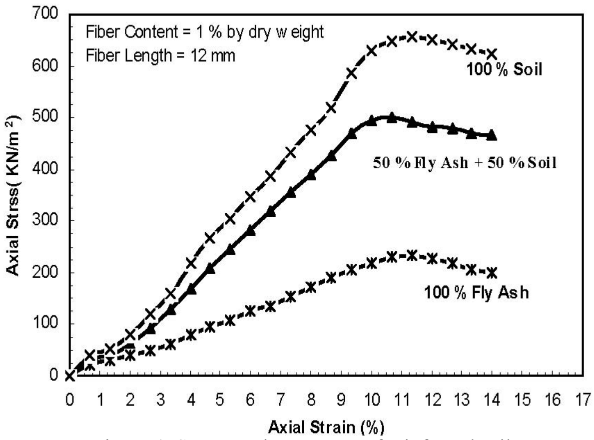

Figure 4: Stress strain response of reinforced soil-fly ash mixtures

For all the fiber reinforced soil-fly ash mixtures tested, the peak strength increases with fiber content. It was also observed that some fiber-reinforced specimens (with fiber length 24 mm) do not show distinct reduction in axial stress. UCS in such situations is generally defined by permissible amount of deformation. Usually UCS is taken at a corresponding strain of 15 or 20 %. Thus, in the present analysis, the UCS has been defined as the stress corresponds to the peak stress condition or at 15 % axial strain, whichever is earlier.

By comparing UCS of soil fly ash specimens, it is seen that, in un-reinforced condition, fly ash has a higher UCS than soil and soil- fly ash specimens. However, the inclusion of fibers improves the UCS of soil and soil- fly ash specimens significantly than that in fly ash.

The increase in UCS due to addition of polypropylene fibers is measured in the terms of relative gain (Gpf), which is defined as –

$Gpf = (q_{pfo} – q_{un}) / q_{un}$

Where q_{un} – UCS of un-reinforced soil – fly ash specimens, and

q_{pfo} – UCS of reinforced soil – fly ash specimens.

It was observed from the results that Gpf increases as q_{un} decreases. Similar behavior was observed in soil−fly ash mixtures reinforced with 1% by weight polyester fibers 20 mm in length. (Kaniraj and Havanagi, 2001).

In order to quantify the influence of fiber content and fiber length on relative gain in UCS due to fiber, the variation in Gpf was plotted with fiber content as shown in fig.5.

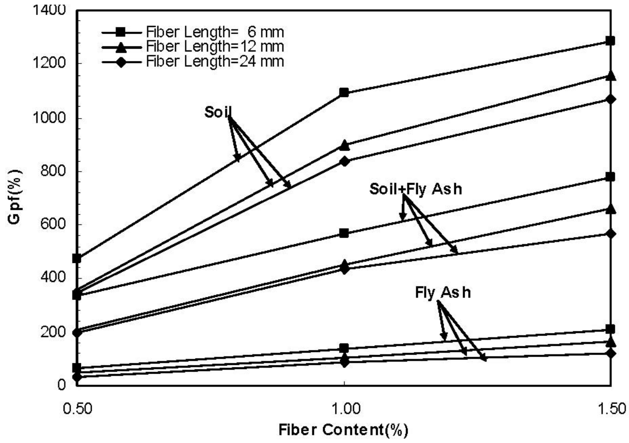

Figure 5: Variation in relative gain Gpf with fiber content.

It is clearly from the figure that for all soil-fly ash mixtures Gpf increases with fiber content. The variation in Gpf ranges from 35.35 % to 1283.92 % .Similar observations were made in fiber reinforced sand (Gray and Al-Refeai 1986; Maher and Gray 1990).

It is also clear from figure, in all soil –fly ash mixtures, increasing fiber length decreased the contribution of fibers to the relative gain Gpf. Similar type of observations were obtained for fiber – kaolinite composite (Maher and Ho, 1994).

The effect of increasing fiber content and length on the strain energy absorption capacity of soil- fly ash mixtures is presented in fig.6. The energy absorption capacity was calculated by taking into consideration the area under the stress –strain curves up to a limiting axial strain of 15 %. As shown in figure, the strain energy absorption capabilities of all soil-fly ash mixtures increase with fiber content. The increase was significant up to fiber content of 1.00 % by weight and fiber length of 12 mm.

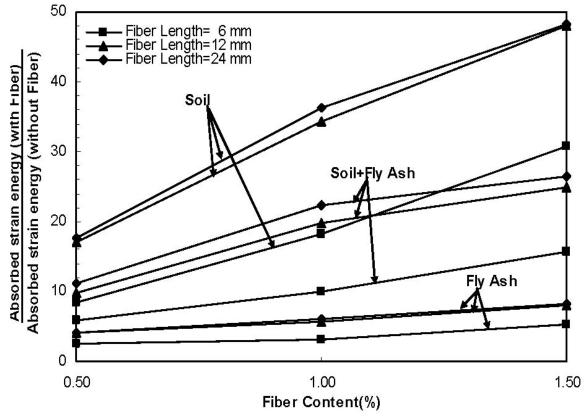

Figure 6: Variation in normalized strain energy absorption capacity with fiber content.

California Bearing Ratio (CBR) Tests

The CBR method is recommended by Indian Road Congress specifications for design of flexible pavements (IRC 37-2002).CBR values for different soil-fly ash and polypropylene fibers have been determined in soaked condition. The values of CBR for plain and reinforced soil-fly ash mixtures with varying percentages of polypropylene fibers are tabulated in Table 2.

TABLE 2: SOAKED C.B.R. VALUES (%) OF FIBER REINFORCED SOIL-FLY ASH SPECIMENS

Fiber Content (%)	Soaked CBR values	Fiber length= 6mm	Fiber length= 12mm	Fiber length= 24mm
0% : 100 %	0.00	3.25	3.25	3.25
	0.50	4.20	5.20	4.70
	1.00	7.16	12.65	9.79
	1.50	9.29	13.99	10.63
50% :50 %	0.00	3.02	3.02	3.02
	0.50	5.15	6.15	4.87
	1.00	8.84	12.48	10.86
	1.50	9.06	13.21	11.86
100 % : 0%	0.00	2.63	2.63	2.63
	0.50	4.81	6.55	5.37
	1.00	8.67	14.72	12.03
	1.50	9.74	15.05	12.48

The relative benefit in CBR values due to fibers is defined as $Bpf = (CBRpf - CBR_{un}) / CBR_{un}$

Where CBR_{un} – CBR of un-reinforced soil – fly ash mixtures, CBRpf – CBR of reinforced soil – fly ash mixtures.

To quantify influence of fibers with respect to content and length on relative benefit Bpf , the variation in Bpf was plotted with fiber content and fiber length as shown in figure 7 and figure 8.The variation Bpf ranges between 29.23 % to 472.24 % .

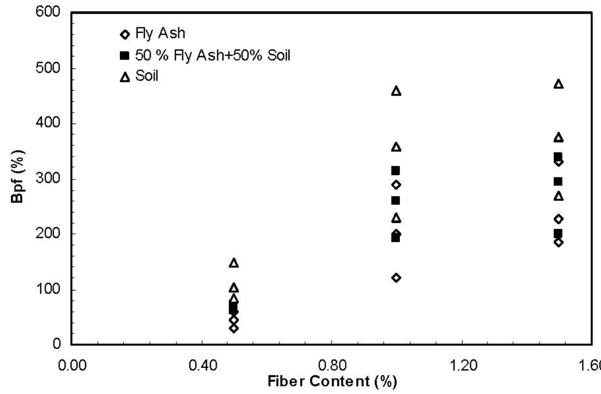

Figure 7: Variation of relative benefit Bpf with fiber content.

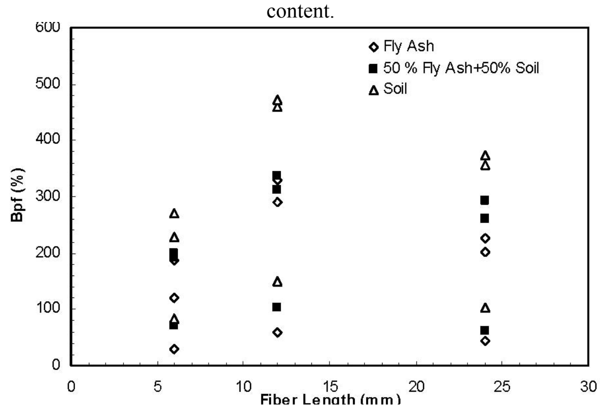

Figure 8: Variation of relative benefit Bpf with fiber length.

Fig.7 clearly indicates that Bpf increases significantly up to 1.00 % by weight of soil-fly ash mixtures beyond which increase in Bpf is negligible. Also, it is clear from figure 8 that Bpf increases only up to 12 mm fiber length for all soil –fly ash specimens.

IV. Conclusion

The inclusion of fibers had a significant influence on the engineering behavior of soil-fly ash mixtures. The following are the major conclusions of this study on engineering behavior of fiber reinforced soil-fly ash mixtures-

The moisture –density relationship of soil-fly ash mixtures significantly affected due to addition of fibers. The MDD increases and OMC decreases in fly ash and soil- fly ash mixtures. Whereas the soil shows reverse trend but less noticeably.

Inclusion of fibers increased the peak compressive strength and ductility of soil-fly ash specimens. The increase in the UCS of soil –fly ash specimens depends on the UCS of the un-reinforced specimens. The relative gain in UCS increases as the UCS in the un-reinforced state decreases.
Increase in fiber length reduced the contribution of fibers to peak compressive strength, while increasing the contribution to energy absorption capacity or ductility of soil- fly ash specimens.

The relative benefit in CBR values due to fibers increases only up-to 1.00 % by dry weight and length up to 12mm for all soil-fly ash specimens.

The results of study of a randomly oriented fiber reinforced soil- fly ash mixtures indicted that a maximum performance was achieved with 12 mm fibers in optimum dosage of 1.00 % by dry weight of soil- fly ash mixtures.

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