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Performance evaluation of polypropylene fibers on sand-fly ash mixtures in highways

H.S. Chore, A.A. Kumthe, S.B. Abnave, S.S. Shinde, S.S. Dhole and S.G. Kamerkar

Department of Civil Engineering, Datta Meghe College of Engineering
Sector-3, Airoli, Navi Mumbai-400708, India

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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. Many studies have been reported in the literature on the performance evaluation of soil- fly ash system as well soil- fly ash- fiber system. Although ample studies have been reported with the randomly distributed fibers, relatively lesser amount of work is found in respect of polypropylene fibers. In view of this, an experimental investigation for the performance evaluation of polypropylene fiber- sand- fly ash system is reported in this paper. The objective of this investigation is to quantify the optimum quantity of randomly distributed polypropylene fibers and fly ash on the performance in terms of CBR as well as values of the angle of internal friction of sand as a highway material. The effect of fiber variables such as length and contents was considered. The study revealed that there is a significant improvement on the CBR value as well as angle of internal friction with inclusion of randomly distributed fibers. Further, it was observed that the optimum moisture content increases and maximum dry density decreases with increase in percentage of fly ash mixed with sand.

Keywords: Fly ash, Sand, Polypropylene Fibers, California Bearing Ratio (CBR), Box Shear Test

1. Introduction

Electricity is the most vital infrastructural inputs for the growth of the Indian economy. A fly ash is a waste byproduct from thermal power plants which use coal as fuel. About 100 MT of residue, commonly called as fly ash, is being produced annually from different thermal power plants in the world. Mainly 80% of this is in the form of fly-ash and balanced 20% in the form of bottom ash. This needs thousands of hectares of precious land for its disposal causing severe health and environmental hazards also. The environmentally acceptable disposal of this material has become an increasing concern.

In spite of the continuous efforts made and incentives offered by the government agencies, the fly ash is not fully used for gainful purposes like brick making, cement manufacturer, soil stabilization and as a fill material. As thermal power plants are spatially distributed all over the world, utilization of fly ash from these plants for road construction not only helps to consume bulk quantities of fly ash solving its disposal problems to a certain extent; but also satisfies the construction requirements.

Quality construction materials are not readily available in many locations and further, are difficult to transport over long distances which renders the construction costly. On this backdrop, over last few years environmental and economic issues have stimulated interest in development of many alternative materials are used that can fulfill design specifications. In order to utilize fly ash in bulk quantities, ways and means are being explored all over the world to use it for the construction of embankments and roads as fly ash satisfies major design requirements of strength and compressibility except for its susceptibility to erosion and possible liquefaction under extreme conditions. The well established technique of soil- fly ash stabilization by adding cementous materials and reinforcement in the form of discrete fibres caused significant modification and improvement in engineering behavior of soil fly ash. Fibers are simply added and mixed randomly with soil and fly ash.

One of the most promising approaches in this area is the large scale utilization of fly ash in geotechnical construction like embankments, road sub bases, structural land fill, as a use of fly ash as a replacement to the conventional weak earth material and fiber as reinforcement would solve two problems with one effort - 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. Both these problems are becoming acute in the urban environment because most coal fired generating plants are located there and the supply of natural construction material is also becoming scarce.

Different types of materials are being increasingly employed in various civil engineering activities including highway engineering to facilitate construction, better performance and reduce maintenance. Reinforced soils can be obtained by either incorporating continuous reinforcement inclusions (e.g., sheet, strip or bar) within a soil mass in a defined pattern (i.e., systematically reinforced soils) or mixing discrete fibers randomly with a soil fill (i.e., randomly reinforced soils). The concept of reinforcing soil with natural fiber materials originated in ancient times. However, randomly distributed fiber reinforced soils have recently attracted increasing attention in geotechnical engineering. In comparison with systematically reinforced soils, randomly distributed fiber reinforced soils exhibit some advantages. Preparation of randomly distributed fiber reinforced soils mimics soil stabilization by admixture. Randomly distributed fibers offer strength isotropy and limit potential planes of weakness that can develop parallel to oriented reinforcement. Further, the fiber reinforcement causes significant in tensile strength, shear strength, bearing capacity, other properties as well as economy. The experimental and numerical studies on the fiber reinforced soils, fiber reinforced –fly ash-soil system, stabilization of soil using admixtures and utilization of fly ash is briefly reviewed in the following section.

2. Review of literature

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 reported in the past by many researchers (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 stabilizations of soils or soil- fly ash mixtures have been extensively reported in the literature (Ingles and Metcalf, 1972; Brown, 1996; Edil et al., 2006). The study by Gray and Ohashi (1983) indicated that with the inclusion of discrete fibers, shear strength and ductility increases and post peak strength loss reduces. Along similar lines, many researchers worked on this aspect (Gray and Al-Refeai, 1986; Gray and Maher, 1989; Al-Refeai, 1991; Michaowski and Zhao, 1996; Ranjan et al, 1996; Michalowski and Cermak, 2003).

Maher and Ho (1994) carried out the investigations using consolidated drained triaxial tests and corroborated the findings of Gray and Ohashi (1983). Consoli et al. (1998) indicated that due to inclusion of polyethylene terephthalate fiber in fine sand improves both pick and ultimate strength which is dependent upon the fiber content. Kumar and Tabor (2003) studied the strength behavior of silty clay with nylon fiber for varying degree of compaction. Chakraborty and Dasgupta (1996) studied the effect of the inclusion of polymer fibers on plain fly ash by conducting triaxial tests. The fiber contents ranging from 0-4% by weight of fly ash was used with constant fiber aspect ratio of 30. The angle of internal friction was reported to increase with the inclusion of polymer fibers.

Kaniraj and Havanagi (2001) studied the soil fly ash mixture with 1% polyster fibers of 20 mm length and found significant effect of fly ash and fiber on the performance of soil. Prabhakar and Sridhar (2002) carried out the performance studies on the strength characteristics and CBR values of the soft soil reinforced with bio-organic material such as Sisal fibers. The study reported that the sisal fibers improve the apparent cohesion, failure deviator stress and CBR values considerably. Pazare and Chaterjee (2002) studied the behaviour of silty soil reinforced with glass fibers. The investigation by Kaniraj and Gayatri (2003) indicated that 1% polyester fibers (6 mm length) increases strength of raw fly ash and change brittle failure into ductile one. Consoli et al (2002) studied the engineering behavior of a sand reinforced with plastic waste.

Dhariwal (2003) evaluated the performance of fly ash reinforced with jute and woven geo fibers system in terms of California Bearing Ratio. Day et al.(2003) confirmed that unconfined compressive strength (UCS) and axial strain at failure increases with an increase in percentage of randomly distributed coir fibre. Soil reinforced with randomly distributed coir fibre indicates that at particular water content the UCS and failure strain are direct function, while MDD is an inverse function of the fibre content of soil sample. Yetimoglu and Salbas (2003) studied the effect of the contents of randomly distributed discrete fibers on shear strength of sands. It was observed that the peak shear strength and initial stiffness of sand were not affected significantly by the fiber reinforcements. The results further revealed increase in residual shear strength angle of sand by adding fiber reinforcements.

Gosavi et al (2004) conducted tests to improve the properties of black cotton soil subgrade reinforced with synthetic fibers and found considerable increase in CBR value. Ravishankar and Raghvan (2004) confirmed that for coir-stabilized lateritic soils, the soil decreases with addition of coir and the value of OMC increase in percentage of coir. The CBR increases up to 10% of coir content and further, increases in coir quantity results in reduction of the values. Tensile strength of coir-reinforced soil was found to increase with increase in the percentage of coir. Further, the study revealed that the tensile strength of both the soil and coir-reinforced soil at OMC is considerably lower than the tensile strength obtained from oven dry samples. Kumar et al. (2005) studied the effect of randomly distributed polypropylene fibers on fly ash embankments. Laboratory CBR tests, triaxial shear tests, plate load tests and field CBR tests were carried out to investigate the effect of fiber inclusion on the strength behaviour of fly ash. The investigation indicated significant improvement in CBR value, angle of internal friction and modulus of subgrade reaction. Tang et al. (2007) studied the effect of sand content on strength of polypropylene fibers reinforced clay soil.

Jadhav and Nagarnaik (2008) carried out the experimental studies for the performance evaluation of silty soil- fly ash –fiber mixture. The fibers were randomly oriented polypropylene fibers. The performance evaluation was tested by using 50-50% soil- fly ash proportion. Kumar and Singh (2008) studied the effects of polypropylene fiber reinforcements on conventional parameters of fly ash such as unconfined compression strength, modulus of elasticity, shear strength and C.B.R. The effect of reinforcements and confinements on permanent strength, resilient strain and resilient modulus of fly ash were also studied. Tests were carried out to study the effect of reinforcement on rut depth formation on a model section with simulation of field conditions. Based on the results, it was concluded that fly ash is suitable in subbase, if it is reinforced with polypropylene fibers. Chauhan et al. (2009) reported performance evaluation of silty-sand subgrade reinforced with fly ash and fibre reinforcement (coir fibers and synthetic fibers). Extensive laboratory investigation indicated that both the permanent and resilient strains in all materials decrease with confining pressure but increase with number of load cycles and deviator stress in reinforced and un-reinforced conditions. Coir fiber shows better resilient response against the synthetic fibers by higher coefficient of friction. Sadek et al. (2010) carried out the experimental study for evaluating the shear strength of fiber reinforced sand.

3. Scope of present work

It is found from the literature that the significant amount of work reported on the performance evaluation of soil- fly ash system as well as soil- fly ash –fiber system. Though many studies have been reported with the randomly distributed fibers, relatively less amount of work is reported in respect of polypropylene fiber. Similarly, few works are reported on the sand- fly ash- fiber system. Keeping in view such gaps in the available literature, the experimental investigations were undertaken to study the behaviour of sand- fly ash- fiber mixture for road construction. Four different combinations of sand and fly ash were considered in the proportions of 25% -75%, 50 % -50%, 65% -35% and 75% -25% respectively. For each of these combinations the percentage contents of the randomly distributed polypropylene fibers considered were 0, 0.5, 1.0 and 1.5. Length of the fibers considered were 6 mm and 20 mm, respectively. California bearing ratio (C.B.R.) and box shear tests were performed and the results were used to evaluate the performance of the mixture.

4. Experimental programme

4.1 Materials used

Locally available creek sand was used in the soil- fly ash mixtures. The grain size distribution curve indicated that the soil was primarily coarse grained with approximately 3% silt size, 28% fine sand , 43% medium sand, 8% coarse sand and 18% of gravels. The specific gravity of soil solids was 2.7. The fresh fly ash samples of Nashik Thermal Power Station were from procured M/s Supreme Ready Mixed Concrete

Plant, Thane (Maharashtra, India). The chemical composition and the physical properties of the fly ash are shown in Table 1.

The polypropylene fibers used in the investigation were modified virgin polypropylene. The polypropylene fibers are hydrophobic, non-corrosive and resistant to alkalis, chemicals and chlorides. The characteristics of the polypropylene fibers as provided by the suppliers- M/s Innovative Group, Lower Parel, Mumbai, are given in Table 2.

4.2 Proportioning and preparation of the sample

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

$$W= W_s+W_f+W_{pf} \tag{1}$$

Where W_s, W_f, W_{pf} are the weights of soil, fly ash, and polypropylene fibers, respectively.

Table 1
Properties and composition of fly-ash

Chemical Composition			
Property	Value	Property	Value
Silica (SiO_2)	60.41	Titanium Oxide(TiO_2)	-
Alumina (Al_2O_3)	30.48	Calcium Oxide (CaO)	1.32
Ferric Oxide (Fe_20_3)	3.89	Magnesium Oxide (MgO)	0.86
Sulpher Tri Oxide (SO_3)	0.11	Sodium Oxide (Na_2O)	0.26
Physical Properties			
Specific Gravity			2.2
Liquid Limit (%)			27
Shrinkage Limit (%)			31.46

Table 2
Characteristics of the Polypropylene Fibers

Property	Value
Length (mm)	6 and 20
Sp. Gravity	0.91
Elongation	15%
Nature	Inert
Water Absorbing Capacity	Nil

The proportions of sand, fly ash and fibers in sand fly ash mixture are defined as the ratio of their respective dry weight to the combined dry weight of sand fly ash. Thus, above equation can be written as

$$W= (P_s+P_f+N_{pf}) (W_s+W_f) \tag{2}$$

where P_s = proportion of sand=$W_s/(W_s+W_f)$; P_f= proportion of fly ash=$W_f/(W_s+W_f)$ and N_{ps}= polypropelene fibre content =$W_{pf}/(W_s+W_f)$.

The sum of P_s and P_f is unity. The different values adopted in the present study for P_s were 0.00,0.50, 1.00 and 1.50.

The samples were prepared by dry blending of sand, fly ash and fiber with required amount of water obtained from modified proctor test. The samples were mixed manually with proper care to get homogeneous mix.

4.3 Tests conducted

The various tests were such as grain size analysis, specific gravity test, Atterberg's limit tests, conducted to evaluate the index properties of the soil. Based on this, the modified proctor test was performed to find out the maximum dry density (MDD) and optimum moisture content (OMC) on the given samples by compaction method. Subsequently, the CBR tests and Box Shear tests were also conducted. All the tests were carried out in accordance with the relevant Indian Standard specifications.

5. Results and discussion

The observations from the modified proctor tests and CBR tests were analyzed to study the effect of polypropylene fibers on the engineering behaviour of different proportions of sand- fly ash mixtures.

5.1 Modified proctor test (MPT)

The modified proctor tests were carried out on un-reinforced and reinforced sand- fly ash mixture. In case of sand- fly ash- fiber mixtures, the dry weight of total mixtures (W) was taken as per the Equation (1). The moisture- density relationship obtained from the modified proctor test shows that the increase in fiber content from 0-1.5% by dry weight of sand- fly ash and fiber length of 6 mm and 20 mm was found to have significant effect on the maximum dry density (MDD) and optimum moisture content (OMC) of the mixtures.

The maximum dry density (MDD) and optimum moisture contents (OMC) obtained for different mix proportions of sand- fly ash mixtures in respect of the varying contents of the fibers of length 6 mm and 20 mm are given in Table 3. It is observed that in respect of un-reinforced sand- fly ash mixtures, the maximum dry density (MDD) is 1.536 kN/m^3. The MDD is found to be 1.57 kN/m^3 for sand- fly ash proportion of 25-75% corresponding to 0.5% fiber contents in respect of 6 mm long fibers. The values of the density are observed to be 1.54 kN/m^3 and 1.521 kN/m^3, respectively corresponding to 1% and 1.5% fibers contents. In respect of 20 mm long fibers, the values of MDD are 1.633 kN/m^3, 1.629 kN/m^3 and 1.595 kN/m^3 corresponding to 0.5%, 1% and 1.5%, respectively.

From this, it is seen that the MDD is less in respect of the un-reinforced case of sand- fly ash mixtures as compared to that of fiber reinforced mixture of sand and fly ash. Further, it is observed that the value of MDD goes on decreasing with increase in fiber contents in respect of either length of fibers. The trend of reduction in MDD with increase in fiber contents holds good for all the proportions of sand- fly ash mixtures. The optimum moisture content obtained in respect of various proportions of sand- fly ash mixture for different contents of fibers considered in the study is also shown in Table 3. It is observed that in respect of un-reinforced sand- fly ash mixtures, the optimum moisture content (OMC) is 10.58%. The OMC is found to be 10.56% for 25-75% sand- fly ash proportion corresponding to 1% and 1.5% fiber contents . In respect of 20 mm long fibers, the values of OMC are 9%, 12.20% and 15.91%, respectively corresponding to 0.5%, 1% and 1.5% fiber contents. The OMC is found to increase with increase in fiber contents. Further, it is observed that the OMC goes on decreasing with reduction in contents of fly ash.

5.2 California Bearing Ratio (CBR) tests

The california bearing ratio tests were carried out on un-reinforced and reinforced sand-fly ash mixtures. In case of sand- fly ash – fiber mixtures, the dry weight of total mixture (W) was taken as per Equation (1). The CBR values obtained for different mix proportions of sand- fly ash mixtures in respect of the varying contents of the fibers of length 6 mm and 20 mm are given in Table 4. The values of the angle of internal friction are also given in Table 4.

The variation in CBR with varying fiber contents of 6 mm and 20 mm length for different proportions of sand – fly ash mixtures are shown in Figure 1(a-d).

Table 3
Maximum dry density for different mix proportions and fiber contents

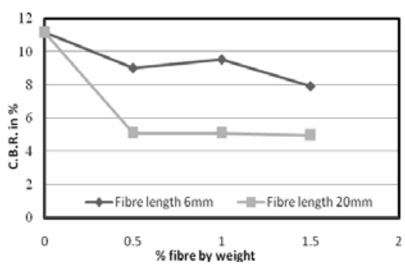
Mix proportion (Sand :Fly Ash)	Fibre content (%)	Maximum Dry Density (kN/m^3)		Optimum Moisture Content (OMC)	
		Fiber Length=6mm	Fiber Length=20mm	Fiber Length=6mm	Fiber Length=20mm
25%-75%	0.0	1.536	1.536	10.58	10.58
	0.5	1.57	1.633	10.56	9.00
	1.0	1.54	1.629	12.50	12.20
	1.5	1.521	1.595	13.04	15.91
50%-50%	0.0	1.849	1.849	10.00	10.00
	0.5	1.877	1.878	7.69	7.69
	1.0	1.829	1.811	8.33	9.47
	1.5	1.761	1.789	10.10	11.76
65%-35%	0.0	1.923	1.923	9.35	9.35
	0.5	1.998	1.99	8.53	9.21
	1.0	1.958	1.939	8.77	10.58
	1.5	1.894	1.847	9.80	11.70
75%-25%	0.0	1.971	1.971	9.17	9.17
	0.5	1.973	1.935	9.30	8.91
	1.0	1.948	1.926	11.11	10.09
	1.5	1.920	1.915	12.24	12.50

The CBR values shown in Table 4 indicates that the increase in fiber content for 6 and 20 mm long fibers considered was found to have significant effect on CBR value. The CBR value is found to be higher in respect of the un-reinforced sand- fly ash mixtures for 25-75% sand-fly ash proportion as compared to the reinforced mixture. In respect of the fibers having 6 mm length, the CBR values are found to be 9.01, 9.22 and 7.92 corresponding to 0.5%, 1 % and 1.5% fibers content. In the case of 20 mm long fibers, the corresponding CBR values are 5.11, 5.12 and 4.97, respectively.

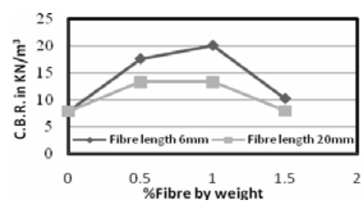
Unlike that observed in case of the un-reinforced sand- fly ash- mixtures for 25-75% sand-fly ash proportion, the CBR is found to be higher for the fiber reinforced sand- fly ash mixture in respect of the remaining three proportions of sand- fly ash, such as 50%-50%, 65%-35% and 75%-25%. The CBR value is found to be 17.63 for 50-50% sand-fly ash proportion corresponding to 0.5 % fibers contents in respect of 6 mm long fibers. The CBR values are found to be 20.08 and 10.28 corresponding to 1% and 1.5% fibers contents. In respect of 20 mm long fibers, the values of CBR are 13.3, 13.35 and 7.97 corresponding to 0.5%, 1 % and 1.5%, respectively.

Table 4
Values of CBR and angle of internal friction for different mix proportions

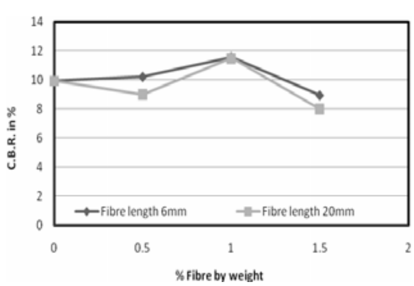
Mix proportion (Sand :fly ash)	Fibre content (%)	Unsoaked CBR Values		Angle of internal friction	
		Fiber length=6mm	Fiber length=20mm	Fiber length=6mm	Fiber length=20mm
25%-75%	0.0	11.17	11.17	28.59	28.59
	0.5	9.01	5.11	26.33	24.29
	1.0	9.22	5.12	29.59	28.00
	1.5	7.92	4.97	21.70	20.01
50%-50%	0.0	7.85	7.85	23.11	23.11
	0.5	17.63	13.30	34.52	32.94
	1.0	20.08	13.35	36.94	34.62
	1.5	10.28	7.97	31.79	29.59
65%-35%	0.0	9.94	9.94	27.11	27.11
	0.5	10.21	9.00	33.09	30.50
	1.0	11.58	11.57	34.37	32.12
	1.5	8.93	8.00	30.92	17.53
75%-25%	0.0	8.10	8.10	24.32	24.32
	0.5	9.03	6.23	29.85	20.91
	1.0	9.24	7.84	30.14	30.41
	1.5	8.40	5.80	27.15	17.01



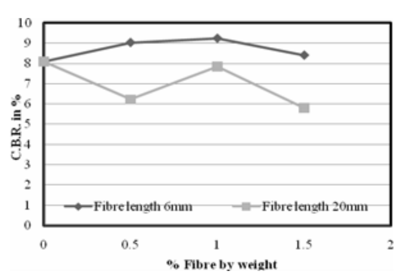
(a) 25- 75 % proportion of sand- fly ash mixture



(b) 50- 50 % proportion of sand- fly ash mixture



(c) 65- 35 % proportion of sand- fly ash mixture

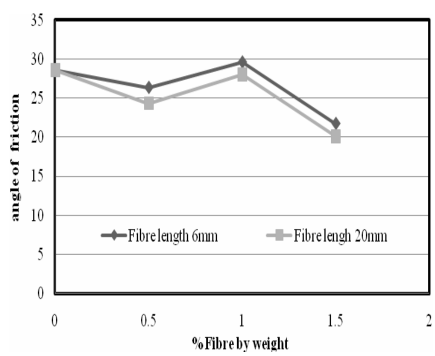


(d) 75- 25 % proportion of sand- fly ash mixture

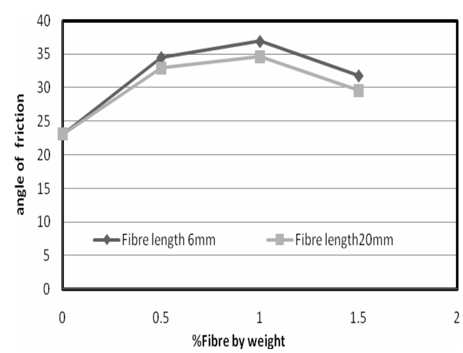
Figure 1. Variation of CBR Values with fiber contents for various proportions of sand- fly ash mixture

For 65-35% sand-fly ash proportion the CBR values are found to be 10.21, 11.58 and 8.93 corresponding to 0.5 %, 1% and 1.5% fibers contents in respect of 6 mm long fibers. The corresponding CBR values are 9, 11.57 and 8 in respect of 20 mm long fibers. The CBR value are found to be 9.03, 9.24 and 8.4 corresponding to 0.5% , 1% and 1.5% fiber contents for 75-25% sand-fly ash proportion in respect of 6 mm long fibers. In respect of 20 mm long fibers, the values of CBR for the corresponding percentage of fiber contents are found to be 6.23, 7.84 and 5.80.

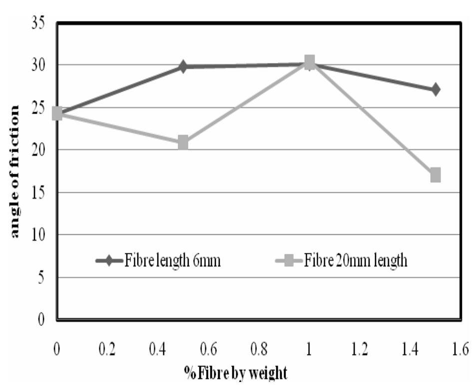
From this, it is observed that the CBR values are on higher side in respect of the un-reinforced case as compared to that of fiber reinforced mixture of sand and fly ash for 25-75% proportion. Further, it is observed that the CBR values are found to be less in respect of the un-reinforced case of sand- fly ash mixtures as compared to that of fiber reinforced mixture of sand and fly ash for the remaining three proportions of the sand-fly ash mixtures. The CBR is found to increase with the increase in fibers contents up to 1% and decreases for 1.5% of fiber content. The trend of increase in CBR with the increase in fiber contents up to 1% holds good for all the proportions of sand- fly ash mixtures in respect of either length of fibers considered in the present investigation. It is further observed that the maximum value of CBR is found to be 20.08 at 1% fiber contents for the sand-fly ash proportion of 50-50%.



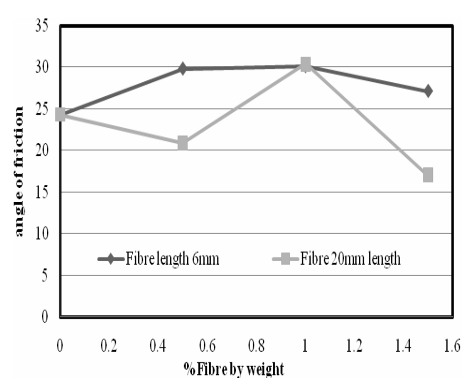
(a) 25- 75 % proportion of sand- fly ash mixture



(b) 50- 50 % proportion of sand- fly ash mixture



(c) 65- 35 % proportion of sand- fly ash mixture



(d) 75- 25 % proportion of sand- fly ash mixture

Figure 2. Variation of angle of internal friction with fiber contents for various proportions of sand- fly ash mixture

5.3 Direct shear test

The Direct Shear Test was carried out on un-reinforced and reinforced sand-fly ash mixtures. In case of sand- fly ash- fiber mixtures, the dry weight of total mixtures (W) was taken as per the Equation (1). The values of the angle of internal friction (Ø) were obtained from the Direct Shear Test. It shows that the increase in the fiber contents from 0 -1.5 % by dry weight of sand-fly ash is found to have significant effect on the values of the angle of internal friction (Ø) in respect of either lengths of fibers considered in the study. The values of the angle of internal friction obtained for different mix proportions of sand- fly ash mixtures from the Direct Shear Test in respect of the varying contents of the fibers is given in Table 4. The variation in CBR with varying fiber contents of 6 mm and 20 mm length for different proportions of sand - fly ash mixtures are shown in Figure 2 (a-d).

The values of angle of internal friction shown in Table 5 indicate that in respect of un-reinforced sand- fly ash mixtures, the value of the angle of internal friction (Ø) is 28.59. These values are on higher side as compared to that observed in respect of reinforced mixture. The values of the angle of internal friction are found to be 26.33, 29.59, and 21.70 corresponding to 0.5%, 1 % and 1.5% fiber contents in respect of 6 mm long fibers. Further in respect of 20 mm long fibers, the corresponding values are found to be 24.29, 28.00 and 20.01. For the mixture having 50%-50% sand-fly ash proportion, the values of the angle of internal friction are found to be 34.52, 36.94 and 31.79 corresponding to 0.5 % , 1% and 1.5% fibers contents in respect of 6 mm long fibers. The corresponding values observed for the mixture having similar proportion but with 20 mm long fibers are 32.94, 34.79 and 29.59.The variation of angle of internal friction with fiber contents for the mixture having 65 % -35% proportion of sand and fly- ash is shown in Fig. 5.7. The values of the angle of internal friction are found to be 33.09, 34.37 and 30.92 corresponding to 0.5 % , 1% and 1.5 % fibers contents in respect of the fibers having 6 mm length. The corresponding values are observed to be 30.50, 32.12 and 17.53 in respect of 20 mm long fibers. The variation of the values of angle of internal friction for the sand- fly ash mixture having proportions of 75 % -25% is shown in Fig. 5.8 and it reveals that the values of the angle of friction are 29.85, 30.14 and 27.15 corresponding to 0.5 %,1% and 1.5% fibers contents in respect of 6 mm long fibers. The values in respect of the fibers having 20 mm length are 20.91, 30.41 and 17.01.

From the foregoing discussion in the context of the variation of angle of internal friction with fiber contents for different mix proportions, it is observed that the values of the angle of internal friction are less in respect of the un-reinforced case of sand- fly ash mixtures as compared to that of fiber reinforced mixtures of sand and fly ash for 50%-50%, 65-35% and 75-25% proportions. The values of the angle of internal friction increases with increase in fibers contents up to 1% and decreases for 1.5% of fiber contents in respect of the fibers having 6 mm as well as 20 mm long fibers. The trend of increase in angle of internal friction values with increase in fiber contents holds good for all the proportions of sand- fly ash mixtures. However, the apparatus used in the experimental programme for this study is applicable for the material up to size of 2mm whereas the materials (such as sand) used in the present study have a size in the range of 4.75 mm; and the size of fiber was more. Hence, the results obtained pertaining to the angle of internal friction is considered to be approximate on the backdrop of the un-availability of the apparatus of appropriate size.

6. Summary and conclusions

Following are some of the broad conclusions deduced from the present study:

i. The value of the CBR was found to increase significantly when 1% fibers were used. It indicates that optimum quantity of polypropylene fibers to be 1%.

ii. The fibers having 6 mm length was found to yield maximum performance as compared to that in respect of the fibers having 20 mm length.

iii. It was observed that OMC increases and MDD decreases with increased percentage of fibers in sand-fly ash- mix.

iv. The time required for the soil plane to shear was found to be more when fibers were used as compared to that without fibers.

v. In case of box shear test, it was observed that the angle of internal friction increases up to 1% fiber contents and thereafter decreases at the rate of 1.5% fibers contents.

vi. The sand gave maximum performance when sand-fly ash was used in 50%-50% proportion.

The study revealed that there is significant improvement on the CBR value as well as angle of internal friction with inclusion of randomly distributed fibers. The experimental study presented here underscores the significance of the fiber reinforced soil system in highway constructions.

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