STRENGTH BEHAVIOUR OF FIBER REINFORCED FLYASH

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ABSTRACT. Quality Construction materials are not readily available in many locations and, are difficult to transport over long distances which renders the construction costs. On backdrop, over last few years environmental and economic issues have stimulated interest in the development of much alternative material are used that can fulfill design specifications. 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 landfill, as a use of fly ash as replacement to the conventional weak earth material and fibers 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.

In this paper to analyze the behaviour of fiber reinforced fly ash under a varying range of fiber length (6mm, 12mm, 19mm) and fiber percentage (0.5, 1.0, and 1.5). For this series of triaxial tests have been carried out at varying rage of confining pressures from 98.1 kPa to 294.3kPa. An undrained test has been carried out on polypropylene fiber reinforced fly ash. An experimental result indicates that there is a significant effect from the addition of fiber on the mechanical behaviour of fly ash. Particularly, the effect noted is peak stress, strength parameters, and shear strength. The addition of fiber increases the peak stress, shear parameters, and shear strength. Increase in confining pressure also increases the strength but the individual effect of the addition of fibers was more pronounced at high confining pressure.

Keywords: Reinforcement, Tri-axial Test, Fly ash, Shear strength, Confining Pressure.

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INTRODUCTION

Coal based thermal power plants have been a major source of power generation in India, Where 75% of the total power is obtained is from coal based thermal power plants. The coal reserve of India is about 250 million tonnes approximately. About 70% of this is used in power sector only. In India, unlike in most of the developed countries, ash content in the coal used for power generation is 30-40%. High ash coal means more wear and tear of the plant and machinery, low thermal efficiency of the boiler, slogging, choking and scaling of the furnace and most serious of them all, generation of fly ash. India ranks fourth in the world in the production of coal ash by-product waste after USSR, USA and China, in that order. The estimation fly ash generation and it's utilization in India as shown in figure 1. Coal burningelectric utilities annually produce million tons of fly ash as a waste by product worldwide and the environmentally acceptable disposable of this material has become an increasing concern [4]. Due to continuous and high volume of material it requires, the construction industry is often looked upon as a potential consumer of fly ash. On the same note, the construction of highways and roads in India, which has taken a boom in the recent years, requires a huge amount of natural soil and aggregates. To meet this demand ruthless exploitation of fertile soil and natural aggregate is being adopted. This has brought the situation to an alarming state. To address these problems fly ash has been tried in the low lying areas as structural fills and embankment construction for highways. However, due to lack of sufficient knowledge and confidence its use has not taken momentum. The basic andessential parameters of fly ash, to be used either as structural fill or embankment material.

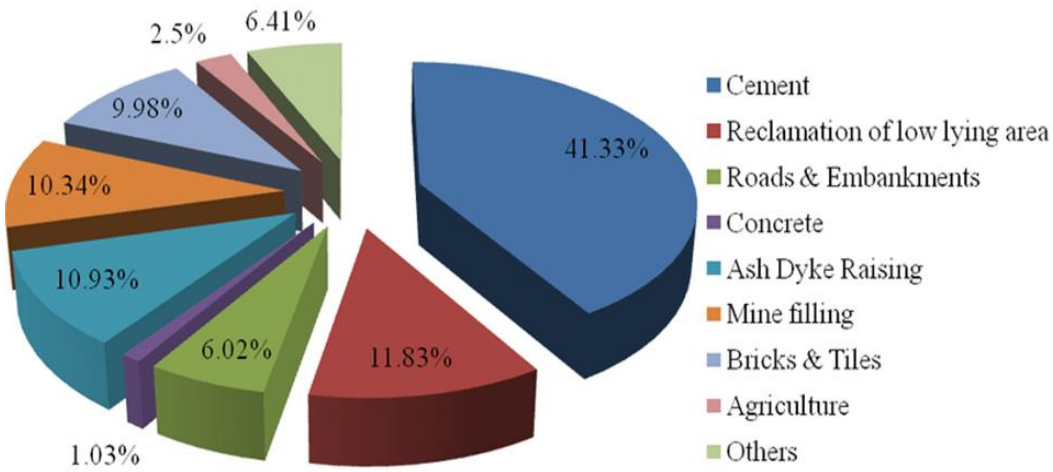

Figure 1 Mode of Fly Ash Utilisation during 2010-11(Source CEA annual report 2012 -2013)

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 stabilization by adding cement, lime or fly ash and reinforcement in form of discrete fibres cause significant modification and improvement in strength characteristics of soils. Fibres are added and mixed randomly with soil or fly ash. Concepts involving the reinforcement of soils using fibres have been used since ancient times. For example, early civilizations added straws and plant roots to soil bricks to improve their properties, although the reinforcing mechanism may have not been fully understood. While building the Great Wall of China, the clay soil was mixed with tamarisk branches. The ancient method of addition of straw of wheat locally called “Turi” to the clay mud plaster is still very popular in villages. Improvement of soil by trees roots is similar to the work fibres. Gray (1947, 1978), Waldron (19770 and Wu et al (1988) reported that plant roots increase the shear strength of the soil and, consequently the stability of natural slopes. Synthetic fibres have been used since the late 1980s, when the initial studies using polymeric fibres were conducted. Specially, triaxial compression tests, unconfined compression tests [1], direct shear tests and CBR tests had been conducted to study the effect of fibre reinforcement on strength characteristics and other engineering properties of fibre reinforced soil. During last twenty – five years, much work has been done on strength deformation behaviour of fibre reinforced soil and it has been established beyond doubt that addition of fibre in soil improves the overall engineering performance of soil. Once of the primary advantages of randomly distributed fibres s the absence of potential planes of weakness that can be developed parallel to oriented reinforcement (Maher, 1990). Among the notable properties that improve are greater extensibility, small loss of post peak strength, isotropy in strength and absence of planes of weakness.

A number of materials have been reported to be successfully used as reinforcements such as steels, geofabrics, geogrids, aluminium, glass fibre, wood, rubber and concrete. In developed countries polypropylene based synthetic fibres and grids are now preferred due to their available with desired properties and durability [2]. However, they are yet to be used widely in India as they are more costly. The reinforcement may take the form of strips, grids, sheet materials, rope and other combinations. The major requirements of the reinforcing materials are strength, durability, ease of handling, high adhesion or friction with soil and availability at low-cost.

Although several researchers have worked on fibre reinforced materials, the most of the reported work has been limited the same range of fibre length or fibre content. [Boominathan and hari (2002), Kaniraj and Gayathri (2003) [10][11], Kumar et al (2005), Jadhao and Nagarnaik (2008), Kumar and Singh (2008), Bhardwaj and Mandal (2008) [2], Viswanadham et al (2009) , Bera et al (2009), Ahmet Senol (2011), H.P. Singh (2011), Vaidya et al (2013) [27]].

MATERIAL AND METHODOLOGY

Fly ash

Fly ash was procured from Guru Gobind Singh thermal power plant, Ropar. The collected samples were mixed thoroughly to get the homogeneity and oven dried at the temperature of 105-110˚C for the preparation of specimen. Figure 2shows the oven dried sample of fly ash.

Figure 2 Oven dried sample of fly ash

The basic properties of fly ash were found out by performing various test i.e. particle size analysis, optimum moisture content, maximum dry density, specific gravity etc. Table1 indicates the index properties of fly ash. Experimental work is carried out as per IS 2720.

Table 1 Index properties of Fly ash

PROPERTY	VALUE
Specific Gravity	2.11
Maximum Dry Density (kN/m^3)	13.89
Optimum Moisture Content	26
Liquid Limit	43
Plastic Limit	Non Plastic
Colour	Grey
Classification	ML
Cohesion (kPa)	38.53
Angle of internal friction ϕ	25.5°

Fibres

Polypropylene fibres shown in Figure 3 are used as the reinforcing material throughout the study. Polypropylene fibres used in the experiment were provided by the Nina Concrete System.

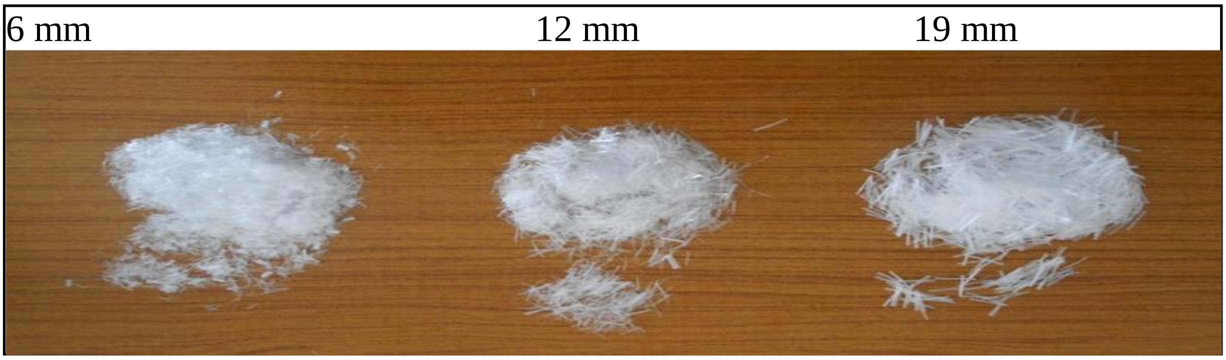

Figure 3 Polypropylene fibres

Pvt. Ltd. The length of the polypropylene fibres used in current investigations is 6mm, 12mm and 19mm. Fibres are of fibrillated type.

Polypropylene is one of the most versatile polymers available with applications, both as a plastic and as a fibre, in virtually all of the plastics and end-use markets. The general properties of the fibre used are given in Table 2.

Table 2 Physical and Mechanical Properties of fibres

PROPERTY	**VALUE**
Specific Gravity	0.9-0.91
Cut Length	6mm, 12mm and 19mm

Water Absorption	0.3% (after 24 hours immersion in water)
Colour	White
pH value	Not applicable
Melting point	165° C
Solubility in water	Below 0.1%
Acid resistance	Excellent
Alkali resistance	Excellent

***** Provided by the supplier (Nina Concrete Systems Pvt. Ltd.)

SAMPLE PREPARATION

Fly ash-Fibre mixture preparation

The Fly ash was first dried at 105-110˚C for the preparation of specimen. The total dry weight of the mixture required to prepare a specimen, W; is known from the specimen's dimension and dry unit weight. W can be expressed as,

$$W = Ws + Wf$$

Where W_s and W_f is weight of the dry fly ash and fibres respectively. To prepare the fly ash-fibre mixture, first the required amount of fly ash and fibres were measures and mixed together in dry state. As the fibres tended to lump together, it requires considerable care and time to separate them to get an even distribution of fibres in the mixture. The dry fly ash-fibre mixture was then mixed with required amount of water. Table 3 shows the maximum dry density and optimum moisture content of the different mixes.

Table 3 Mix combinations and respective MDD/OMC

MIX NAME	FIBRE LENGTH	COMBINATION	MDD (kN/M^3)	OMC %
-	-	100%FA	13.89	26
F1P0.5	6mm	100%FA+0.5%PF	13.64	24
F1P1.0	6mm	100%FA+1.0%PF	13.38	24
F1P1.5	6mm	100%FA+1.5%PF	13.15	26
F2P0.5	12mm	100%FA+0.5%PF	13.19	26
F2P1.0	12mm	100%FA+1.0%PF	13.00	26
F2P1.5	12mm	100%FA+1.5%PF	12.87	26
F3P0.5	19mm	100%FA+0.5%PF	13.15	26

F3P1.0	19mm	100%FA+1.0%PF	12.91	26
F3P1.5	19mm	100%FA+1.5%PF	12.87	26

* FA- Fly ash and PF Polypropylene fibre

Different Mix names are given to the different mixes with different fiber length and varying percentage as shown in Table 3.

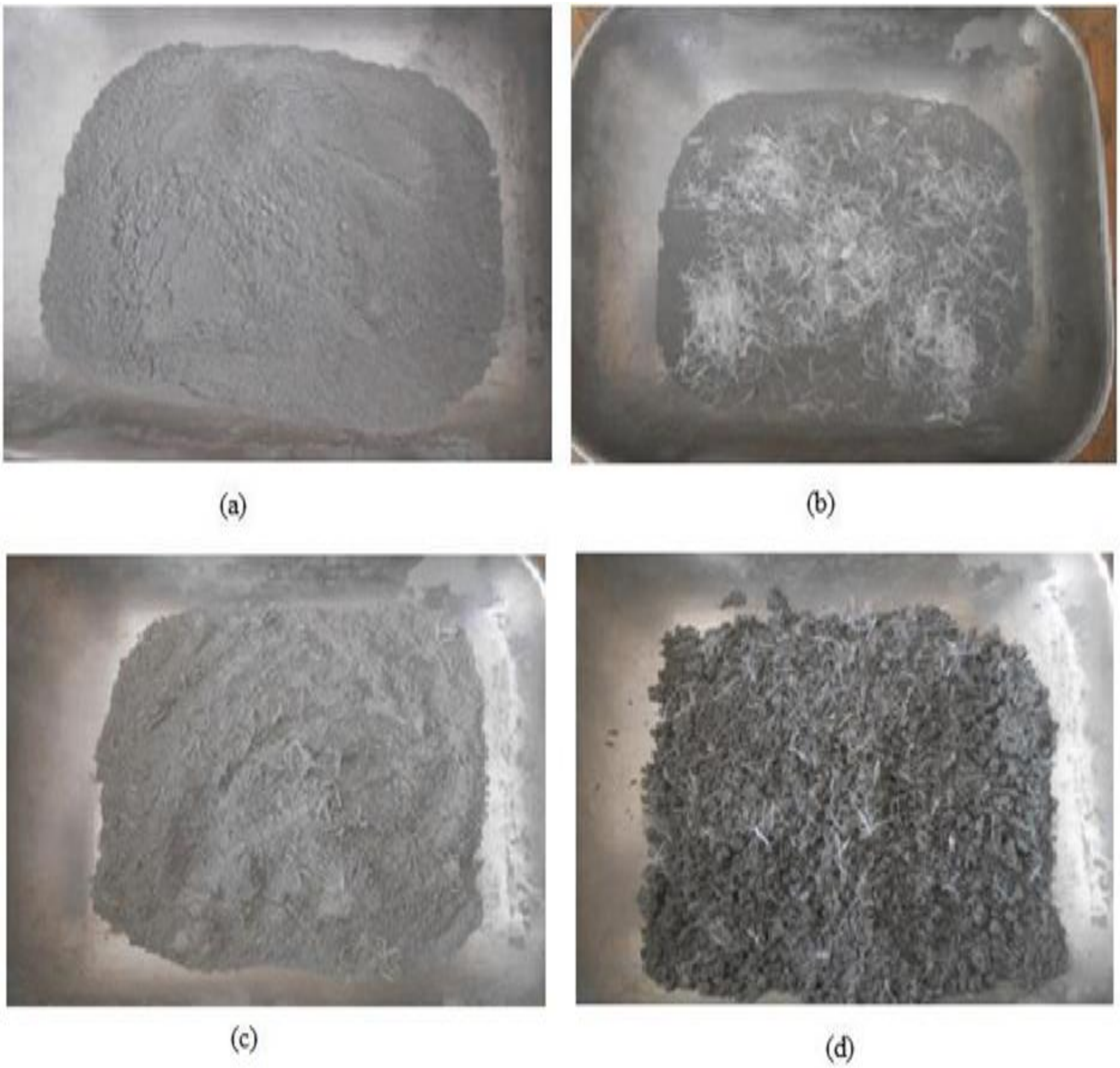

Figure 4 (a) Dry sample of fly ash (b) Fibres dispersed on the fly ash (c) Fibres mixed with fly ash (d) Prepared sample at OMC

Figure 4 (a) shows the oven dried sample of fly ash. Figure 4 (b) and (c) represents the sample dispersed with fiber on it and mixing the fiber with fly ash. Figure 5 (d) presents the fly ash-fiber mixture prepared at OMC.

Specimen Preparation

For triaxial shear tests, A 38 mm inner diameter, 76 mm long metallic mould was used to prepare cylindrical specimens. Samples were prepared by dry blending of fly ash, with required amount of water obtained from Modified Proctor test. All mixing was done manually and proper care was taken to prepare homogeneous mixture at each stage of mixing as shown in figure 6. A few additional grams of fly ash and milliliters of water were taken to provide for losses during preparation of specimen. The compacted specimen was extruded from the mould using Frame extractor. The procedure is preparing and placing the sample in loading frame for the testing as shown in Figure 5.

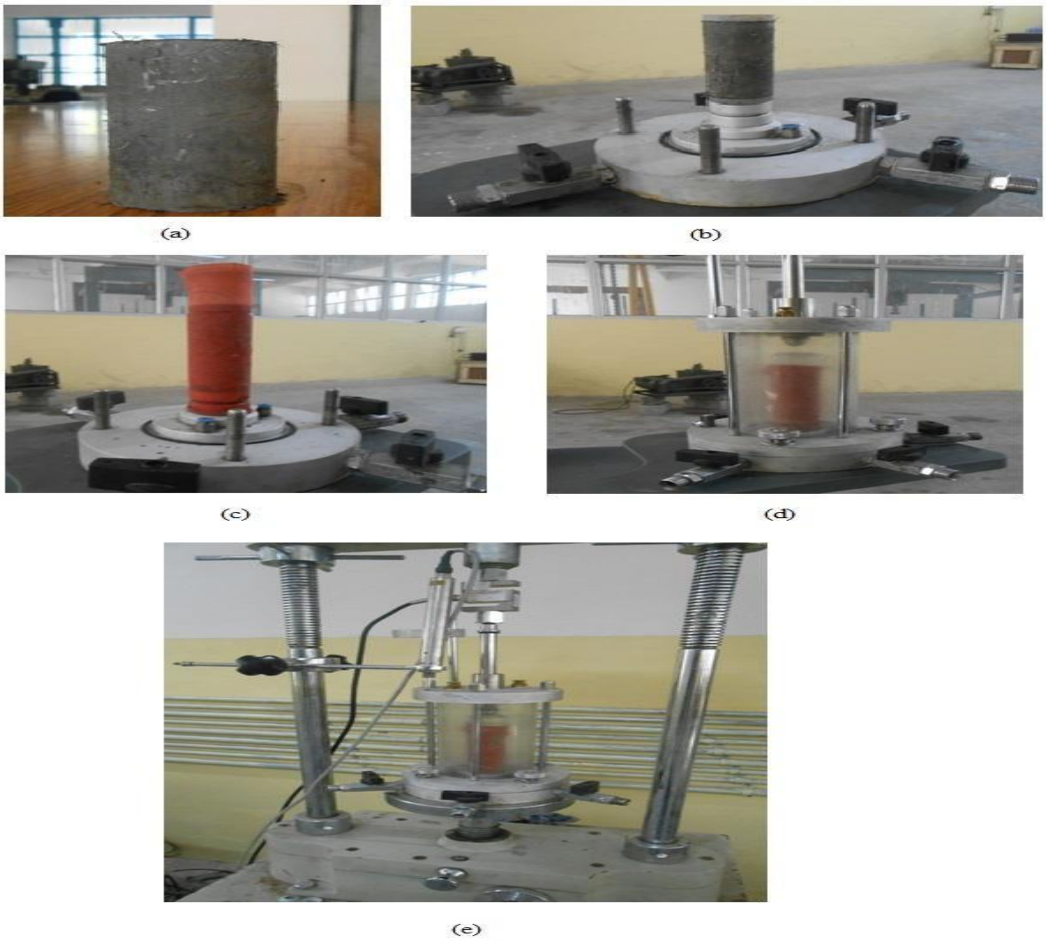

Figure 5 (a) Prepared Specimen (b) Placing over the triaxial cell (c) Putting rubber membrane and ‘O’ ring (d) Enclosing it with Perspex (e) Placing the triaxial cell on loading frame

Testing of Sample

The specimen preparation as well as testing of Unconsolidated Undrained (UU) triaxial compression of fly ash samples has been carried out in accordance with IS 2720: (Part VIII)-1993 using computerized triaxial testing system (Figure 6).
All the specimens have been testes under three different confining pressure of 98.1, 196.2 and 294.3 kPa. All the UU tests are carried out under a deformation-controlled loading mode at a constant rate of 06 mm/min until the specimen failed/strain of 20% whichever was earlier. HEICO computer data logger was used throughout for data acquisition.

Unconsolidated undrained triaxial strength is applicable to situations where the loads are assumed to take place so rapidly that there is insufficient time for the induced pore-water pressure to dissipate and for consolidation to occur during the loading period (that is, drainage does not occur).

Figure 6 Whole Setup of Triaxial test

RESULTS AND DISCUSSION

The Discussion on the results obtained from the experimental work has been made in this section, highlighting the effects of different parameters item-wise also with reference to relevant graph and plots.

Influence of Fibre on Compaction Characteristics

Figure 7is the actual value of the compaction curves which facilitates the compaction characteristics of fly ash with that of the mix proportions madefor the reinforcement of flyash. The Maximum dry density (MDD) of the fly ash is observed as13.89 kN/m^3. Analysis of test results showed that MDD for all the combinations of fibres decreased with the increase in fibre content as well as fibre length as shown in Figure 7. It is observed that addition of fibre content 0.5 % (by weight) decreases the Dry density to 13.64 kN/m^3, 13.19kN/m^3, 13.15 kN/m^3 for 6mm, 12mm and 19mm fibres respectively. Similar inclination is observed for 1.0 % (by weight) and 1.5 % (by weight) of fibre inclusions. MDD values observed for6mm, 12mm and 19mm fibre lengths are 13.38 kN/m^3, 13.00 kN/m^3, 12.91 kN/m^3, and 13.15 kN/m^3, 12.87 kN/m^3, 12.87 kN/m^3 for 1% and 1.5 % fibres respectively. Decrease in MDD values may be due to replacement of flyash with low specific gravity fibres.

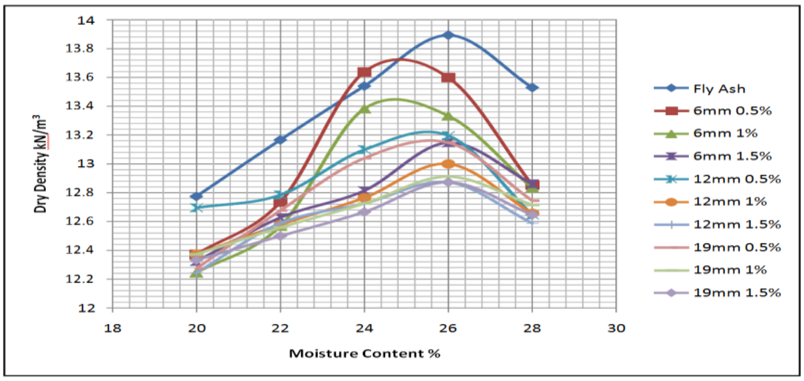

Figure 7 Compaction Curves of Fly ash mixed with Polypropylene fibre in different proportions

For any fibre length, an increase in fibre content causes a reduction in dry density as shown in Figure 8. This may be due to reduction of average unit weight of the solids in the soil fibre mixture.

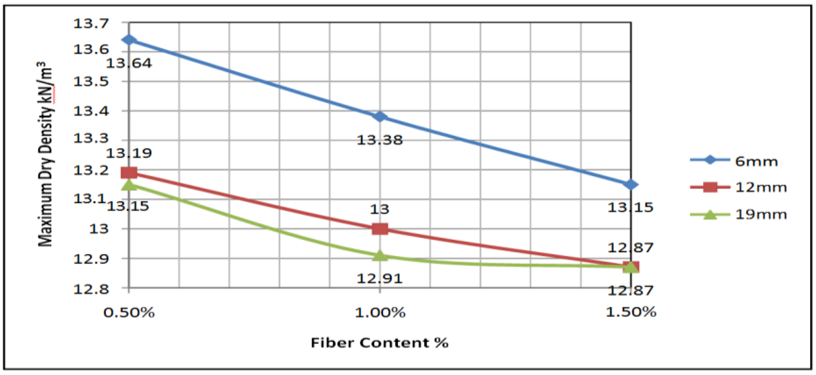

Figure 8 Variation of Maximum Dry Density with different fibre content

Also for any fibre content; an increase in fibre length causes a reduction in dry density. This may be attributed to the fact that the fibre shorter in length has lesser frictional resistance as compared to the fibre longer in length. So fibre shorter in length has less resistance capacity and particle can move easily while compacting thus making the mix denser. But in case of inclusion of longer fibre it contributes more frictional resistance thus making it less dense.

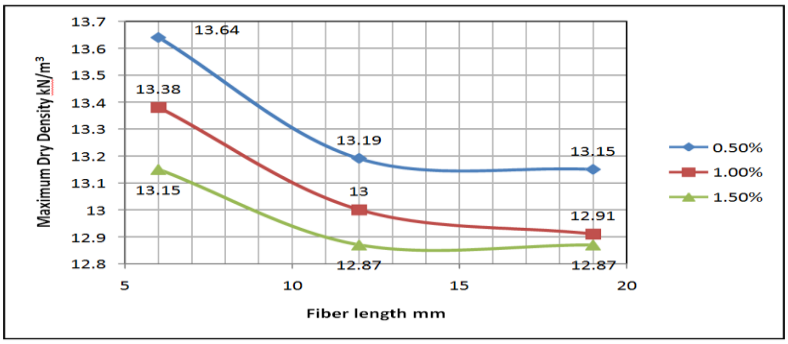

Figure 9 Variation of Maximum Dry Density with different fibre length

The decrease in optimum moisture content for shorter length of fibres can be attributed to the decreased amount of fines which require more water content because of their larger surface area in comparison to the fibre content added in it. For greater length the water absorption capacity of fibre may be the reason for the again increased OMC. The effect on the OMC is not very significant. The differences in the behaviour of the raw and fibre reinforced fly ashes would be only due to the fibre inclusion.

Influence of confining pressure on stress-strain response

The stress-strain curved obtained from triaxial test on fibre reinforced fly ash are shown in Figure 10-18. The stress strain curves shown in the figure reveal that, by the increase in confining pressure there is an increase in stiffness of the material for all pressure ranges. By the gradual increase in the confining pressures it is observed that the tendency to attain peak in the stress-strain curves is being yielded. Moreover, it can be noticed that the peak stress is delayed by the gradual increase in the confining pressures. Hence, it can be said that peak deviator stress increases with an increase of confining pressure and the axial strain at which peak strength has increases as well. For instance, at all the pressure the peak stresses are reached within 5% of the axial strain. It can also be seen that for greater fibre length (19mm) at confining pressure of 98.1 KPa, 196.2 KPa and 294.3 KPa the material has strain hardened and there is no definite peak. As expected, the confining pressure has increased the peak deviator stress, initial stiffness of the specimens. Fibre reinforced fly ash demonstrated a failure mode that is brittle at shorter fibre length and ductility is increased at greater fibre length. The response by the frictional components of the deformation resistance mechanism under higher confining stresses can be reason for increased ductility. The reason for the change further can be augmented by frictional components between ash and fibre. As, Fibre greater in length contributes more frictional resistance comparatively fibre shorter in length. Thus, for the change in failure mode seems to be contribution of both confining pressure and fibre reinforcement.

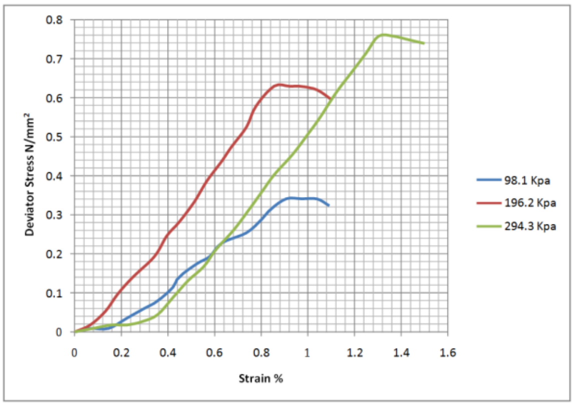

Figure 10 Variation of Deviator stress at different confining pressure at 0.5% fibre content of 6mm length

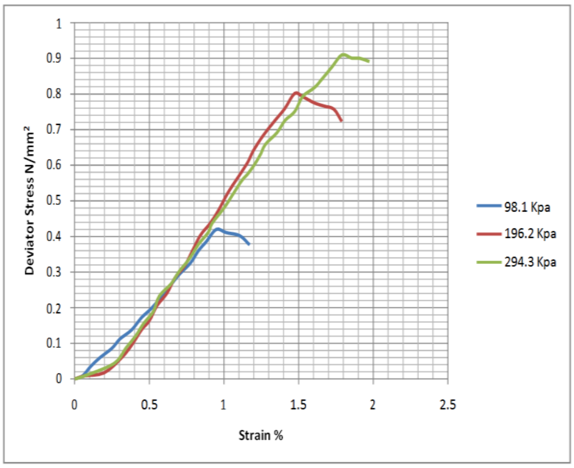

Figure 11 Variation of Deviator stress at different confining pressure at 1.0% fibre content of 6mm length

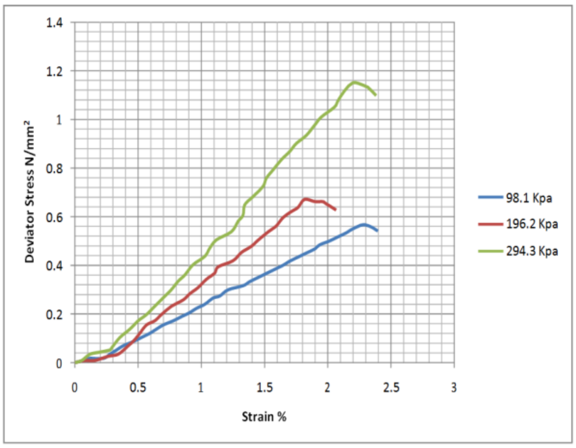

Figure 12 Variation of Deviator stress at different confining pressure at 1.5% fibre content of 6mm length

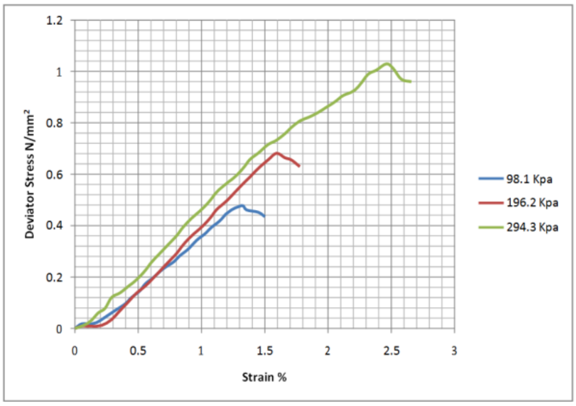

Figure 14 Variation of Deviator stress at different confining pressure at 0.5% fibre content of 12mm length

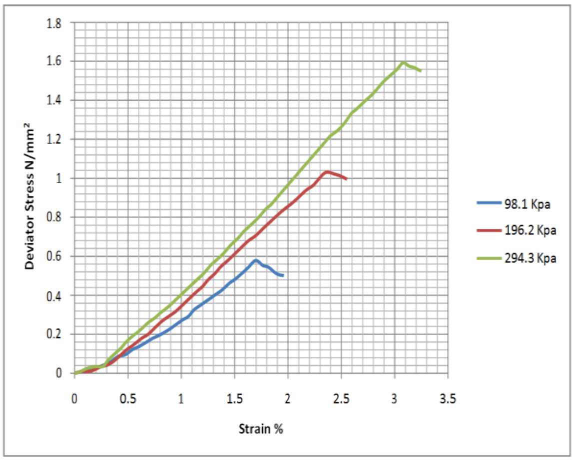

Figure 16 Variation of Deviator stress at different confining pressure at 1.0% fibre content of 12mm length

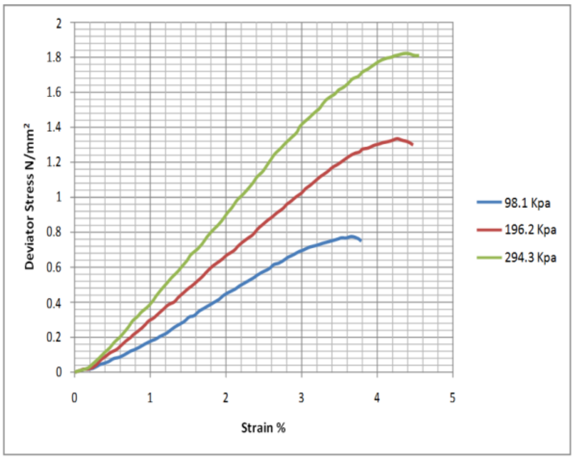

Figure 15 Variation of Deviator stress at different confining pressure at 0.5% fibre content of 19mm length

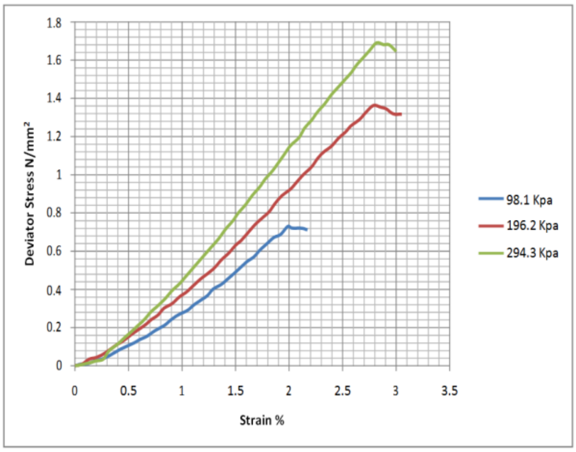

Figure 13 Variation of Deviator stress at different confining pressure at 1.5% fibre content of 12mm length

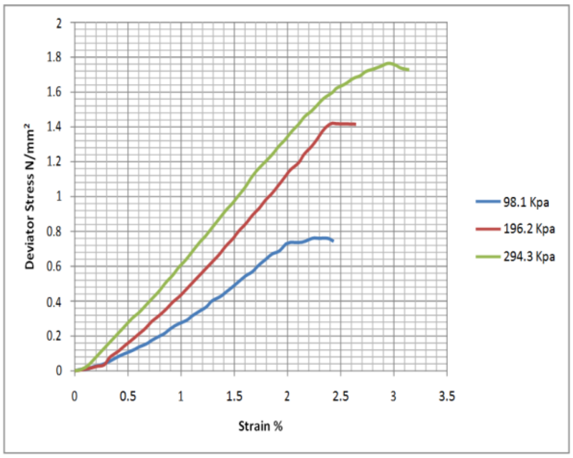

Figure 17 Variation of Deviator stress at different confining pressure at 1.0% fibre content of 19mm length

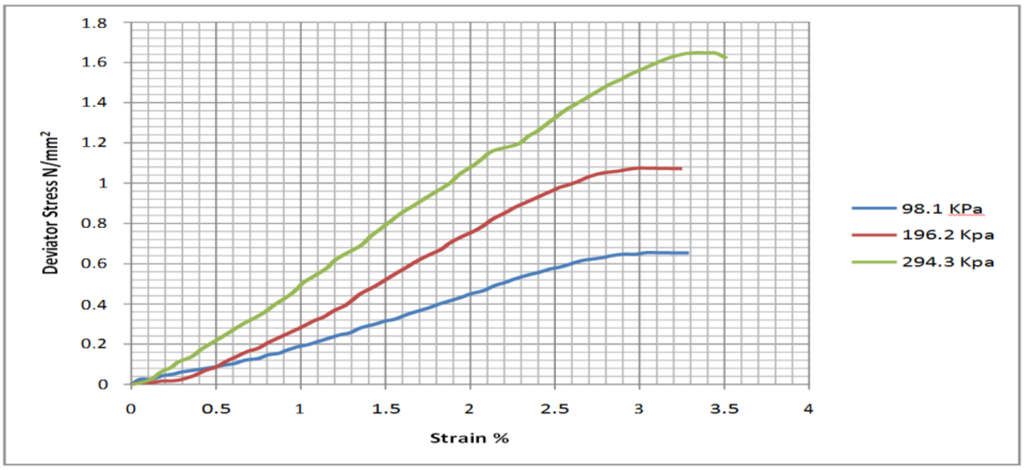

Figure 18 Variation of Deviator stress at different confining pressure at 1.5% fiber content of 19mm length

Modes of Failure

A failure mode is the manner where by the failure is observed. Generally, it describes the way in which the failure happens. Traditionally failure in compression is categorized in two modes. In the first, a sample may show strain localization and fail by strain softening and brittle failure under relatively low confining pressure. Moreover, in the second, it may show barrelling and fail by strain hardening under elevated confining pressure. While at intermediate pressures, a transitional regime is sometime observed, with failure modes involving complex localized features such as conjugate shearbands.

Considering the effect of addition of fibre content, fibre length, the failure conditions were examined on the bases of the laboratory investigations. It was observed that the ductile behaviour increased with the increasing content of fibre and increase in confining stress. The mode of failure for a specimen with increasing fibre content is shown in Figure19

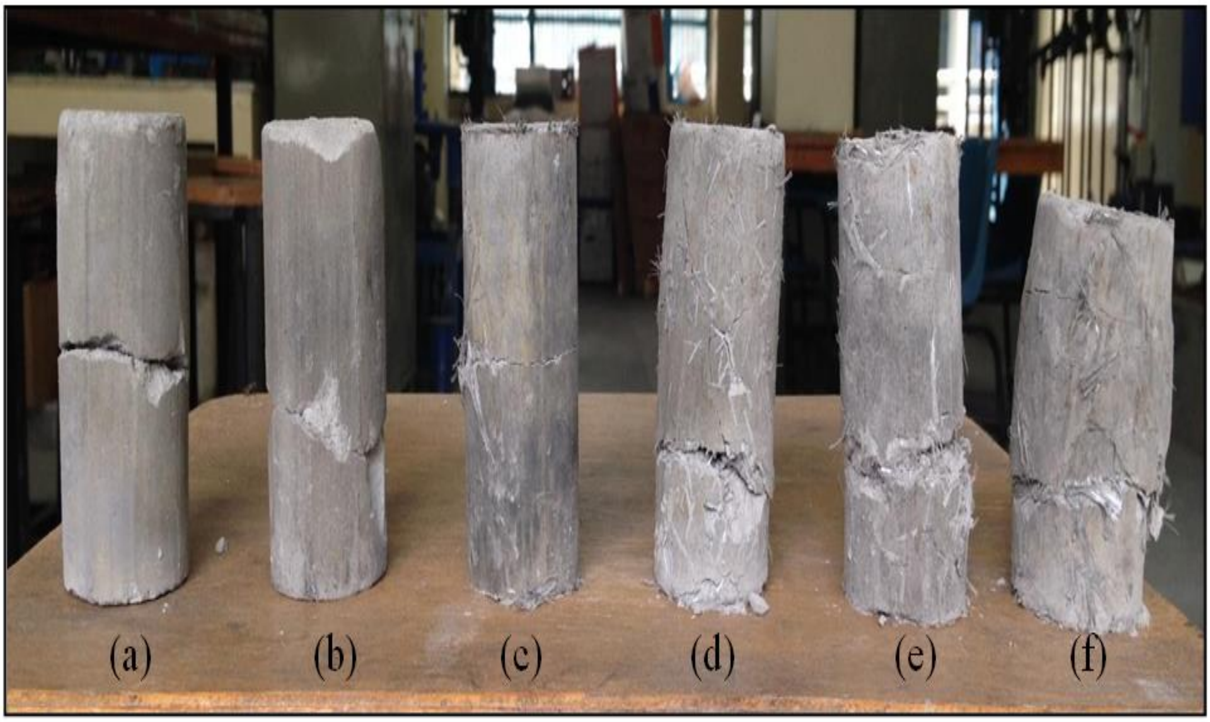

Figure 19, Mode of failure: (a) Fly ash at 98.1 KPa (b) Fly ash at 196.2 Kpa(c) 6mm at 0.5% at 196.2 KPa (d) 6mm at 1.5% at 294.3 KPa (e) 12mm at 1% at196.2 KPa (f) 19mm at 0.5% at 294.3 Kpa

Influence of Fibre on shear strength parameters

To determine the value of shear strength parameters (c and ϕ) of reinforced fly ash for various fibre content, a number of failure envelope (stress path) were drawn as shown in Figure 20-25 and shear strength parameters were computed by using these plots as shown in Table 4.It is observed that with the increase in fibre content as well as fibre length the value of c and ϕ increases. The value of ϕ is observed as consistently increasing with the inclusion of fibre up to 12 mm fibre after that inclusion of fibre has no tangible effect on the value of ϕ. Also the value of c is increasing with the fibre inclusion but no trend is observed. The increase in shear strength parameters of fly ash due to inclusion of polypropylene fibre 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 mobilizing the tensile strength of discrete inclusion. Thus, fibre reinforcement works as frictional and tension resistance element. Further, addition of fibre makes the fly ash a composite material whose strength is greater than that of unreinforced flyash.

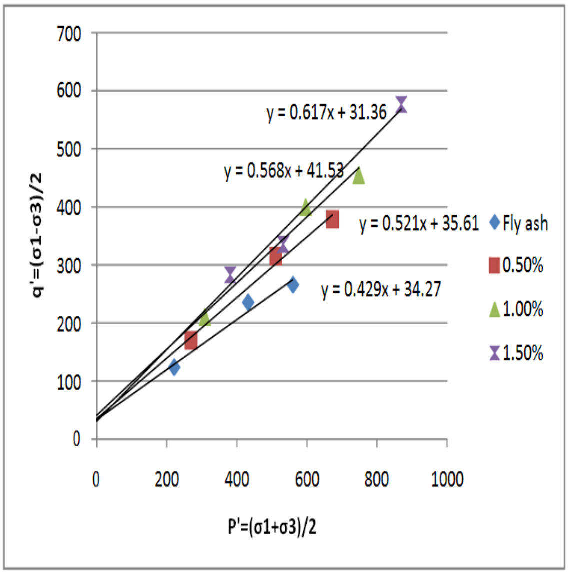

Figure 20 p-q plot comparison of 6mm length fibre at different fibre content

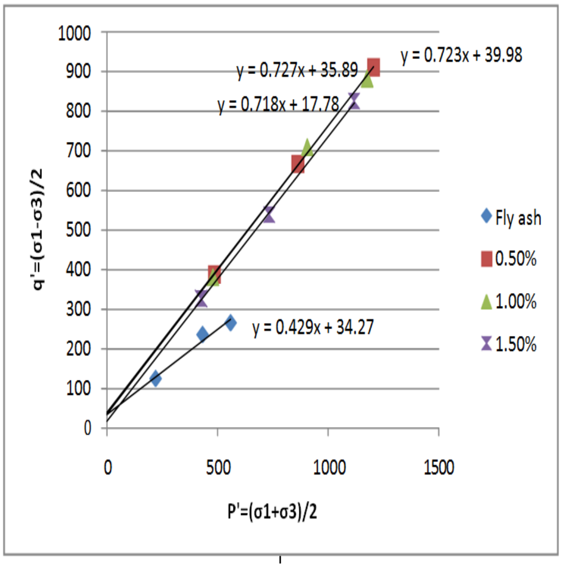

Figure 21 p-q plot comparison of 19mm length fibre at different fibre content

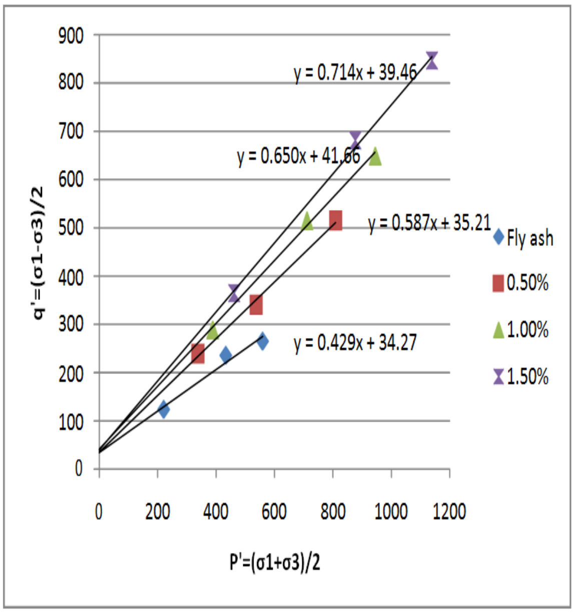

Figure 22 p-q plot comparison of 12mm length fibre at different fibre content

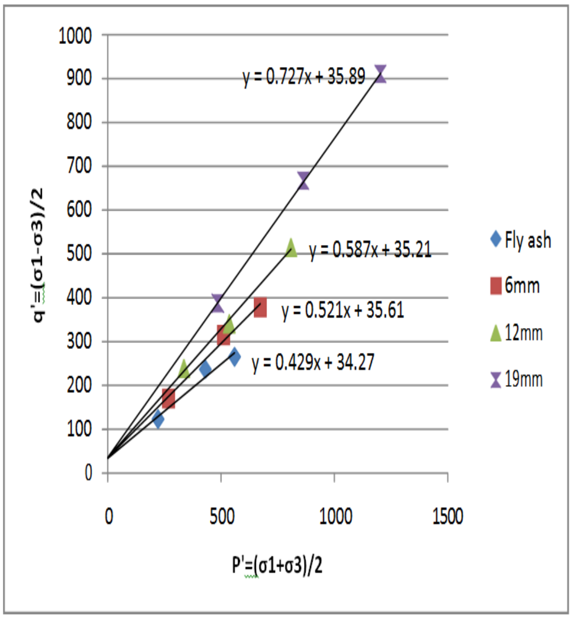

Figure 23 p-q plot comparison of different fibre length 0.5% fibre content

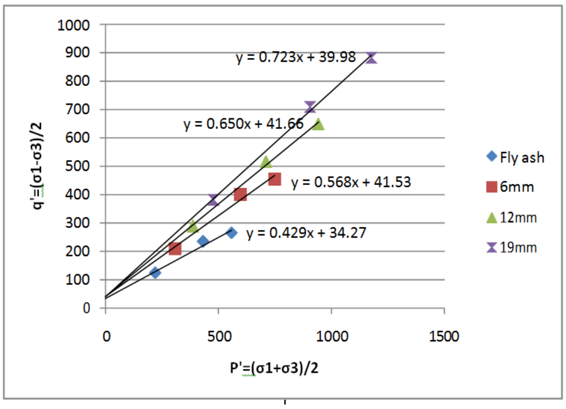

Figure 24 p-q plot comparison of different fibre length 1.0% fibre content

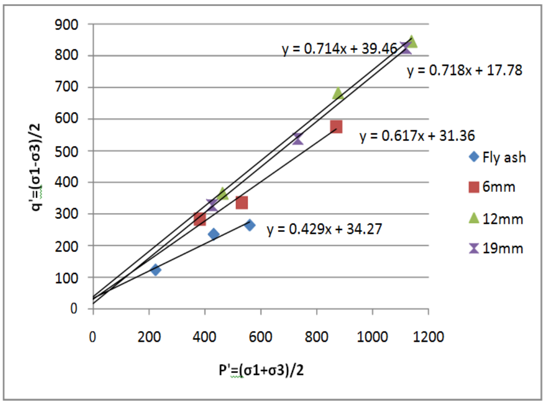

Figure 25 p-q plot comparison of different fibre length 1.5% fibre content

Table 4 Shear strength parameters (Unconsolidated Undrained) computed using stress path method

FIBRE LENGTH	COMBINATION	C (KN/M^2)	Φ(DEGREES)
-	100FA	38.53	25.5
6mm	100FA+0.5%PF	41.74	31.4
6mm	100FA+1.0%PF	50.50	34.7
6mm	100FA+1.5%PF	39.60	38.1
12mm	100FA+0.5%PF	43.51	35.9
12mm	100FA+1.0%PF	53.99	40.6
12mm	100FA+1.5%PF	56.45	45.6
19mm	100FA+0.5%PF	52.31	46.7
19mm	100FA+1.0%PF	57.87	46.3
19mm	100FA+1.5%PF	25.68	45.9

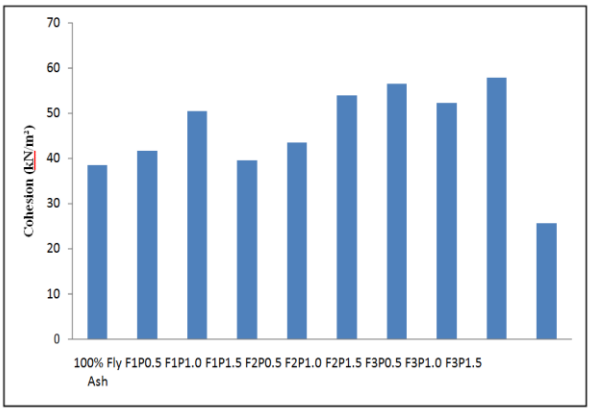

Figure 26 Comparison of cohesion values of different mix combinations

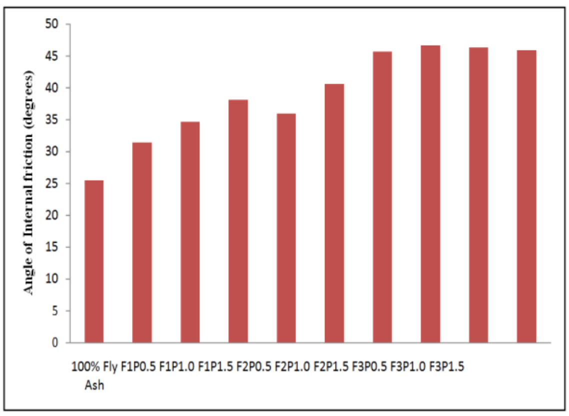

Figure 27 Comparison of angle of internal friction values of different mix combinations

Table 5 gives the shear strength using Mohr-Coulomb equation. Fly ash solely possesses very low shear strength. It can be observed that the increase in shear strength is very much prominent for the fibre greater in length but higher shear strength observed in the work is for 19mm fibre length at 0.5% and 1% fibre content following 12mm fibre length at 1.5%. For higher percentage drop in shear percentage might be due to the reason that the balling of fibre takes place inside the specimen.

Table 5 Shear strength of different combinations

FIBRE LENGTH (mm)	FIBRE %	COHESION(C) (KPA)	ANGLE OF INTERNAL FRICTION (Φ) (DEGREE)	CONFINING PRESSURE (Σ_3) (KPA)	MAJOR PRINCIPAL STRESS AT FAILURE (Σ_1) (KPA)	SHEAR STRENGTH ($S = C + \Sigma_1 \tan \Phi$)(KPA)
-	0	38.53	25.5	98.1	345.64	203.3
				196.2	666.86	356.42
				294.3	824.51	431.57
6	0.5	41.74	31.4	98.1	439.03	309.56
				196.2	825.95	545.58
				294.3	1051.81	683.37
6	1	50.5	34.7	98.1	518.14	409.04
				196.2	997.72	740.9
				294.3	1203.74	883.46
6	1.5	39.6	38.1	98.1	664.74	560.46
				196.2	867.48	719.32
				294.3	1445.42	1172.17
12	0.5	43.51	35.9	98.1	576.36	460.45
				196.2	877.52	678.3
				294.3	1324.15	1001.39
12	1	53.99	40.6	98.1	676.6	633.49
				196.2	1227.16	1105.03
				294.3	1593.69	1418.95
12	1.5	56.45	45.6	98.1	827.58	900.87
				196.2	1559.09	1647.25
				294.3	1984.83	2081.66
19	0.5	52.31	46.7	98.1	873.51	978.49
				196.2	1530.14	1674.71
				294.3	2115.33	2295.18
19	1	57.87	46.3	98.1	859.56	956.62
				196.2	1615.11	1746.6
				294.3	2058.14	2209.82
19	1.5	25.68	45.9	98.1	752.62	801.69
				196.2	1270.86	1336.04
				294.3	1942.84	2028.91

CONCLUSIONS

In this paper has investigated the behaviour of fibre reinforced fly ash to improve the mechanical properties. On the basis of the results of this work, the following conclusions may be deducted:

1. Fly ash is a non-plastics lightweight having specific gravity relatively lower than similar graded conventional earth materials.
2. There was no tangible effect of fiber inclusion on optimum moisture content fly ash and it remained unchanged. However there was slight decrease in Maximum Dry Density of Fly Ash.
3. The inclusion of fiber reinforcement in fly ash caused an increase in peak deviator stress, axial strain at failure, weakens the brittle behaviour of reinforced fly ash.
4. The Results of the triaxial Tests performed on fly ash show that addition of fiber content could improve the strength of fly ash under undrained condition. Shear strength parameters increases in the UU tests, due to addition of fiber.
5. The addition of fibers also induced cohesion in fly ash. The cohesion increase from 38.53 kPa in unreinforced fly ash to 57.87 kPa in fly ash reinforced with 19 mm at 1%.The strength envelopesis appeared to be straight-line at low confining pressure and with the increasing confining pressure becomes slightly curved.
6. The significant increase the value of angle of internal friction can be seen as it reaches up to 45.9 degree with inclusion of 19mm fibre at 1.5% as comparatively 25.5 degree of unreinforced fly ash.
7. The addition fiber content in the fly ash can markedly augment the strength. The result shows enhancement. These features become more pronounced with increase fiber content and prevail event under high confining pressure. The percentage increase in cohesion in fly ash due to addition of fibre is 50% utmost. The reduction in strength due to the addition of fibre is observed only for fibre length 19mm at 1.5%.
8. Also the addition of fibre in fly ash showed the prominent effect on the increase in percentage of angle internal friction. The percentage increase in ϕ is 83.0 % for fibre length 19 mm with 0.5 % fibre content at utmost.
9. Inclusion of fibres gives ductility to the specimen as and hence higher strength values.
10. The stabilization of fly ash with polypropylene fibres is effective in order to enhance strength parameter.

It can be concluded thet the waste material such as fly ash can be used effectively in the engineering constructions.

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