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A Comprehensive Study on Reinforced Flyash and concrete composites

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ABSTRACT

This paper presents the comprehensive study of Reinforced Flyash and mechanical properties of concrete with fibre reinforced fly ash. Using fly ash as a partial alternate for cement in concrete construction has become popular, mainly because of its accessibility and economic in large volume construction. But, the resulting deficiency in performance of the concrete has been a cause of concern, and in this study, it is proposed to introduce some content of fibers adaptively to compensate for strength. An experimental program was carried out with fly ash, fiber content and layers as parameters. The fly ash content is varied from 0 % to 30% and the fiber content from 0 to 0.60%. It was found that the loss due to introduction of fly ash could be easily compensated through fibers. This study has been carried out to have a proper estimate of the feasibility of use of polypropylene fibers and the effect of fiber length and fiber content in concrete to perform better structural properties. The use of fibres improves specific material properties of the concrete, impact resistance, flexural strength, toughness, fatigue resistance, and ductility.

Keywords: flyash, concrete, composites, reinforced, fibre.

INTRODUCTION

The quantity of fly ash produced from thermal power plants in India is approximately 80 million tons each year. The infrastructure needs of our country is increasing day by day and with concrete is a main constituent of construction material in a significant portion of this infra-structural system, it is necessary to enhance its characteristics by means of strength and durability. It is also reasonable to compensate concrete in the form of using waste materials and saves in cost by the use of admixtures such as fly ash, silica fume, etc. as partial replacement of cement. One of the many ways this could be achieved by developing new concrete composites with the fibres which are locally available that makes even non-engine. Construction of buildings and other civil engineering structures on weak soil is highly risky because such soil is susceptible to excessive settlements due to its poor shear strength and high compressibility. There are also advantages in using randomly distributed fibres as these are added and mixed randomly in much the same way as cement or other additives, also randomly distributed fibres limit potential planes of weakness that can develop parallel to oriented reinforcement. The use of fly ash in concrete is found to affect strength characteristics adversely at early age. One of the ways to compensate for the early-age strength loss associated with the usage of fly ash is by incorporating fibres, which have been proved very efficient in enhancing the strength characteristics of concrete. The addition of fibres to concrete considerably improves its structural characteristics such as static flexural strength, impact strength, tensile strength, ductility and flexural toughness. For long term, strength and toughness and high stress resistance, steel fibre reinforced concrete (SFRC) is increasingly being used in structures such as flooring, housing, precast, tunnelling, heavy duty pavement and mining. Fly ash is finely divided residue resulting from the combustion of powdered coal and transported flue gases and collected by electrostatic precipitator.

Fly ash is the most widely used pozzolanic materials all over the world. Fly ash was first used in large scale in the construction of Hungry Horse dam in America in the approximate amount of 30 percent by weight of cement. In recent time, the importance and use of fly ash in concrete has grown so much that it has almost become a common ingredient in concrete, particularly for making high strength and high performance concrete. Extensive research has been done all over the world on the benefits that could be occurred in the utilization of fly ash as a supplementary cementitious material, High volume flyash concrete is a subject of current interest all over the world. The use of flyash as concrete admixture not only extends technical advantages to the properties of concrete but also contributes to the environmental pollution control. In India alone, we produce about 75 million tons of flyash per year the disposal of which has become a serious environmental problem. The effective utilization of fly ash in concrete making is therefore attracting serious considerations of concrete technologies and government departments.

Concrete has also ability to get cast in any form and shape. The prevention of prolongation of cracks under load can result in improvement in static and dynamic properties of cement based matrix. It has been found that the addition of small closely spaced and uniformly distributed fibers to concrete would act as crack arrestors and substantially improve the tensile strength, cracking resistance, impact strength, wear and tear and fatigue resistance All basic ingredients of concrete are natural origin. But the properties of concrete can be change by adding some special natural or artificial ingredients. The concrete has many advantageous properties such as good compressive strength, durability, impermeability, specific gravity and fire resistance. However the concrete has some bitter properties, like- weak in tension, brittleness, less resistance to cracking, lower impact strength, heavy weight, etc. Some remedial measures can be taken to minimize these bitter properties of concrete. The some of the bitter properties of concrete are due to micro cracks at mortar aggregate interface. To overcome this, the fibers can be added as one of the ingredients of concrete. The fibers inclusion in cement base matrix acts as unwanted micro crack arrester.

Many a times the industrial wastes (flyash, blast furnace slag etc.) also termed as an artificial soil, if available locally and found suitable can reduce the construction cost significantly apart from encouraging the sustainable development and reducing the environmental problems.

LITERATURE REVIEW

Many researchers have investigated the use of fly ash as sub base material as partial or full replacement with some additive reinforcements for better performance. Also researches have been carried out for increasing the shear strength of Fly Ash by addition of different fibres (Jute fibre, polypropylene fibre, polyester fibre etc.) as reinforcements. Different fibres with different combinations are used according to their physical, chemical properties and it is decided whether these fibres are suitable or not in general use as reinforcements for fly ash or fly ash soil mixture.

Characterization of Fly Ash

Acquiring open lands for disposal in developing countries like India is difficult due to small land to population ratio. Flyash produced by Indian coal based TPPs is around 90x106 tonnes per year requiring an area of 265 km2 as ash pond (Das and Yudhbir 2005) for safe disposal and presently less than 15% of this flyash is being gainfully utilized.

Gray and Ohashi (1983) have investigated on RFDS, they reinforced the dry sand (Dr= 20% and 100 %,) with reed, polypropylene and copper fiber. Their direct shear test result shows that the shear strength soon reaches a limiting level in all type of fiber.

Lindh and Eriksson (1990) have reinforced the sand (Cu= 3.5 and D50=0.5mm) with monofilament polypropylene fibre at fibre content of 0.25% and 0.5%. They were conducted a field experiment by placing a reinforced sand layer on the existing road surface for field experiment. Their result shows that no rutting is taken place.

Maher and Gray (1990) have reinforced the coarse sand of nine types at Cu=1 to 4, D50=0.09 to 0.65mm, 10% moisture content with rubber (dia=1.1mm,ar=20, fl=22mm), glass (dia=0.3mm, ar=60, 08, 125, fl=45mm), reedfiber (dia=0.3, ar=20, f=18, 24, 38mm). Their Drain triaxial tests shows that low modulus fibres(rubber) contribute little to strength despite higher interface friction. Faliure surface are plain and oriented at (45+Φ/2).An increase in particle sphericity is higher in critical confining pressure and lower fibre contribution. Higher aspect ratio resulted lower confining pressure and increasing shear strength.

Martin et al (1990) studied the different properties viz. Compaction, Shear strength, Compressibility and permeability of fly ashes for using it in embankments or building fills material. They suggested that it is probable that fly ash, available at little or no cost, will often be quite competitive with customary common fill materials.

Kaniraj and Havanagi (2001) made correlations for MDD and OMC for both light and heavy compaction. The correlation for MDD in terms of OMC and G and that between MDD and OMC might be expressed in the form of log-log, exponential and linear curves and can be used to make a preliminary estimate of the of the likely range of MDD and OMC if the specific gravity of fly ash is known.

N.S. Pandian (2004) carried out review of characterization of fly ash with reference to geotechnical application. He summarized that fly ash with some modification/additives can be effectively utilized in geotechnical applications.

Kaniraj and Gayathri (2004) studied the Permeability and Consolidation characteristics of compacted Fly ash. The testing program included the compaction test, permeability test, consolidation test for characterization. Unconsolidated Undrained (UU) Triaxial test, Consolidated Drained(CD) Triaxial test, Unconfined Compression Test were performed for computing shear strength parameters. The results showed that coefficient of permeability and consolidation of the compacted fly ash was comparable to those of Non-plastic silts. The variation in head loss across the specimen had only a small influence on the coefficient of permeability. Even at a high effective stress there was no appreciable reduction in the coefficient of permeability.

Das and Yudhbir (2006) made the comparative study of geotechnical properties of low calcium and high calcium fly ash, to evaluate their suitability as embankment materials and reclamation fills. Compared to low calcium fly ash, Optimum Moisture Content (OMC) is low and Maximum Dry Density (MDD) is high for high calcium fly ash. They gave that the gain in strength with time for high calcium fly ash is very high compared to that of low calcium fly ash due to presence of reactive minerals and glassy phase. Also the mode and duration of curing have significant effect on strength and stress-strain behaviour of compacted fly ash.

Pal and Ghosh (2009) studied the shear strength properties of some Indian Coal ashes. They conducted the Unconsolidated Undrained Triaxial test on the collectively set of nine fly ash, bottom ash and pond ash samples collected from different thermal power plants in India. All the specimens were tested under three different confining pressures of 100, 200 and 300 kPa. They concluded that value of ϕuu and Cuu vary within range of 29.91°–36.93° and 14.31–59.59 kPa respectively. They also concluded that fly ash achieves most of its shear strength from internal friction and exhibits some amount of apparent cohesion.

Raju Sarkar et al (2011) carried out series of test on the coal ashes collected from different power plants for assessing its behaviour when used in geotechnical engineering applications.

Polypropylene fibres

Boominathan and Hari (2002) studied the effect on the Liquefaction strength of the fly ash with the inclusion of randomly distributed fibres. Two forms of reinforcement namely; fibre and mesh; made from non proven polypropylene geogrid sheets was used in the study. The effects of parameters such as fibre content, fibre aspect ratio, confining pressure, cyclic stress ratio on liquefaction resistance of fly ash have been studied. The results showed that the gain in liquefaction of fly ash due to mesh/fibre reinforcements is more pronounced at lower confining pressures.

Kumar et al (2005) studied the effect of inclusion of polypropylene fibres with fly ash. CBR tests, Triaxial shear test, Plate Load test and Field CBR tests were carried out to investigate the effect of fibres.

Jadhao and Nagarnaik (2008) studied the influence of the polypropylene fibre on the engineering behaviour of Soil, Soil-Fly ash mixtures and Fly ash. They conducted a series of Unconfined Compression Strength test (UCS) for evaluating the relative gain in strength and ductility. Specimens were made with polypropylene fibres at 0%, 0.5% 1.0% and 1.5% by dry weight with varying length 6mm, 12mm and 24mm. The results showed that the inclusion of randomly distributed fibres significantly increased UCS, residual strength and absorbed energy of the mixtures. Figure 1 shows the typical stress strain relationship observed with different fibre content mixed with fly ash.

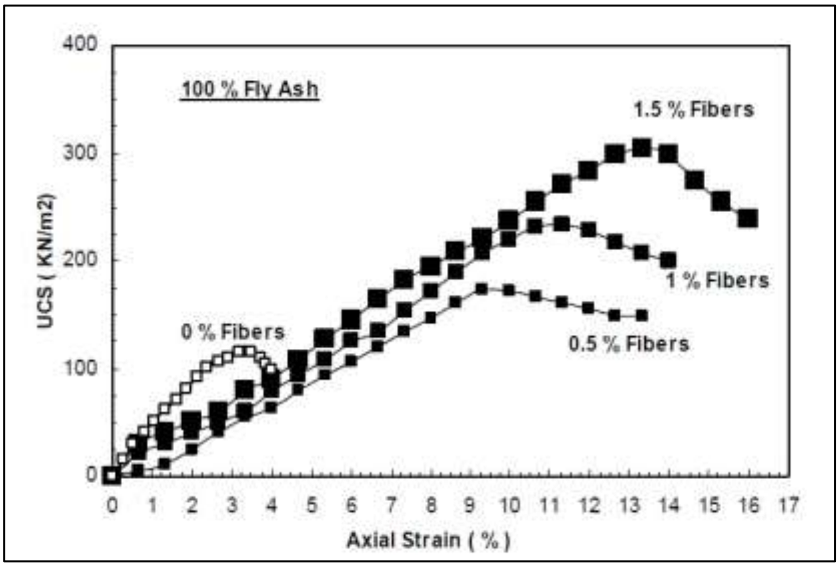

Figure 1 Typical stress strain relationship of fly ash with different fibre content

Kumar and Singh (2008) carried out the experiments to study the effect of polypropylene fibres reinforcement on conventional parameters of fly ash such as Unconfined Compressive Strength, CBR, Shear strength and Modulus of elasticity. The results showed that the UCS, CBR value of fly ash, deviator stress at failure and modulus of elasticity for a given fibre content, increases with the increase in aspect ratio up to 100, thereafter the gain in strength is smaller. Also the fly ash CBR comes out to be 8.5%, so it cannot be used as sub-base as such; so the fly ash reinforced with fibre is suitable for road sub-bases.

Bhardwaj and Mandal (2008) studied the effect of Polypropylene fibres on the fly ash slopes. The polypropylene fibre of 1 % by dry weight was used with fly ash for the experimental work. Proctor compaction test, direct shear test and

Unconfined compression test was performed without and with fibres. Centrifuge test was also performed at 80% compaction effort to observe the effect of fibre reinforcement taking slope angle (θ = 78.6°). It was observed that shear strength of fly ash increases due to fibre reinforcement. Also Polypropylene fibre reinforcement reduces the vertical displacements. To verify the experimental results, Finite Element Analysis based software PLAXIS was used and it showed the same trend of increase.

Ahmet Senol (2011) investigated the effect of the fly ash and polypropylene fibres content on the soft soils. Fly ash and polypropylene fibres are mixed with soil in the proportion 0, 10, 15 % and 0.5, 1.0, 1.5 % respectively by dry weight of soil. Test included in the study are Compaction Test (Standard Proctor Test), unconfined compression Test, California Bearing Ratio Test. The results showed that Polypropylene fibres had the lowering effect on the MDD and OMC of the fly ash-soil mixtures. He concluded that Polypropylene fibres act as reinforcement to the soil and prevents the formation of cracks and inclusions of fibres results in the material having a ductile behaviour.

H.P. Singh (2011) carried out the experiments with varying proportions (0 to 1%) of synthetic polypropylene fibres of fibrillated type. It was found that inclusion of fibres has significant effect on the shear strength parameters as well as on the CBR value. Figure 2 shows the trend observed of stress-strain curve for reinforced fly ash at different fibre content.

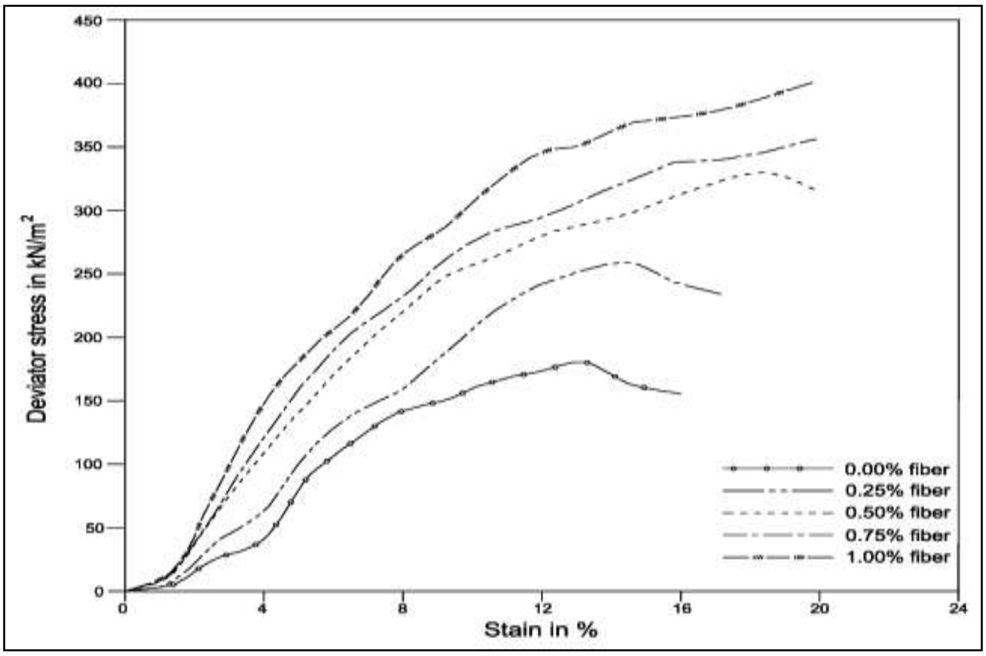

Figure 2: Stress-Strain Curve for Reinforced Fly ash at 50 kPa Confining Pressure

Polyester fibres

Kaniraj and Gayathri (2003) conducted a set of experiments on the fly ash of different thermal power plants with randomly oriented polyester fibres inclusion. Polyester fibres used in the experiments are of 6mm and 20mm length at1% of the dry weight of fly ash. They observed that the fibre inclusion increased the MDD and decreased the OMC. Also the increase in shear strength parameters C_{uu} and ϕ_{uu} is observed.

Moinul and saiful (2012) studied the effect of fly ash on strength development of mortar and optimum use of fly ash in mortar. Fly ash mortar mix with cement replacement level upto 50% exhibit satisfactory results for both compressive and tensile strength. The optimum fly ash content may be about 40% of cement.

Baboo et al (2012) studied the properties of fresh and hardened waste virgin plastic concrete sand was partially replaced by waste plastic flakes in 0%, 5%, 10%, 15% by volume with and without Complast SP320 superplasticizer. They observed that compressive strength values of waste plastic concrete mixtures decreased at all curing age, the compressive strength tends to increase by 5% when superplasticziers was added to the waste plastic mix concrete. Flexural strength was decreased with the increase in percentage of plastic waste.

Nibudey et al (2013) carried out the experimental work by using material like polyethylene terephthalate (PET) plastic waste. The plastic waste were added from 0% to 3% with 0.5% variation. It was observed that inclusion of fibers content affects flow properties of concrete. The density was also affected but made concrete slightly light weight material. The optimum strength was observed at 1% of fiber content for both compressive and split tensile strength, there after reduction in strength was observed.

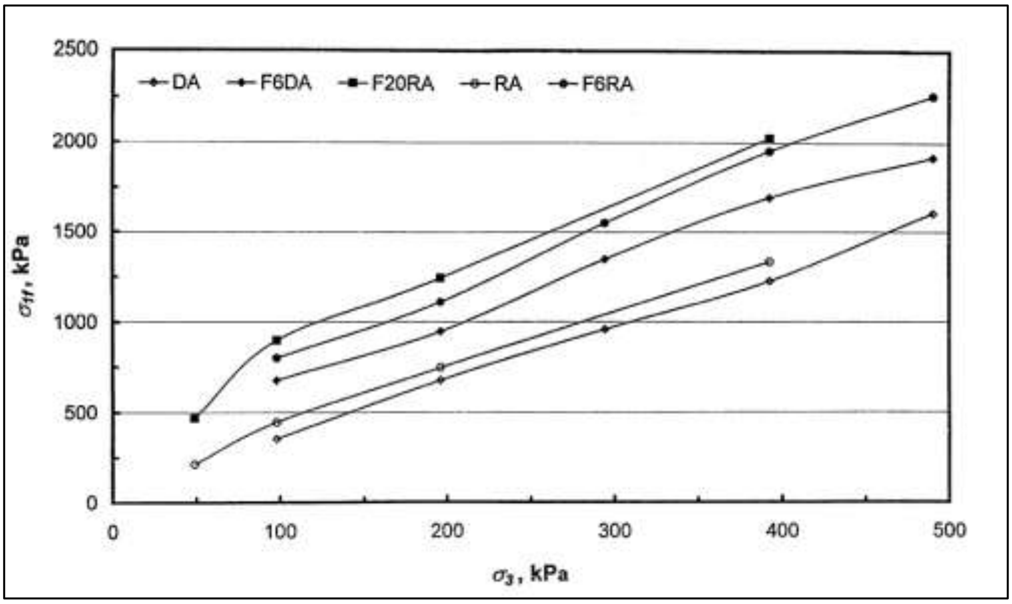

Figure 3: Variation of axial stress at failure with confining stress in UU tests

Jute Geotextile

Bera *et al* (2009) studied the effect of different parameters viz., degree of saturation, size of samples, and number of geotextile layers and age of sample on Unconfined compressive strength of fly ash. A series of Unconfined compressive strength (UCS) tests were conducted on unreinforced fly ash as well as fly ash reinforced with jute geotextile layers. The test results showed that value of UCS are maximum at degree of saturation of 70-75%. The effect of sample size on the value of UCS for unreinforced fly ash is insignificant, whereas with the increase in diameter of sample, value of UCS increase in case of reinforced fly ash. With the increase in number of jute geotextile layers for reinforced fly ash samples, value of UCS increase and maximum enhancement is found to be around 525% with 4 layers of reinforcements. A non-linear regression power model was also suggested to estimate the Unconfined compressive strength (UCS).

Singh and Yachang (2012) conducted the series of CBR test on the fly ash reinforced with Jute Geotextile sheets at different embedment ratio. The embedment ratio was varied from 0.25d to 2d with successive increase of 0.25d. Test results indicated that on inclusion of Jute geotextile layer in the fly ash sample, the CBR value of fly ash increases. It was observed that the CBR value of fly ash increases with the increasing number of Jute Geotextile layers and this increase is maximum corresponding to fly ash reinforced with 4 layers of Geotextile layers.

Polymer Fibre

Chakraborty and Dasgupta (1996) studied the strength characteristics of randomly oriented polymer-fibre reinforced fly ash through Triaxial test. All the three drainage conditions namely, Unconsolidated Undrained tests, Consolidated Undrained tests and Consolidated Drained tests were taken into consideration. The percentage of reinforcement was varied from 1 % to 4 % by weight. An aspect ratio (L/D) of 30 was used in all the tests. For each mix samples were tested under three confining pressures 2 kg/cm^2, 3 kg/cm^2 and 5 kg/cm^2. As the aspect ratio increases, the shear strength parameters also increases op to an aspect ratio of 125. The increase in strength is linear, but beyond 125 the increase in strength is non linear. The percentage of reinforcement increases, both the shear strength parameters increase but after a reinforcement of about 4% the increase in cohesion or angle of internal friction was very less. Therefore, they suggested the percentage of fibre around 3 % to 4% may be taken as most economical.

Topcu and Canbaz studied the effect of steel and polypropylene fibres on the mechanical properties of concrete containing fly ash. According to the results of the study, addition of fibres provide better performance for the concrete, while fly ash in the mixture may adjust the workability and strength-loss caused by fibres, and improve strength gain.

Qian and Stroeven investigated the optimization of fibre size, fibre content, and fly ash content in hybrid polypropylene-steel fibre concrete with low fibre content based on general mechanical properties. The results show that a certain content of fine particles such as those found in fly ash is necessary to evenly disperse fibres.

Gutierrez et al. studied the effects of the pozzolans on the performance of fibre reinforced mortars. They reported that in general, pozzolanic materials, especially silica fume and metakaolin, improve the mechanical performance and the durability of fibre-reinforced materials.

Coir Fibre

H. P. Singh (2013) performed experiments to find out the Strength and Stiffness response of Fly ash reinforced with Coir fibre. In the study the influence of coir fibres on shear strength parameters (c and ϕ) and Stiffness modulus (σ_d/ϵ) of fly ash was investigated. The coir fibre were taken as 0.25%, 0.50%, 0.75% and 1% by dry weight of fly ash and based on the investigation it was concluded that preparation of identical samples of coir fibre reinforced fly ash beyond 1% of fibre content was possible. Figure 4 shows the Stress-strain curves of Reinforced Fly ash under Confining Pressure of 50 kPa. Finally, the shear strength parameters and stiffness modulus of reinforced were compared with that of unreinforced fly ash. Test results indicated that on inclusion of coir fibre, the shear strength and stiffness modulus of fly ash increases and improvement was substantial at fibre content of 1%.

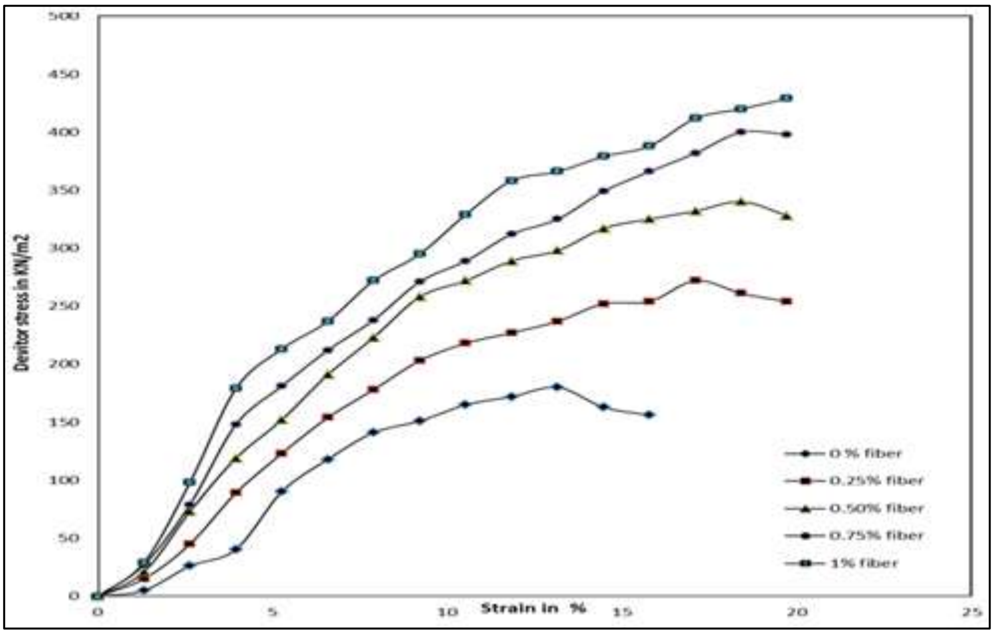

Figure 4: Stress versus Strain Curves of Reinforced Fly ash under Confining Pressure of 50 kPa

Polyvinyl alcohol (PVA) fibres

Hwai-Chung Wu and Peijiang Sun (2007) studied the effect of short polyvinyl alcohol (PVA) fibres. The properties of PVA fibre reinforced fly ash composites are evaluated by splitting tensile test. The experimental results demonstrated that the addition of short polyvinyl alcohol (PVA) fibres can significantly improve the ductility of the fly ash composites. The optimum fibre volume content was estimated to be 1% with class C Fly ash. Poly (viny1 alcohol) is adopted from poly (viny1 acetate) which is readily hydrolyzed by treating an alcoholic solution with aqueous acid or alkali (Feldman 1989), leading to the structure. PVA contains hydroxyl groups (OH) which have the potential to form hydrogen bond between molecules resulting in a remarkable change in surface bond strength between PVA fibers and the matrix (Xu et al. 2010). PVA fibre structure PVA is a white powder with specific gravity ranging from 1.2 – 1.3 (1200-1300 kg/m3) (Toutanji et al.). This powder is then formed and extruded to become PVA fibers which are commercially produced.

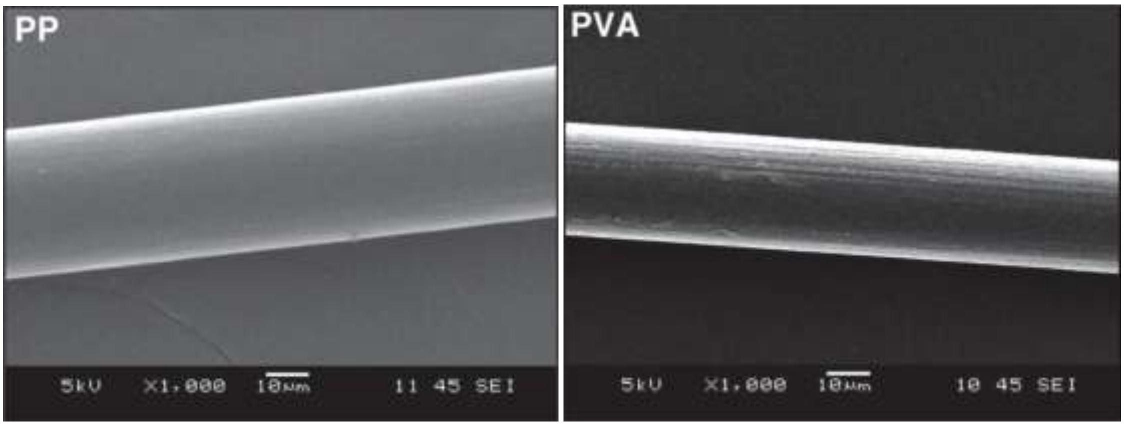

Figure 5: Scanning electron microscope (SEM) images of Polypropylene (PP) and PVA fibres

Synthetic fibres

Synthetic fibres have become more popular in recent years as secondary reinforcement in cementitious materials. This is due to the fact that they can provide effective and relatively inexpensive reinforcement for concrete compared to conventional fibres such as asbestos, steel and glass. Synthetic fibre types that have been utilized in cementitious matrices so far are namely; polyethylene (PE), polypropylene (PP), acrylics (PAN), polyviny1 alcohol (PVA), polyamides (PA), aramid, polyester (PES) and carbon. The properties of synthetic fibres may vary broadly, especially in term of modulus of elasticity. This characteristic plays an important role when fibres are used for producing composites (Zheng & Feldman 1995).

A synthetic fibre can be pronounced as a flexible, macroscopically homogeneous body, with a high aspect ratio and a small cross-section manufactured from naturally occurring macromolecules and synthetic polymers. The chemical, physical and mechanical properties of a synthetic fibre highly depends on the arrangement of the polymer chains in three-dimensional space. By improving the intermolecular chain organization that can generally be described as highly oriented and crystalline, we are able to enhance the characteristics of this type of fibres.

In order to increase the strength of cementitious composites, fibres must have a modulus of elasticity greater than that of the matrix. Since the modulus of elasticity of cementitious composite is ranging from about 15 to 45 GPa, this condition is difficult to meet with most of synthetic fibres. Therefore, to overcome this challenge, attempts have been made to develop fibres with a very high modulus of elasticity. However, both theoretical and applied research have specified that, even by employing low modulus fibres, considerable improvements can be obtained with respect to the strain capacity, toughness, impact resistance and crack control of the FRC.

CONCLUSION

Various studies have indicated that mixing of various fibers can increase the strength of soil. It is true for flyash also. The stress-strain behavior of flyash improved considerably due to increase in fiber content and aspect ratio. For example, at a confining pressure of 98 kPa. Elastic modulus increases with increase in fiber content and aspect ratio. Shear strength parameter; cohesion and angle of internal friction also increases with increase in fiber content.

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