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STUDY ON THE BEHAVIOUR OF HYBRID FIBER REINFORCED SILICA BASED CEMETITIOUS COMPOSITE

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ABSTRACT

This paper highlights the material properties of the engineered cementitious composite for the effective development of new structures and maintenance of existing structures. The material researchers have conducted a lot of experiments based on sustainability, durability and safety point of view. As a result of the attempts, finally a new material was established in the last decade. The proper selection of the fiber, mixing of the composite exhibit strain hardening and multiple cracking behaviour of the material. The strain hardening behaviour of the cementitious composite gives significant advantage under flexural loading. The crack width developed under loading is very small when compared with conventional concrete due to the bridging effect of the fiber. The material properties of ECC reinforced with following 0.5%, 1.0%, 1.5%, 2% of steel fiber and 0.1%, 0.15%, 0.2%, 0.25% of polypropylene fiber. The optimum strength attained at 1.0% of steel fiber and 0.1% of polypropylene fiber and has been claimed to be the most promising proportion of the fiber content. A series of experiments were carried out to determine the compressive strength, tensile strength and flexural characteristics of cementitious composite.

Keywords:Cemetitious concrete,steel fiber,polypropylene fiber

1 INTRODUCTION

Experimental investigations have been carried out to develop a new material which has transfer from brittle to ductile nature. Concrete has been exhibiting the brittle nature, due to this failure happens suddenly and crack development and propagation in the cement paste interface is very easy, also the crack width is very large. In the case of ECC, the short fibres are added. The steel fibre increase the strength and toughness of the material at the same time the addition of polypropylene fibre increase the strain hardening, energy absorption. The cracks development under loading is very small, thus it improves the damage tolerance. The cementitious composite act as a ductile material.

2 LITERATURE REVIEW

Mohammed Ezziane et al (2011): This paper highlighted the behaviour of materials under extreme conditions in terms of temperature. To this comparison was made of the mechanical behaviour of mortars reinforced with steel fibres, PP fibres and a hybrid fibre combination. These mortars were subjected to various heat exposures and tested mechanically protection mechanisms of steel fibres and PP were analysed. SEM observations of steel and fibres shown orientation at high temperatures this orientation impairs the protective effect of steel fibres. The use of ST fibres has no effect on thermal damage for exposures between 100^{o}C to 600^{o}C. After heat exposure at 400^{o}C, the compressive strength of mortar reinforced with ST fibres was 78% of its original 20^{o}C strength. Analysis of four point bending flexural strength test results indicated that throughout the entire temperature angle the strength of ST fibre mortars was significantly greater than of standard mortar, PP fibre mortar hybrid fibre mortar.

Ying chen et. Al (2011): This paper explained the effect of hybrid fibre reinforcement on fracture energy and crack propagation in cement matrix composites. Fibre reinforcement in cementitious materials was known to improve the tensile strength, fracture resistance, and energy adsorption capacity. Proving a system in which a stronger and stiffer fibre improves the first crack stress and ultimate strength, whereas the second , more flexible and ductile fibre increases the toughness and strain capacity in the post cracking zone; forming hybrid reinforcement in which a smaller fibre bridges microcracks to control its growth and results in a greater tensile strength of composite, whereas the second , relatively large fibre arrests the propagating micro cracks and improves the composite toughness. Hybrid fibre reinforcement combines the advantages of both the fibres, to fully understand and maximize the reinforcement efficiency of fibres in a given matrix, the fibre pull out tests are usually performed on macrofibres. The influence of fibre types and their combination is qualified by using the fracture energy and toughness values got from the load- deflection curves.

Vajihollah Alamshahi et al (2012): This paper illustrates the different amounts and lengths of synthetic fibres on mechanical properties of asbestos free fibre cement. Polypropylene and polyester fibre were used for this study. The flexural strength was increased by the addition of PP because of the length increased means the flexural strength was increased. It was found that flexural strength of samples improves by increasing content of synthetic fibres to an optimum amount and the decreases with higher amount. Quality of fibre distribution in cement matrix was a key factor for mechanical performance of composite.

Jun-Yan Wang et al (2012): This paper illustrated that the use of shrinkage reducing admixture (SRA) at various concentrations. In fibre reinforced cementitious composites. The effect of SRA was measured on the fundamental properties such as surface tension of the bulk fluids and the contact angle developed between the fibres and the bulk fluids, on the fresh properties such as the air content and the density, and finally on the hardened mechanical properties, specially the flexural behaviours. SRA with critical concentration could significantly improve the flexural toughness and residual strength of steel fibre reinforced cement mortar. The addition of fibre significantly improves not only the ductility, but also the durability of the concrete. SRA have also shown some negative side effects on concrete properties, it has been observed that addition of SRA to the mix water depresses the dissolution of alkalis in the pore fluid 14 which in some case may delay setting time, reduce the rate of cement hydration and impede strength development.

Eduardo B Pereira et al (2012): This paper investigated in detail how fibres of different types were affecting the bridging behaviour, and if a synergy between these bridging mechanisms in the composite can be established. So they adopted the in the assessment of the tensile performance of fibre reinforced cementitious composites needs to appraise explicitly the importance and role of the micro-mechanisms of each composite phase in the overall composite response. In particular, when multiple fibre-type reinforcements are used, the contribution of each type of fibre and the interaction between different fibre reinforcements and different matrices in the overall composite mechanics needs to be clearly identified. In this research, the single crack tension test was used to assess the tensile performance of six fibre reinforced cementitious composites. The responses obtained showed high sensitivity to the parameters of the different cementitious composites tested, in particular to the different types of fibre reinforcements used.

Kamile tosum et al (2013): This investigates the effects of individual and combined additions of polypropylene and polyvinyl alcohol fibres on the behaviour of cement based composites. The maximum fibre content used in the material was 3%. The samples were subjected to four point loading after 28 days curing. A combination of strain hardening and ductile behaviour is necessary fir high flexural strength performance. The addition of super plasticizer and modification in matrix design may significantly improve the workability of composites incorporating high amounts of fibre. The complete failure of PVA fibre reinforced composites was observed at 10 -15 mm deflection intervals. In cased of PP fibre reinforcement, these fibres still bridge the cracks and transfer the load to the other sections of composite at extremely at high deflection values. The slipping performance form matrix and high elongation ability of PP fibres improved the ductility of composites. A decrease in the PP/PVA fibre ratio shifted the load deflection curves upwards and shortened the tail of the curves. While PP fibres improved the load carrying ability of composites at extremely high deflection values, PVA fibres improved the flexural load resistance of composites at comparatively lower deflection values. Replacement of PP fibres with PVA slightly increased and then fluctuate the first cracking values. High strength PVA fibres were found more effective for improving the first cracking strength PVA fibres when incorporated into a comparatively weaker matrix.

Khin T et. Al (2013): This paper describes experimentally the mechanical properties of a new hybrid fibre-reinforced engineered cementitious composite (ECC) material reinforced with 1.78% polyvinyl alcohol (PVA) fibre and 0.58% steel (SE) fibre. The following experiments such as compressive strength, young are modulus, modulus of rupture, and tensile characteristics of the material were studied. The mechanical properties such as improved tensile strength, ultimate strain capacity with significantly improved tensile strain hardening capacity than the conventional concrete material. These superior mechanical properties and existence of multiple microcrackings equip the ECC material excellent capability of high energy absorption and impact shutter resistance. High ductility was given the interactions between fibre, matrix and and interface in the ECC material. And local failure was delayed by developing multi- cracks. The hybrid fibre- reinforced ECC material exhibited improved tensile strength than the ECC reinforced with PE fibres only and that the hybrid fibre- reinforced ECC material exhibited improved tensile strain capacity than the composites reinforced with steel fibres only. It was found that the new ECC materials exhibits improved compressive strength, young’s modulus, ultimate flexural strength, flexural strain, tensile strength at first crack and ultimate tensile strength.

Serdar Aydin et al (2013): The effects of length and volume fraction of steel fibres on the mechanical properties and drying shrinkage behaviour of steel fibre reinforced alkali- activated slag/silica fume mortars were investigated. Steel fibre with two different lengths of 6 mm and 13 mm, and four different volume fractions of 0.5%, 1%, 1.5%, and 2% were used. The extension and propagation of micro-cracks that occur due to the internal stresses in concrete were prevented by stress transfer capability of randomly distributed fibres. The compressive strength of mortar was increased with the fibre volume and length to compressive strength seems to be more significant at high fibre dosages. Longer fibres resulted in better mechanical performance in terms of compressive strength, flexural strength, and toughness in AASS mortars. The drying shrinkage values decreased with increase of fibre dosages independent from the fibre length. Finally alkali- activated slag/silica fume based high performance fibre reinforced composites may be a promising low-cost alternative material compare to conventional Portland cement based fibre reinforced composite.

3 PROPERTIES OF MATERIALS

3.1 CEMENT

The ordinary Portland cement (OPC) of 53 Grade was used for the production of the cementitious composite. Standard consistency and specific gravity were found. The properties of the cement is shown in the following Table 1

Table 1 Properties of cement

Sl.No	Property	Results
1	Fineness	5%
2	Initial setting time	30 minutes
3	Specific gravity	3.15
4	Standard consistency	31%

3.2 FINE AGGREGATE

The fine aggregate used in this investigation is natural sand and it has a specific gravity of around 2.65. The fineness modulus of sand is taken as 1.18 mm passed sieve. The properties of the fine aggregate is shown in the following Table 2

Table 2 Properties of fine aggregate

Sl.No	Property	Results
1	Specific gravity	2.65
2	Bulking of sand	20%
3	Fineness modulus	2.78
4	Voids ratio	0.21

3.3 COARSE AGGREGATE

Coarse aggregate of maximum size of 20 mm was used in concrete which has been specified in the codal provisions.

Table 3 Properties of coarse aggregate

Sl.No	Property	Results
1	Specific gravity	2.65
2	Water absorption	0.5%
3	Fineness modulus	6.42
4	Crushing strength	2.57 N/mm^2
5	Impact value	7.2%
6	Abrasion value	4.05%

3.4 SILICA FUME

It has white colour in the powder appearance, it gives high sulphate resistance, corrosion resistance. The micro silica of 5% weight of cement is used for the production composite. Thus its density is increased also it produce C-S-H gel at the time of hydration process. It helps to achieve better strength.

Table 4 Properties of silica fume

Sl.No	Property	Results
1	Colour	Whitish powder
2	Physical Properties	Silica fume
3	Average diameter	0.5
4	Specific surface area (m^2/Kg)	22500
5	Density (g/cm^2)	2.65
6	SiO_2	>95
7	Al_2O_3	<5

3.5 STEEL FIBRE

The steel fiber of 0.45 mm diameter along with length of 12.5 mm is used for the production of composite which gives multidirectional reinforcement detailing. It increase crack resistance, ductility, and energy absorption of the composite. Also it provides better the impact resistance and fatigue resistance to composite. Fig.1 shows the steel fiber used in the production of composite.

Fig.1 Steel fiber

3.6 POLYPROPYLENE FIBRE

The polypropylene fiber of 18 µm diameter along with a length of 12 mm is used for the production of cementitious composite. It improves the impact resistance, shatter and abrasion resistance. Increase residual strength and durability. Fig.2 shows the polypropylene fiber used in the production of composite. The properties of the steel fiber and polypropylene fiber shown in the Table 5.

Fig.2 Polypropylene fiber

Table 5 Properties of fiber

Fiber Type	Diameter	Length (mm)	Tensile strength (MPa)	Density (Kg/m^3)
Steel	0.45 mm	12.5	1100	7850
Polypropylene	20 µm	12	300	946

3.7 WATER

Fresh and clean water was for casting and curing of specimens. The water was relatively free from organic matters, silt, oil, sugar, chloride and acidic material as per requirements of Indian Standard.

Table 6 Mix ratio of ECC

w/c ratio	c/s ratio	Silica fume	Steel fibre	PP fibre
0.45	1:3	5% (wt)	0.9 – 1.2%	0.09-0.12%

4 REINFORCEMENT DETAILS

The area of reinforcement was provided in the beam as balanced section. All beams were 1100 mm long, 100 mm wide and 150 mm deep. Provided 2 numbers of 10 mm diameter bar in the tension zone. 10 number of 8 mm diameter stirrups with spacing of 100 mm c/c 1/3rd distance from both supports and 150 mm spacing at intermediate distance. The reinforcement details for the beam is shown in Fig.3.

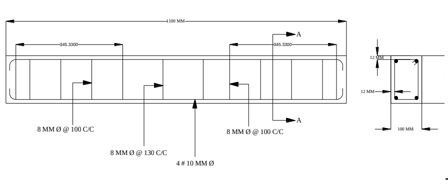

Fig.3 Reinforcement details

Table 6 Size of specimens

Type of Mould	Size(in mm)
Cube	70.6 x 70.6 x 70.6
Beam	1100 x 100 x 150

Table 7 Compressive strength of cubes with Polypropylene fiber

Sl.No	Polypropylene fiber (in volume percentage)	28 days (N/mm^2)
1	0	12
2	0.10	19.06
3	0.15	10.53
4	0.20	15.05
5	0.25	14.04

Fig.4 Failure mode of specimen

Table 8 Compressive strength of cubes with steel fiber

Sl.No	Steel fibre content (in volume percentage)	28 days (N/mm^2)
1	0	12
2	0.5	19.06
3	1.0	20.06
4	1.5	16.55

The compressive strength results showed that the 0.10% polypropylene fiber content composite gives ultimate strength. The Fig.4 given below represents the compressive strength value of polypropylene fiber at 28 days.

Table 9 Compressive strength of cubes with hybrid steel-polypropylene fiber

Sl.No	Hybrid fiber	28 days (N/mm^2)
1	Control	18.06
2	H_1	20.06
3	H_2	26.58
4	H_3	34.61
5	H_4	39.12

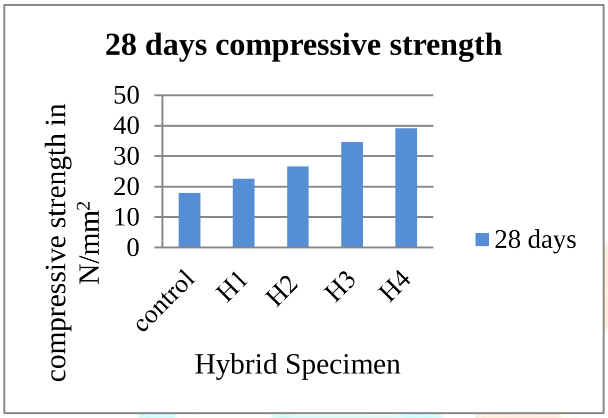

Fig.5 Compressive strength of cubes with hybrid steel-polypropylene fiber

5 SEM ANALYSIS

Scanning electron microscopic analysis was conducted for the control specimen and hybrid specimen. The results show that the pores and voids in the composite is very less due to the addition of silica fume. The strength of the control specimen achieved at 28 days is very low when compare to hybrid composite. Whereas the strength of hybrid fiber achieved at 28 days is $39N/mm^2$. The reason for the achievement is the effective distribution of the fibers. It giveseffect the multi-directional reinforcement. The images for the conventional and hybrid fiber composite. In the case conventional specimen, the surface voids are more than that of hybrid fiber sample. The addition of silica fume reduced the surface voids in the sample. The fibers are almost equally distributed which is act as a multidirectional reinforced system. The fiber bonding is very good in sample. The separation of the particle is very small in the sample. The super plasticizer counteract for the strength attaining of sample.

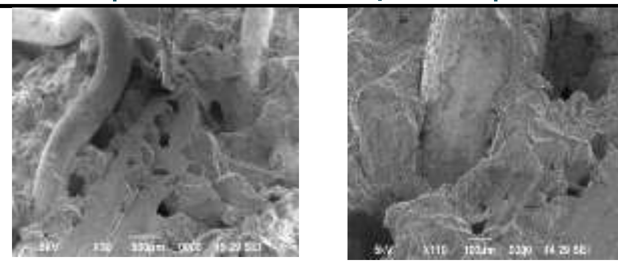

Fig.6 Surface structure & energy absorption of hybrid composite cube

Table 10 Energy absorption of the specimen

Sl.No	Specimen	Energy absorption (Nmm)
1	Control	138.44
2	H_1	244.47
3	H_2	401.4
4	H_3	260.52
5	H_4	190.47

The energy stored in the conventional beam under loading is $138.44x10^3$ Nmm. The energy absorption capacity of the specimen increased 1.9% than the control specimen when compared with hybrid composite.

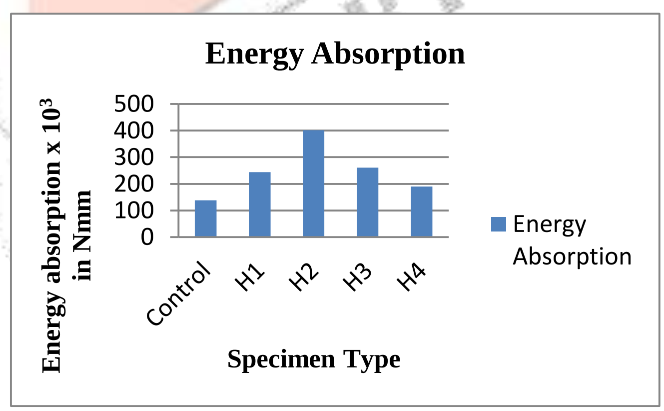

Fig.7 Energy absorption of the specimen

5.1 STIFFNESS

The stiffness results of the specimen under third point loading condition.

Table 11 Stiffness of the specimen

Sl.No	Specimen	Stiffness (N/mm)
1	Control	2.24
2	H_1	7.05
3	H_2	10.4
4	H_3	4.44
5	H_4	13.33

The stiffness is the load required to produce unit displacement. The stiffness of the control specimen is 2.24 N/mm. The stiffness of the specimen is increased 4.95% in the hybrid cementitious composite beam. The stiffness is increased 3.8% in the hybrid composite beam.

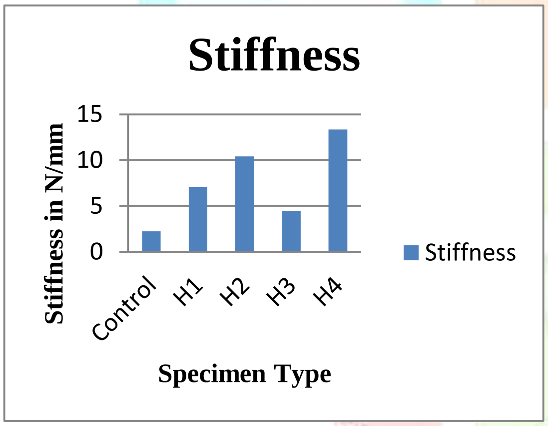

Fig.7 Stiffness of the specimen

5.2 DUCTILITY FACTOR

Table 12 Ductility factor of the specimen

Sl.No	Specimen	Ductility factor
1	Control	2.75
2	H_1	3.48
3	H_2	4.20
4	H_3	3.35
5	H_4	3.53

The ductility is the ability of the material to with stand large load under deformation without failure. The ductility factor is the ratio between deformations at the first crack load to deformation at the ultimate load. The ductility factor of the control specimen is 2.75. The maximum ductility factor shown by hybrid H_2specimen. The ductility factor increased 5.0%. The load carrying capacity of the specimen is increased. The polypropylene fiber content increased the ductility of the specimen.

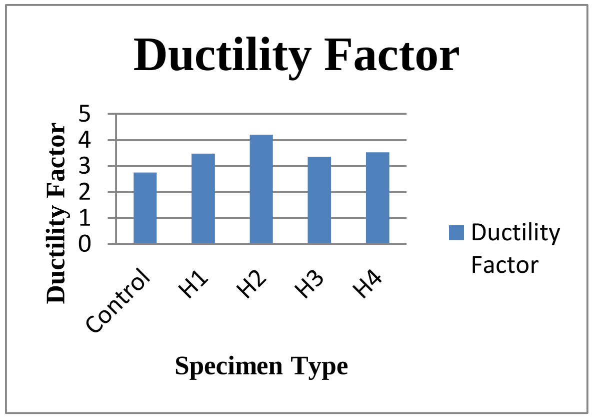

Fig.8 Ductility factor of the specimen

5.3 LOAD Vs. DEFLECTION CURVE

The load carrying capacity of the hybrid beams are increased due to the application of the composite on the beam. The maximum capacity is obtained on at hybrid specimen which carrying 1% of steel fiber and 0.1% of polypropylene fiber.

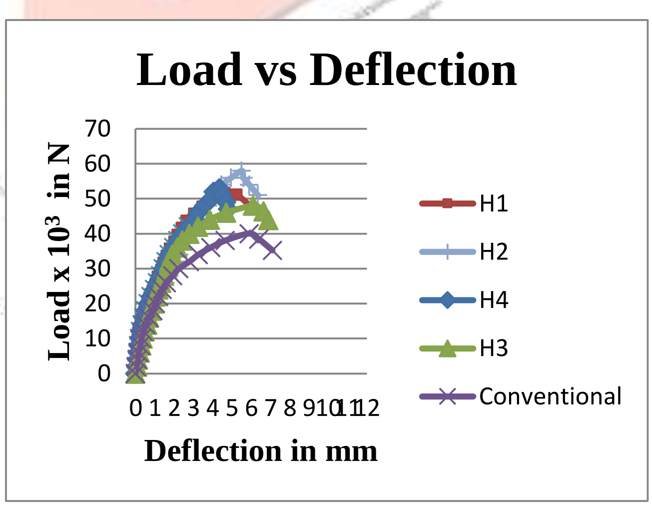

Fig.9 Load Vs. Deflection behaviour of beams

6 CONCLUSION

From the literature review and experimental work, the following conclusions were obtained. The silica fume is increased the strength of the cementitious composite. The contribution of the fibers increased the strength; the polypropylene fiber increased the ductility of the material.

- The study concluded that the compressive strength of the cementitious composite improved 1.2% than the control specimen, the silica content in cementitious composite increased the strength and fibers counteract with strength and ductility.
- The energy absorption capacity of the material is increased 1.9% than the control specimen. The fibers are acting as a multi directional reinforcement. The energy absorption capacity is mainly due to the polypropylene fiber content.
- The voids are reduced by the addition of silica fume due to fineness of it, also the bond strength between the fibers to binding material is very strong in samples.
- The ductility is the ability of the material to withstand large load with small deformation without failure. The ductility is mainly provided by polypropylene fiber. The ductility factor is improved 5.0% of the control specimen.
- The first crack load is increased in the samples due to the fiber content as well as multiple cracks developed due to the bridging effect of the fiber. It increased the load carrying capacity with reducing the crack width
- From the load vs. deflection curve, the load capacity is very large obtain at steel fiber content of 1% and polypropylene fiber of 0.1%. The compressive strength of the cementitious composite is also increased.

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