

# **Strength and Stiffness Response of Itanagar Fly Ash Reinforced with Coir Fiber**

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**Abstract:** Thermal power plants or similar plants in India which use pulverised coal as a fuel, generates million tonnes of fly ash every year as a waste. Conventional disposal of this material which gets easily air-borne and constitutes a serious health hazards to the community, is an expensive operation. On the other hand compacted fly ash can be used in embankments, road sub-bases and also for structural fills. The main limitations of such materials are their limited load carrying capacity and poor settlement characteristics. The performance of such materials can substantially be improved by introducing reinforcing element in the direction of tensile strain. Use of natural materials such as Jute, coir and bamboo, as reinforcing materials to fly ash are very cheap and they are locally available in large quantity. They are biodegradable and hence do not create disposal problem in environment. If these materials are used effectively, the rural economy can get uplift and also the cost of construction can be reduced. Of all the natural fibers, coir has the greatest tearing strength and it retains this property even in wet conditions. Keeping this in view the present study was taken up. In this study the influence of coir fibers on shear strength parameters ( $c$  and  $\phi$ ) and stiffness modulus ( $\sigma_d/\epsilon$ ) of fly ash have been investigated. In the present investigation, samples of fly ash compacted to its maximum dry density at the optimum moisture content were prepared without and with randomly distributed coir fiber for triaxial compression tests. The coir fiber were taken as 0.25 %, 0.5 %, 0.75 % and 1 % by dry weight of fly ash and the shear strength parameters ( $c$  and  $\phi$ ) and stiffness modulus ( $\sigma_d/\epsilon$ ) of reinforced fly ash for each fiber content was determined in the laboratory. Finally these strength parameters ( $c$ ,  $\phi$  and  $\sigma_d/\epsilon$ ) of reinforced fly ash were compared with that of unreinforced fly ash. Tests results indicate that on inclusion of coir fiber, the shear strength parameters and stiffness modulus of fly ash increases. It was also observed that on increasing the fiber content, the values of these strength parameters further increases and the improvement is substantial at fiber content of 1 %. Thus there is a significant improvement in the strength parameters of fly ash due to inclusion of coir fiber.

**Keywords:** Fly ash, Coir Fiber, Shear Strength Parameters, Stiffness Modulus, Fiber content,

## **I. INTRODUCTION**

Fly ash is a finely divided residue produced from thermal power plants, which use coal as fuel. Being generated in large quantity in thermal power stations fly-ash is generally recognized as waste and an environmentally hazardous material. About 600 Metric ton of fly ash is being produced annually from different thermal power plants in the world. This needs thousands of hectares of precious land for its disposal causing severe health and environmental hazards also. However, because of its pozzolonic and slightly cementitious properties it can be converted into meaningful wealth and used for gainful purposes like brick making, cement manufacture, soil stabilization and as a fill material and other civil engineering works. 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. However, the performance of fly ash can be improved by applying soil reinforcement technique with various reinforcing materials such as Coir, Jute, Bamboo, Synthetic fiber, Geogrid sheets etc. Large scale utilization of fly ash in geotechnical construction like embankments, road sub-bases, structural land fill, as a replacement to the conventional earth material will solve two problems with one effort, namely, elimination of solid waste problem on one hand and provision of a needed construction material on the other. 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. Reinforced soil is a composite material which is formed by the association of frictional soil and tension resisting

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elements in the form of sheets, strips, nets or mats of metal, synthetic fabrics or fiber reinforced plastics and arranged in the soil mass in such a way as to reduce or suppress the tensile strain which might developed under gravity and boundary forces. The reinforcement in soil is placed more or less in the same way as steel in concrete and the end product is called reinforced soil. It is very effectively used for retaining structures, embankments, footings, subgrade etc. The incorporation of reinforcement in the earth mass, particularly in case of non-cohesive soils is not only for carrying the tensile stresses but instead meant for anisotropic suppression or reduction of one normal strain rate (Saran 2010). Soil reinforcement technique with randomly distributed fiber is used in a variety of applications like, retaining structures, embankments, footings, pavement subgrade. During last 25 years, much work has been done on strength deformation behaviour of fiber reinforced soil and it has been established beyond doubt that addition of fiber in soil improves the overall engineering performance of soil. Among the notable properties that improved are greater extensibility, small loss of post peak strength, isotropy in strength and absence of planes of weakness etc. Fiber reinforced soil has been used in many countries in the recent past and further research is in progress for many hidden aspects of it. Fiber reinforced soil is effective in all types of soils (i.e. sand, silt and clay). Use of natural material such as Jute, coir, sisal and bamboo, as reinforcing materials in soil is prevalent for a long time and they are abundantly used in many countries like India, Philippines, Bangladesh etc. The main advantages of these materials are they are locally available and are very cheap. They are biodegradable and hence do not create disposal problem in environment.

Studies have shown that durability of natural fiber can be improved using coating of fiber with Phenol and Bitumen. Many studies have been conducted relating to the behaviour of soil reinforced with randomly distributed fiber. Gray and Ohashi (1983) conducted a series of direct shear tests on dry sand reinforced with different synthetic, natural and metallic fiber to evaluate the effects of parameters such as fiber orientation, fiber content, fiber area ratios, and fiber stiffness on contribution to shear strength. Based on the test results they concluded that an increase in shear strength is directly proportional to the fiber area ratios and shear strength envelopes for fiber-reinforced sand clearly shows the existence of a threshold confining stress below which the fiber tries to slip or pull out. Chakraborty and Dasgupta (1996) studied the strength characteristics of randomly oriented polymer-fibre reinforced fly ash using triaxial compression tests. They used the fly ash from Kolaghat Thermal Power Station and the fiber of different aspect ratio (ratio of fiber length to fiber diameter) in their study and found that increase in aspect ratio of fiber increase the shear strength of fly ash. Kaniraj and Gayatri (2003) conducted a series of triaxial compression tests on class F fly ash obtained from Dadri and Rajghat thermal power plants using polyester fiber as reinforcing material and concluded that inclusion of fiber in fly ash increases the shear strength of fly ash significantly at fiber content of 1 % by dry weight of fly ash. They further concluded that brittle behaviour of fly ash changes into ductile behaviour due to inclusion of fiber. Ravishankar and Raghavan (2004) confirmed that for coir fiber-stabilized lateritic soils, the maximum dry density of soil decreases with addition of coir fiber and the value of optimum moisture content increases with an increase in percentage of coir. The CBR value of soil increases up to 10% of coir fiber content and further increase in coir fiber results into decrease in CBR value. Choudhary and Verma (2005) studied the behavior of reinforced fly ash (TISCO fly ash) subgrades using model geogrid and Jute geotextile sheets as reinforcement by conducting a series of laboratory CBR tests on fly ash specimens with and without reinforcement. They concluded that there is a significant improvement in CBR value of fly ash due to addition of reinforcement. Lekha (2004) and Vishnudas et al. (2006) have presented a few case studies of construction and performance monitoring of coir geotextile reinforced bunds and suggested that the use of coir is a cost effective Eco hydrological measure compared to stone-pitching and other stabilization measures used in the protection of slopes and bunds in rural areas. Bhardwaj and Mandal (2008) studied the effect of polypropylene fiber on engineering properties and shear strength parameters of fly ash and found that fiber reinforcement increases the shear strength of fly ash and changes its brittle behaviour into ductile behaviour. Jadhao and Nagarnaik (2008) studied the performance evaluation of fiber reinforced soil-fly ash mixtures. A series of unconfined compressive strength (UCS) tests was carried out on selected soil-fly ash mixtures with and without polypropylene fiber to determine the stress strain behavior. The study showed that the inclusion of randomly distributed fiber significantly increases the UCS, residual strength, ductility and absorbed energy of soil fly ash mixtures. Sivakumar Babu and Vasudevan (2008) and Singh et.al (2011) studied the strength and stiffness response of soil reinforced with coir-fiber. Singh (2011) used the synthetic fiber of propylene type with the Itanagar fly ash and concluded that there is a significant improvement in shear strength parameters and stiffness modulus of fly ash due to synthetic fiber. Singh and Yachang (2012) and Singh (2012) used the Jute Geotextile sheets and coir fiber to improve the laboratory CBR value of fly ash and observed the improvement in CBR value of fly ash due to reinforcement. Singh and Bagra (2013) studied the effects of

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Jute fiber on CBR value of Itanagar soil and found the considerable improvement in CBR value of soil due to addition of Jute fiber. This paper presents the influence of Coir fiber on the shear strength ( $c$  and  $\phi$ ) and stiffness modulus ( $\sigma_d/\epsilon$ ) of Itanagar, Arunachal Pradesh, India fly ash. A number of triaxial compression tests have been conducted on fly ash and fly ash reinforced with Coir fiber. The effects of fiber contents on shear strength parameters and stiffness modulus of fly ash have been investigated and results have been compared with that of unreinforced fly ash.

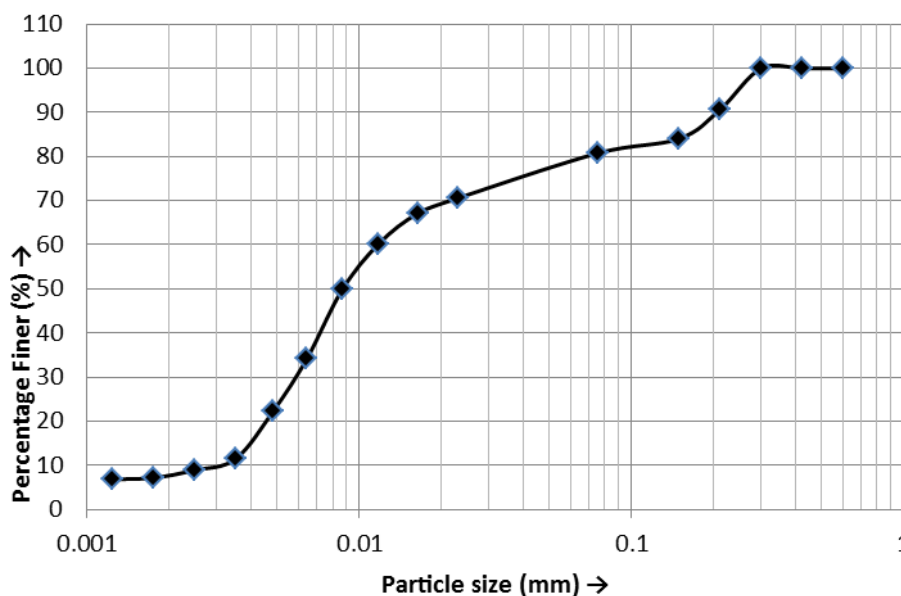
## II. MATERIALS AND TEST PROCEDURE

### A. Fly ash

The fly ash used in this study was taken from the site of Satyam ISPAT factory, situated at Banderdewa, Itanagar, Arunachal Pradesh, India. The various index properties and compaction properties i.e. maximum dry density and optimum moisture content (IS: 2720, Part VII, 1965) of fly ash were determined in the laboratory which is given in Table 1. The grain size distribution curve of fly ash is shown in Fig.1 and dry density versus water content compaction curve of fly ash is presented in Fig.3.

### B. Reinforcement

The reinforcing material used in this study is natural coir fiber of random lengths varies from 5 mm to 30 mm. The average diameter of coir fiber was 1 mm. A typical view of coir fiber is shown in Fig. 2.



**Fig.1:** Particle Size Distribution Curve of Fly ash

**Table 1:** Index and Compaction Properties of Fly ash

1	Specific Gravity (G)	2.46
2	Plasticity Index (PI)	Non-Plastic
3	Particle Size	Gravel Size (> 4.75 mm)
		0

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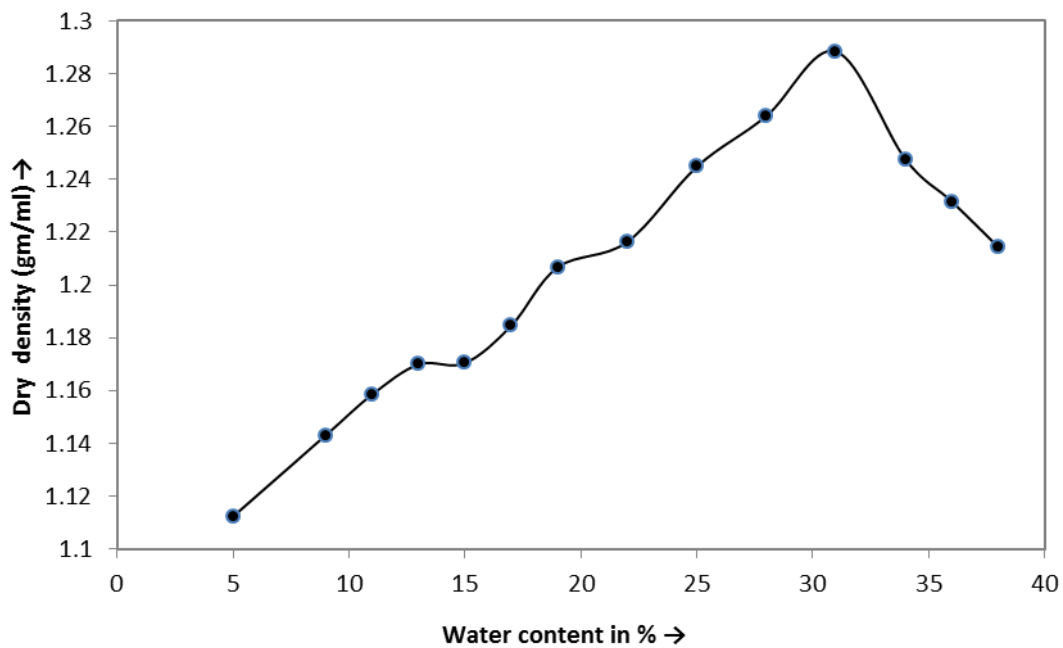
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	Distribution Curve	Sand Size (0.075- 4.75 mm)	19.27 %
		Silt Size (0.002-0.075 mm)	72.73 %
		Clay Size (<0.002 mm)	8 %
5	Co-efficient of uniformity ( $C_u$ )		3.77
6	Co-efficient of curvature ( $C_c$ )		0.96
7	Maximum Dry Density, $\gamma_d$ ( $\text{kN/m}^3$ )		12.99
8	Optimum Moisture Content, OMC (%)		31



**Fig. 2:** View of Coir Fiber



**Fig. 3:** Dry Density versus Water Content Compaction Curve of Fly Ash

**C. Test Procedure**

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Fly ash collected from the site of Satyam steel factory was made oven dried and then sieved through 425 micron sieve. Test specimens of fly ash were prepared in a standard cylindrical split mould of 38 mm diameter and 76 mm long. Because it was not possible to prepare the fly ash samples at its maximum dry density and optimum water content in the split mould for triaxial compression tests, all the tests samples were prepared at a dry density of  $12.50 \text{ kN/m}^3$  (97% of maximum dry density) and at corresponding water content of 30 % to enable a proper comparison of tests results. (Sivakumar Babu and Vasudevan 2008). Dry fly ash of specified weight was mixed with required quantity of water and kept in desiccators for equilibrium. Subsequently, the wet fly ash was taken out from the desiccators and the specified weight of coir fiber (precent by dry weight of fly ash) was distributed uniformly over the fly ash and mixed uniformly. Here, the maximum length of coir fiber was taken as 30 mm (less than 38 mm) for proper random mixing with fly ash. The fiber-fly ash mixture was then kept in a plastic container for equilibration of moisture content of mixture. The required quantity of fly ash-fiber mixture was filled in the split mould and statically compacted and specimens for triaxial testing were obtained. Because preparation of identical samples of coir fiber reinforced fly ash beyond 1 % fiber content was not possible in the laboratory hence the present investigation was restricted up to 1 % of the fiber content only.

All the specimens were tested in a conventional triaxial apparatus under three different confining pressures (ranging from 50 to 150 kPa) in undrained condition. Some tests were conducted under four different confining pressures also. Load was applied at a controlled strain rate of 1.58% per minute until the specimen failed/strain of 20% whichever was reached earlier. Some tests were repeated to check the reproducibility of tests results and it was found that variation is within 10 %. A total number of 20 triaxial compression tests were carried out for various fiber contents under different confining pressures.

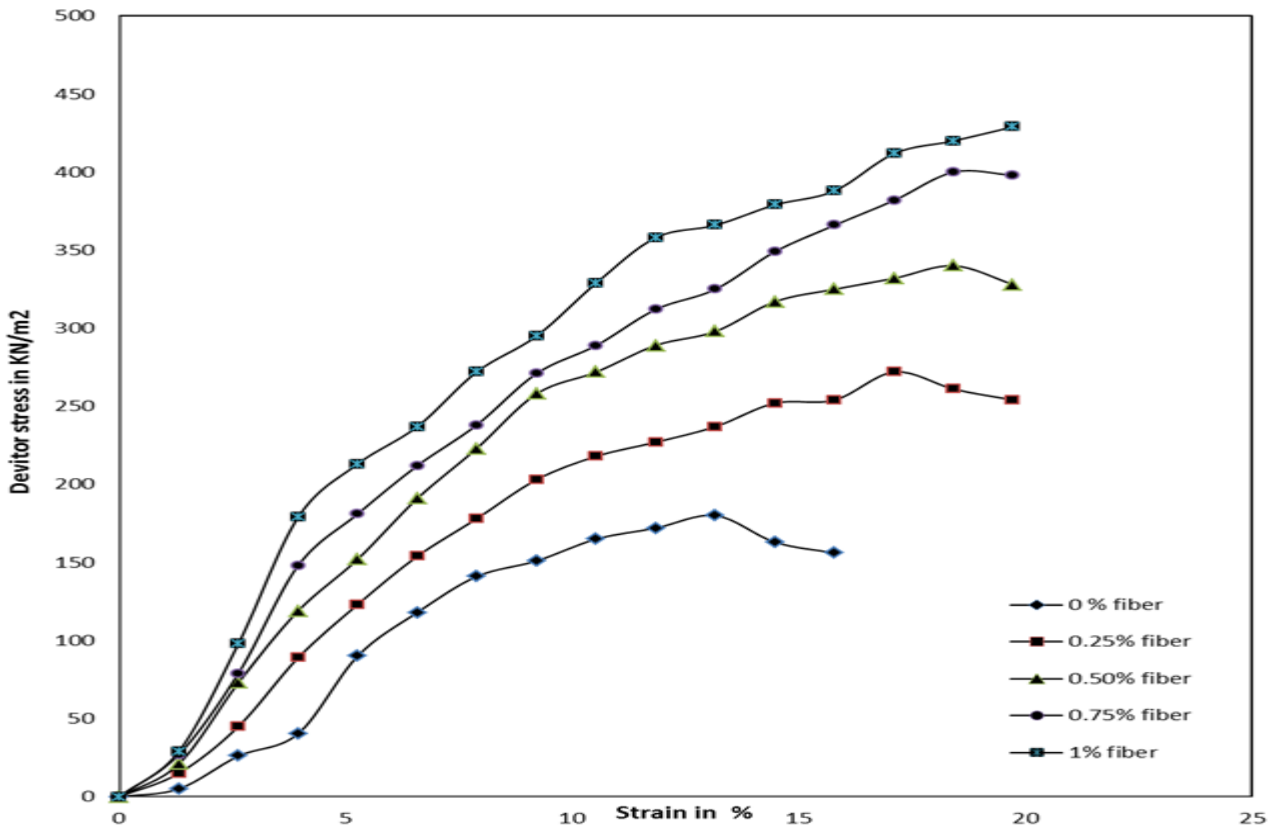
### III. TEST RESULTS AND DISCUSSIONS

A number of stresses versus strains curves were plotted from the tests results of triaxial compression test performed on the fly ash and fly ash reinforced with different fiber contents. One of such stress-strain plots of reinforced fly ash under confining pressure of 50 kPa are shown in Fig. 4. The values of stiffness modulus ( $\sigma_d/\epsilon$ ) for coir fiber reinforced fly ash (CFRF) having different fiber contents were computed from the plots which are shown in Table 2. To determine the values of shear strength parameters ( $c$  and  $\phi$ ) of reinforced fly ash for various fiber contents, a number of modified failure envelopes were drawn and shear strength parameters ( $c$  and  $\phi$ ) were measured from the modified failure envelopes which are given in Table 3. The modified failure envelopes of reinforced fly ash for various fiber content are shown in Figs.5 (a-e).

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**Fig. 4:** Stress versus Strain Curves of Reinforced Fly ash under Confining Pressure of 50 kPa

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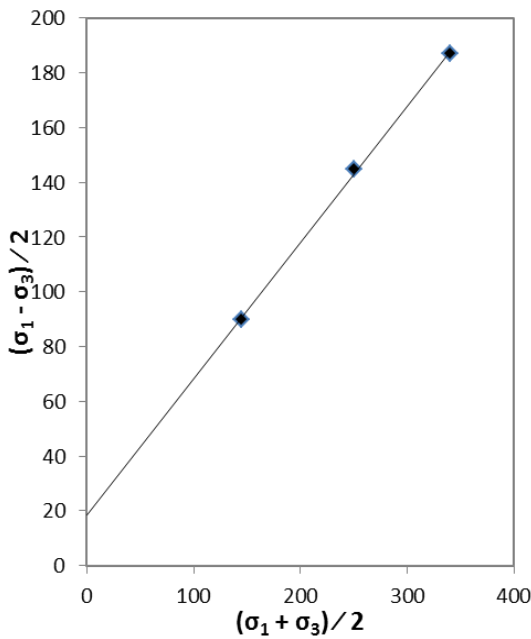


Fig. 5(a): Fly ash with 0 % Fiber Content

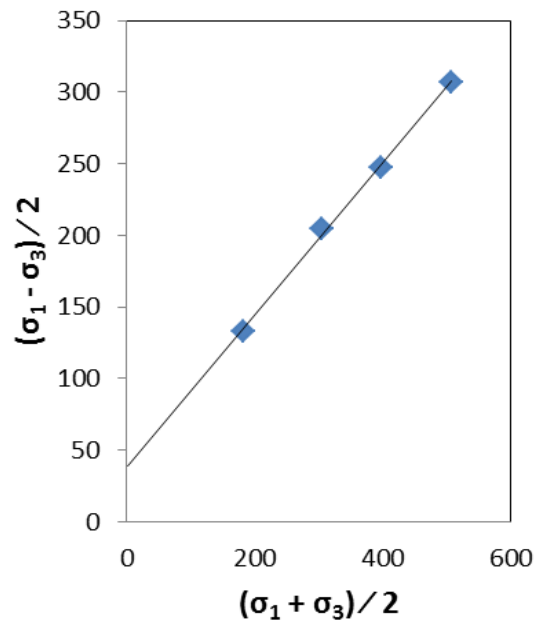


Fig. 5(b): Fly ash with 0.25 % Fiber Content

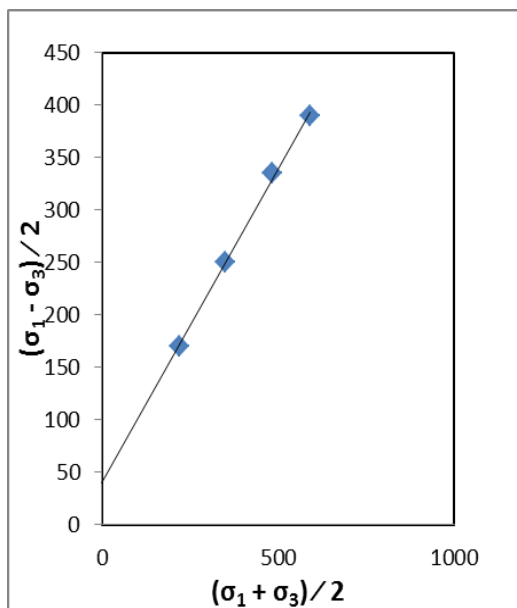


Fig. 5 (c): Fly ash with 0.5 % Fiber Content

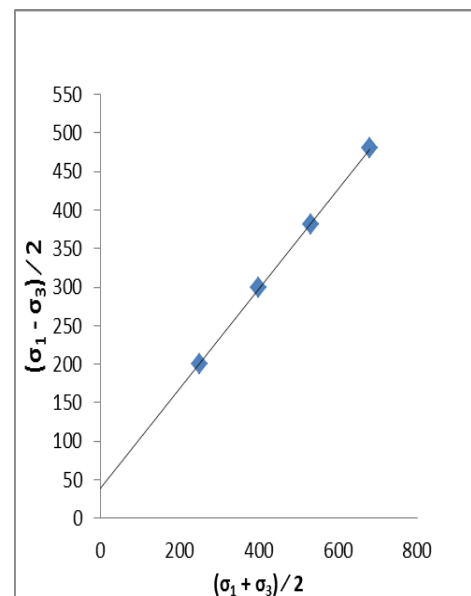
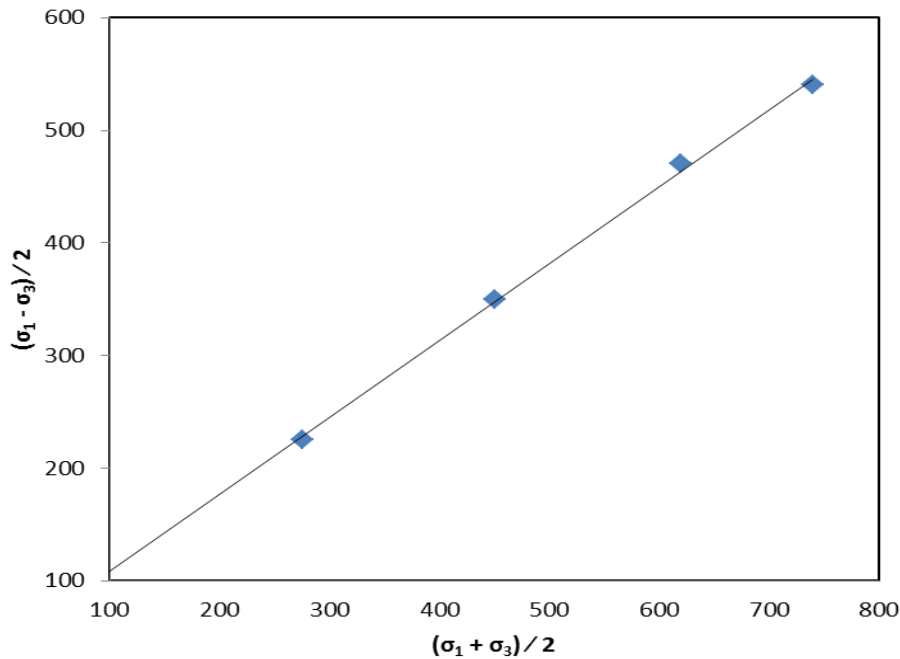


Fig. 5 (d): Fly ash with 0.75 % Fiber Content

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**Fig. 5(e):** Fly ash with 1 % Fiber Content

**Table 2:** Stiffness Modulus of Reinforced Soil for Various Fiber Contents at Different Confining Pressure

Fiber Content (%)	Confining Pressure (kN/m <sup>2</sup> )	Deviator Stress (kN/m <sup>2</sup> )	Strain (ε)	Stiffness Modulus (σ <sub>d</sub> /ε)	Average Stiffness Modulus	Increase in Average Stiffness Modulus	Percentage Increase in Average Stiffness Modulus
0	50	170	0.132	1292	1696	-	-
	100	325	0.184	1766			
	150	374	0.184	2032			
0.25	50	272	0.184	1472	2196	500	27
	100	410	0.184	2228			
	150	494	0.174	2888			
0.5	50	340	0.184	1847	2682	986	53
	100	499	0.20	2495			
	150	682	0.184	3706			
0.75	50	400	0.20	2000	3069	1373	81
	100	601	0.20	3500			
	150	762	0.184	3706			
1	50	429	0.20	2145	3448	1752	103
	100	700	0.20	3500			
	150	940	0.20	4700			



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**Table 3:** Shear Strength Parameters (c and  $\phi$ ) of Reinforced Fly ash

Fiber Content (%)	c (kN/m <sup>2</sup> )	$\phi$ (Degree)	Percentage Increase in (c)	Percentage Increase in ( $\phi$ )
0	34	28	-	-
0.25	45	34	32	21
0.5	50	39	47	39
0.75	52	42	53	50
1	55	45	61	60

**A. Effect of fiber content**

Based on the results of triaxial compression tests performed on reinforced fly ash at different fiber content varying from 0 % to 1 % the computed values of stiffness modulus and shear strength parameters of reinforced soil are shown in Table 2 and Table 3 respectively. It is observed from Table 2 that the stiffness modulus of reinforced fly ash increases with the increase in confining pressure and fiber content. The results of column 5 of Table 2 show the values of stiffness modulus of reinforced fly ash corresponding to different confining pressures and different fiber contents. It is clear from the values of stiffness modulus that it increases with the increase in confining pressure and this aspect can be observed for all the fiber contents. This is due to the fact that under higher confining pressures fly ash samples are more confined and more resistant to deformation which results into higher deviator stress at failure. It is further observed from the results of column 6 of Table 2 that the average increase in stiffness modulus of reinforced fly ash increases with the increase in fiber contents and this trend is observed for all the fiber content. For instance the average stiffness modulus of unreinforced fly ash is 1696. When 0.25 % coir fiber is added to the fly ash, the stiffness modulus of reinforced fly ash increases to 2196 i.e. improvement in stiffness modulus of fly ash is 27 % (last column of Table 2) due to 0.25 % inclusion of coir fiber. Similar trend is observed from the results of Table 2 for fiber contents of 0.5 %, 0.75 % and 1 % also and the maximum improvement in average stiffness modulus of fly ash is 103 % for fiber content of 1 %. The significant increase in average stiffness modulus of fly ash due to addition of coir fiber improves the load-settlement characteristics of fly ash and the amount of immediate settlement would be reduced significantly. It is observed from Table 3 that the shear strength parameters (c and  $\phi$ ) of reinforced fly ash increases with the increase in fiber content and this aspect can be observed for all the fiber content. Column 2 and Column 3 of Table 3 show the values of cohesion (c) and angle of internal friction ( $\phi$ ) of reinforced fly ash. Column 4 and Column 5 of Table 3 presents the percentage increase in (c) and ( $\phi$ ) values of fly ash due to inclusion of coir fiber. The results of Column 4 and Column 5 clearly show that the percentage increase in (c) value and ( $\phi$ ) values are 32,47,53,61 and 21, 39, 50, 60 respectively for fiber contents of 0.25 %, 0.5 %, 0.75 %, and 1 %. The significant increase in shear strength parameters of fly ash due to addition of coir fiber improves the load carrying capacity of fly ash and coir fiber reinforced fly ash can be used as foundation material for supporting heavier loads of civil engineering structures. Similar trend of results was observed by Sivakumar Babu and Vasudevan (2008), Singh et al. (2011) and Singh (2011) also with the natural and geosynthetic fiber reinforced soil and fly ash. The increase in stiffness modulus and shear strength parameters of fly ash due to inclusion of coir fiber is due to the fact that randomly oriented discrete inclusions incorporated into fly ash mass improves its load deformation behaviour by interacting with the fly ash particles mechanically through surface friction and also by interlocking. The function of bond or interlock is to transfer the stress from fly ash to the discrete inclusion by mobilising the tensile strength of discrete inclusion. Thus, fibre reinforcement works as frictional and tension resistance element. Further, addition of coir fiber makes the fly ash a composite material whose strength and stiffness is greater than that of unreinforced fly ash.

**IV. CONCLUSIONS**

Based on the present investigation it is concluded that preparation of identical samples of coir fiber reinforced fly ash beyond 1% of fiber content was not possible and hence optimum fiber content is 1 %. The value of stiffness modulus of reinforced fly ash increases with the increase in fiber content and the maximum percentage increase is 103 % over the plain fly ash for fiber content of 1 %. The shear strength parameters (c and  $\phi$ ) of fly ash increases with the increase in

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fiber content. The maximum increase in the values of (c) and ( $\phi$ ) are 61 % and 60 % respectively over the plain fly ash for fiber content of 1 %. The stiffness modulus of reinforced fly ash increases with the increase in confining pressure.

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