International journal of Engineering Research-Online
A Peer Reviewed International Journal
Articles available online http://www.ijoer.in

Vol.2., Issue.4, 2014

RESEARCH ARTICLE

ISSN: 2321-7758

BEHAVIOUR OF SIFCON PRODUCED WITH HYBRID FIBRES UNDER SULFATE ATTACK

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Article Received: 09/08/2014 | Article Revised on: 21/08/2014 | Article Accepted on:22/08/2014

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ABSTRACT

Slurry infiltrated concrete (SIFCON) was first produced in 1979 in the USA, by incorporating large amounts of steel in moulds to form very dense network of fibres. The network is then infiltrated by a fine liquid cement based slurry or mortar. The matrix was different from normal FRC in the sense that in FRC, volume usually varies from 1 to 3 percent by volume whereas in SIFCON, contents may range from 5 to 20 percent using special manufacturing techniques. The matrix consists of cement sand slurry or flowing cement mortar. The process of manufacturing is also different. The SIFCON is prepared by infiltrating cement slurry with high fluidity into a bed of pre-placed fibres in order to achieve a monolithic mass. Since, relatively small length and/or small aspect ratio is used to achieve uniform distribution, volume fraction, is tremendously increased thereby improving mechanical properties significantly. However, SIFCON is more expensive due to its high content and intensive labour requirement.

In this work the behavior of slurry infiltrated hybrid reinforced concrete under sulfate attack is studied. Different types of hybrid fibres used in this study are (SF+HDPEF), (SF+WPF), (SF+PPF). The durability properties of slurry infiltrated reinforced concrete produced by hybrid fibres under sulfate attack is compared with slurry infiltrated reinforced concrete produced with mono fibres. The durability characteristics under sulfate attack are studied by evaluating the strength characteristics such as compressive strength, tensile strength, flexural strength, shear strength and impact strength on the specimens which are immersed in sulfate solution of 15 percent concentration for a minimum of 90 days.

KEYWORDS: SIFCON, hybrid Fiber, slurry , Steel , High density polyethylene fibres, Waste plastic fibres, Polypropelene fibres.

INTRODUCTION

Concrete structures are subjected to many stresses like compression, tension, flexure, impact, fatigue, etc. Concrete made with portland cement has certain characteristics, it is relatively stronger in compression but weak in tension and tends to be brittle. The weakness in tension can be overcome by the use of conventional rod reinforcement and to some extent by the inclusion of a sufficient volume of certain fibres. The use of the fibres also alters the behaviour of the fibre-matrix composite after it has cracked, thereby improving its toughness.

The combination of two or more different types of the fibres (different types and/or geometries) is becoming more common, with the aim of optimizing overall system behaviour. The intent is that the performance of these hybrid systems would exceed that induced by each type alone. That is, there would be a synergy. Banthia and Gupta classified these synergies into three groups, depending on the mechanisms involved:

1. Hybrids based on the constitutive response, in which one is stronger and stiffer and provides strength, while the other is more ductile and provides toughness at high strains.
2. Hybrids based on the dimensions, where one is very small and provides microcrack control at early stages of loading; the other is larger, to provide a bridging mechanism across macrocracks.
3. Hybrids based on the function, where one type of the provides strength or toughness in the hardened composite, while the second type provides fresh mix properties suitable for processing [1].

SIFCON is made by preplacing short, discrete fibres in the moulds to its full capacity or to the desired volume fraction, thus forming a network. The network is then infiltrated by a fine liquid cement-based slurry or mortar. The fibres can be sprinkled by hand or by using fibre-dispensing units for large sections. Vibration is imposed if necessary during placing the fibres and pouring the slurry. The main differences between FRC and SIFCON, in addition to the clear difference in the volume fraction, lie in the absence of coarse aggregates in SIFCON which, if used, will hinder the infiltration of the slurry through the dense network. Furthermore, SIFCON contains relatively high cement and water contents when compared to conventional concrete.[2]

Sulfate attack is one of the phenomena that may disintegrate concrete structures depending on the type and concentration of the acid. Certain acids, such as oxalic acid, are considered harmless, while weak solutions of some acids have insignificant effects. Although acids generally attack and leach away the calcium compounds of the paste, they may not readily attack certain aggregates, such as siliceous aggregates. Calcareous aggregates often react readily with acids. However, the sacrificial effect of calcareous aggregates is often a benefit over siliceous aggregate in mild acid exposures or in areas where water is not flowing (Chang et al., 2005). With calcareous aggregate, the acid attacks the entire exposed concrete surface uniformity, reducing the rate of attack on the paste and preventing loss of aggregate particles at the surface. Also, calcareous aggregates tend to neutralize the acid, especially in stagnant locations[4].

MATERIALS AND METHODOLOGY

MATERIALS

In this experimental work, ordinary Portland cement (OPC) 43 grade with cement content of 413.33 Kg /m3 conforming to IS: 8112 – 1989 [5] was used. Natural sand confirming to IS 383-1970 of Zone II [6] and Water fit for drinking was used.

Different types of the fibres are used in combinations such as(SF+HDPEF) (1%+1%), (SF+WPF) (1%+1%), (SF+PPF) (1%+1%), SF (2%), HDPEF (2%), PPF (2%), and WPF (2%) by volume fraction.

METHODOLOGY

A slurry of cement and sand with a proportion of 1:1was prepared with a water cement ratio of 0.45.

SIFCON is prepared by placing the slurry into the moulds at bottom, then adding the fibres over the slurry and again pouring the slurry over the fibres and the process is continued till the mould fills.

No vibration was given during placing of fibres. The vibration was externally applied using a vibrating table after the mould is filled. Usually, vibration during matrix placing was necessary to avoid honeycombing or voids. The weight of to be put in the mould depends on the required volume fraction, the dimensions of the mould, and, of course, on the specific gravity of the itself.

For compressive strength test, the cubes of size 150 x 150 x 150 mm were cast and tested under compression testing machine of 2000 kN capacity as per IS: 516-1959 [7]. For splitting tensile strength test, the cylinders of 150 mm diameter and length 300 mm were cast and were tested under compression testing machine as per IS: 5816-1999 [8]. For the flexural strength test, beams of dimension 100 x 100 x 500 mm were cast and were tested on an effective span of 400 mm with two point loading as per IS: 516-1959 [7]. For shear strength test L shaped specimens as shown in fig. 1 were used.

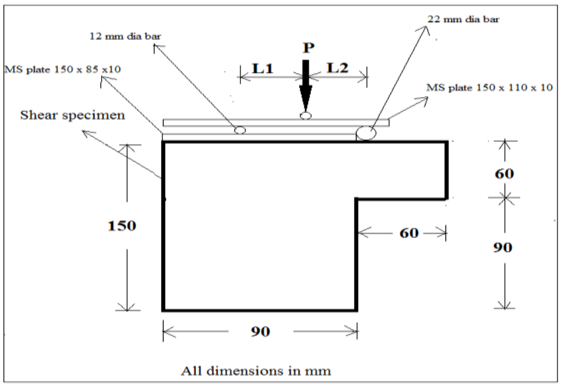

Fig.1 Shear test on L shaped specimen

The specimen was centrally placed on the compression testing machine and load is applied continuously and uniformly. The load is increased until the specimen fails and record the maximum load carried by each specimen during the test. Computation of the shear strength was done as follows. Failure load = WL1/(LI+L2),Shear strength = (Failure load/A) × 1000 Where,W = Load in kn, A = Area of shear surface = 60 x 150 mm^2 , L1 = 25 mm and L2 = 25 mm.

For impact test strength, cylindrical specimens of 150mm diameter & 60mm height were prepared. Drop weight test was adopted for testing impact specimen. The specimens were kept in the Schrader's impact testing machine and a hammer weighing 4.54 kg was dropped from a height of 457mm. Number of blows required to cause first crack and final crack were noted down. The final failure is defined as the opening of cracks in the specimen sufficiently so that pieces of concrete are touching at least three out of the four positioned lugs on the base plate. These numbers of blows were converted into impact energy by the following formulae:

Impact energy = W*H*N

Where,

W = weight of the hammer = 45.4 N.

H = height of the fall =0.457 m.

N = number of blows required to cause first crack and final crack as the case may be

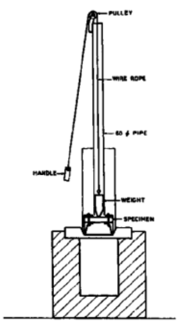

Fig 2 – Impact strength test set up

RESULTS AND DISCUSSIONS

Table 1 gives the overall results of compressive strength of SIFCON with mono fibres and hybrid fibres with and without subjecting to sulfate attack. The table also gives the percentage increase of compressive strength of SIFCON with hybrid fibres as compared to the respective mono fibers.

Table 2 gives the overall results of tensile strength of SIFCON with mono fibres and hybrid fibres with and without subjecting to sulfate attack. The table also gives the percentage increase of tensile strength of SIFCON with hybrid fibres as compared to the respective monofibres.

Table 3 gives the overall results of flexural strength of SIFCON with mono fibres and hybrid fibres with and without subjecting to sulfate attack. The table also gives the percentage increase of tensile strength of SIFCON with hybrid fibres as compared to the respective monofibres.

Table 4 gives the overall results of shear strength of SIFCON with mono fibres and hybrid fibres with and without subjecting to sulfate attack. The table also gives the percentage increase of shear strength of SIFCON with hybrid fibres as compared to the respective monofibres.

Table 5 gives the overall results of impact strength of SIFCON with mono fibers and hybrid fibers with and without subjecting to sulfate attack. The table also gives the percentage increase of impact strength of SIFCON with hybrid fibers as compared to the respective mono fibers.

Table 1-Overall results of compressive strength.

Description of SIFCON	Compressive strength without subjecting to sulphate attack	Percentage increase of compressive strength without subjecting to sulphate attack	Compressive strength subjecting to sulphate attack	Percentage increase of compressive strength subjecting to sulphate attack	Percentage decrease of compressive strength when subjected to sulphate attack
SF+HDPEF	50.81	7.85	47.10	4.25	7.30
SF+PPF	49.93	10.85	47.10	7.80	5.67
SF+WPF	47.70	8.04	45.62	5.85	4.36
SF	47.55	-	46.51	-	2.18
HDPEF	47.11	-	45.18	-	4.10
PPF	45.04	-	43.69	-	2.99
WPF	44.15	-	43.10	-	2.38

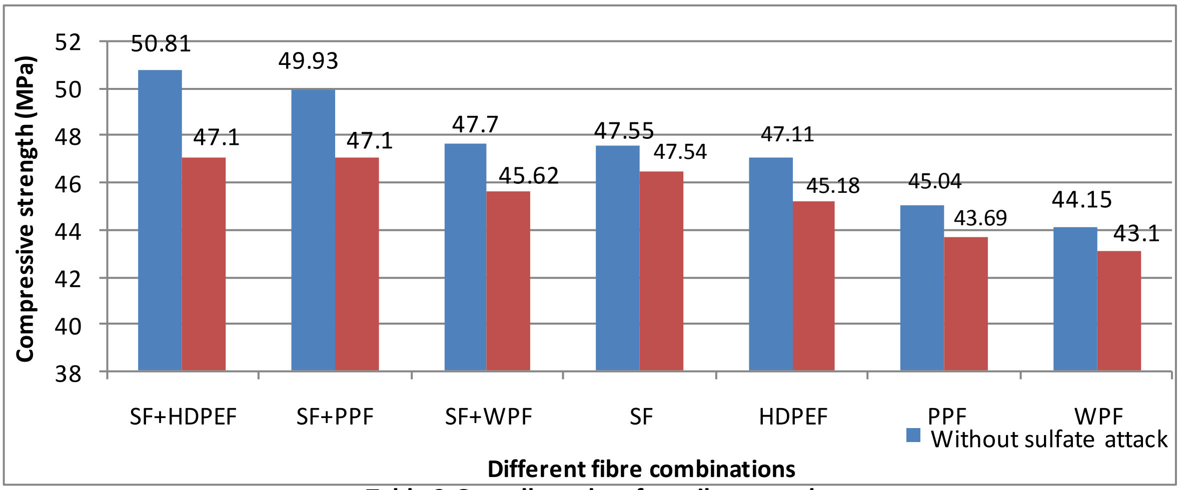

Table 3-Overall results of tensile strength

Description of SIFCON	Tensile strength without subjecting to sulphate attack	Percentage increase of tensile strength without subjecting to sulphate attack	Tensile strength subjecting to sulphate attack	Percentage increase of tensile strength subjecting to sulphate attack	Percentage decrease of tensile strength when subjected to sulphate attack
SF+HDPEF	6.18	14.02	4.48	15.76	27.50
SF+PPF	6.04	14.39	4.20	12.90	30.46
SF+WPF	5.89	15.71	3.82	11.04	35.14
SF	7.03	-	5.09	-	27.59
HDPEF	5.42	-	3.87	-	28.59
PPF	5.28	-	3.72	-	29.54
WPF	5.09	-	3.44	-	32.41

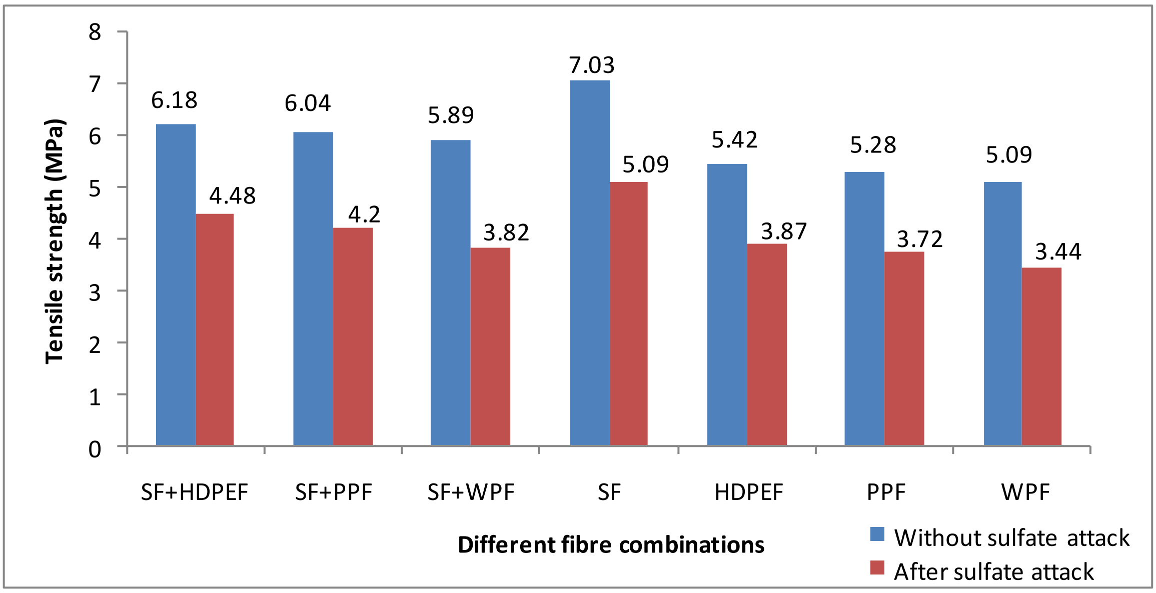

Fig 4 Variation of tensile strength

Table 3-Overall results of flexural strength

Description of SIFCON	Flexural strength without subjecting to sulphate attack	Percentage increase of flexural strength without subjecting to sulphate attack	Flexural strength subjecting to sulphate attack	Percentage increase of flexural strength subjecting to sulphate attack	Percentage decrease of flexural strength when subjected to sulphate attack
SF+HDPEF	14.40	10.17	12.53	38.14	12.98
SF+PPF	13.07	4.13	9.87	13.57	24.48
SF+WPF	12.27	9.55	9.47	12.88	22.82
SF	13.87	-	12.00	-	13.48
HDPEF	13.07	-	9.07	-	30.60
PPF	12.53	-	8.53	-	31.92
WPF	11.20	-	8.13	-	26.22

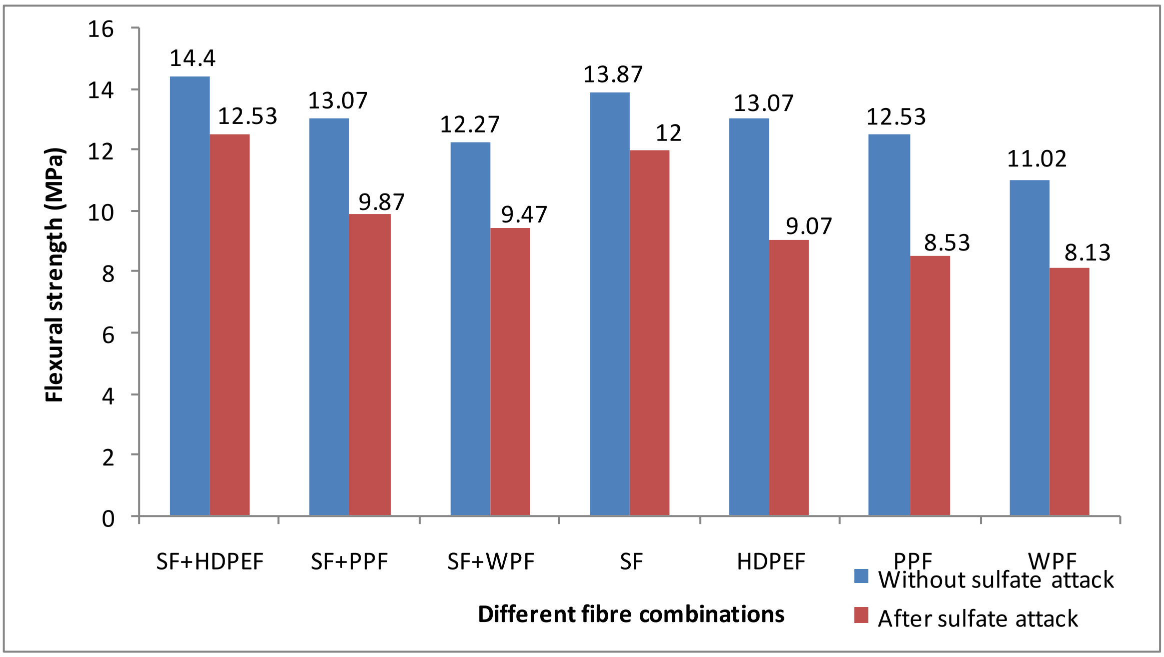

Fig 5 variation of flexural strength

Table 4-Overall results of shear strength

Description of SIFCON	Shear strength without subjecting to sulphate attack	Percentage increase of shear strength without subjecting to sulphate attack	Shear strength subjecting to sulphate attack	Percentage increase of shear strength subjecting to sulphate attack	Percentage decrease of shear strength when subjected to sulphate attack
SF+HDPEF	13.52	21.69	10.56	19.31	21.83
SF+PPF	11.67	6.67	9.07	16.58	22.27
SF+WPF	11.30	13.00	7.78	4.99	31.15
SF	12.59	-	9.81	-	22.08
HDPEF	11.11	-	8.52	-	23.31
PPF	10.93	-	7.78	-	28.82
WPF	10.00	-	7.41	-	26.63

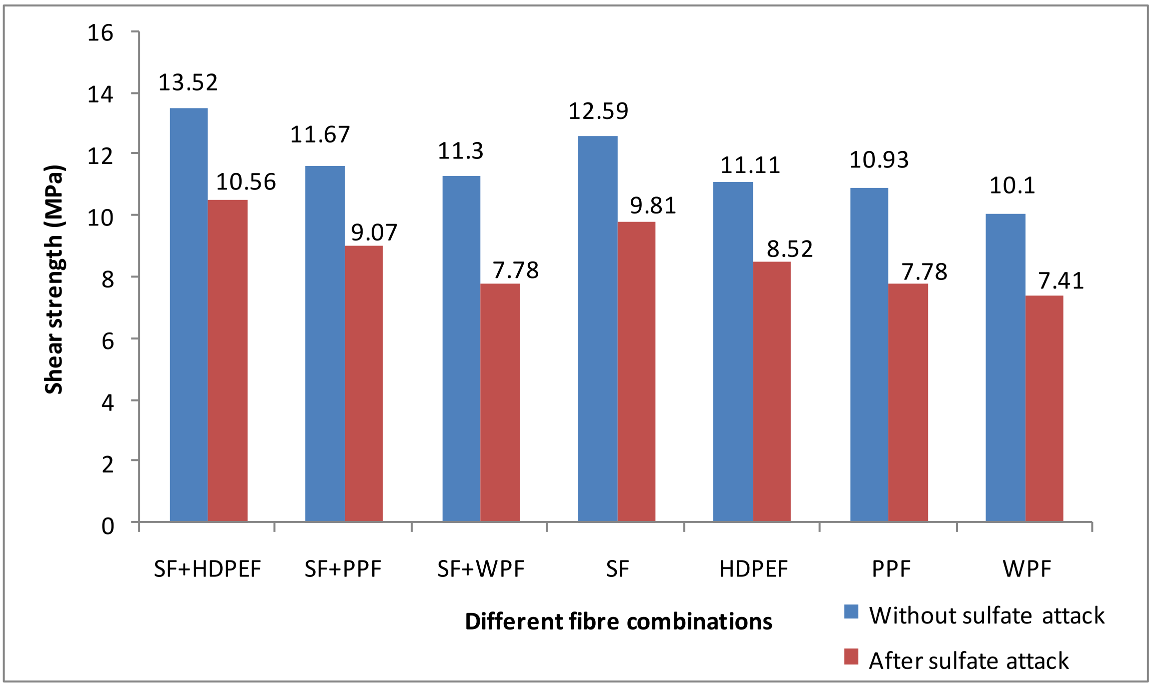

Fig 6 Variation of shear strength

Table 5-Overall results of impact strength

Description of SIFCON	Impact strength for first crack without subjecting to sulphate attack	Percentage increase of impact strength for first crack without subjecting to sulphate attack	Impact strength for first crack subjecting to sulphate attack	Percentage increase of impact strength for first crack subjecting to sulphate attack	Percentage decrease of impact strength for first crack when subjected to sulphate attack
SF+HDPEF	5148.11	9.95	4716.24	7.83	8.38
SF+PPF	4757.37	10.33	4503.74	8.77	5.33
SF+WPF	4490.03	13.52	4126.71	6.73	8.09
SF	6162.65	-	5909.01	-	4.11
HDPEF	4681.97	-	4373.49	-	6.58
PPF	4311.80	-	4140.42	-	3.97
WPF	3955.34	-	3866.22	-	2.25

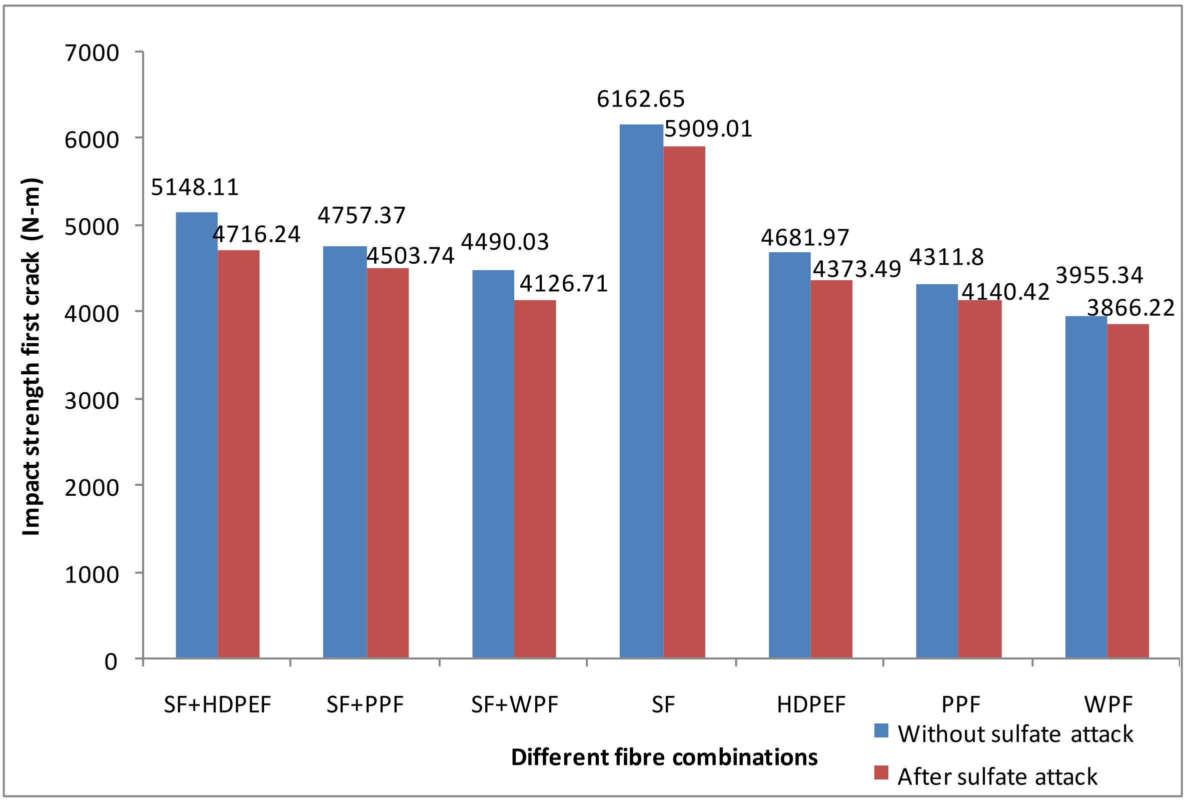

Fig 7 Variation of impact strength for first crack

It is observed that the compressive strength of SIFCON produced with hybrid fibers show higher compressive strength as compared to the SIFCON produced with respective mono fibers. SIFCON produced with hybrid fibres with the combinations (SF+HDPF), (SF+PPF), (SF+WPF) show 7.85%, 10.85% and 8.04% increase in compressive strength as compared to SIFCON produced with respective mono fibres.

It is observed that the tensile strength of SIFCON produced with hybrid fibers show higher tensile strength as compared to the SIFCON produced with respective mono fibers. SIFCON produced with hybrid fibres with the combinations (SF+HDPF), (SF+PPF), (SF+WPF) show 14.02%, 14.39% and 15.71% increase in tensile strength as compared to SIFCON produced with respective mono fibres.

It is observed that the flexural strength of SIFCON produced with hybrid fibers show higher flexural strength as compared to the SIFCON produced with respective mono fibers. SIFCON produced with hybrid fibres with the combinations (SF+HDPF), (SF+PPF), (SF+WPF) show 10.17%, 4.30% and 9.55% increase in flexural strength as compared to SIFCON produced with respective mono fibres.

It is observed that the shear strength of SIFCON produced with hybrid fibers show higher shear strength as compared to the SIFCON produced with respective mono fibers. SIFCON produced with hybrid fibres with the combinations (SF+HDPF), (SF+PPF), (SF+WPF) show 21.69%, 6.67% and 13.00% increase in shear strength as compared to SIFCON produced with respective mono fibres.

It is observed that the impact strength of SIFCON produced with hybrid fibers show higher impact strength as compared to the SIFCON produced with respective mono fibers. SIFCON produced with hybrid fibres with the combinations (SF+HDPF), (SF+PPF), (SF+WPF) show 9.95%, 10.33% and 13.52% increase in impact strength as compared to SIFCON produced with respective mono fibres.

It is observed that the compressive strength of SIFCON produced with hybrid fibers and subjected to the sulfate attack for 90days show higher compressive strength as compared to the SIFCON produced with respective mono fibers. SIFCON produced with hybrid fibres with the combinations (SF+HDPF), (SF+PPF), (SF+WPF) and subjected to sulfate attack show 4.25%, 7.8% and 5.85% increase in compressive strength as compared to SIFCON produced with respective mono fibres.

It is observed that the tensile strength of SIFCON produced with hybrid fibers and subjected to the sulfate attack for 90days show higher tensile strength as compared to the SIFCON produced with respective mono fibers. SIFCON produced with hybrid fibres with the combinations (SF+HDPF), (SF+PPF), (SF+WPF) and subjected to sulfate attack show 15.76%, 12.90% and 11.04% increase in tensile strength as compared to SIFCON produced with respective mono fibres.

It is observed that the flexural strength of SIFCON produced with hybrid fibers and subjected to the sulfate attack for 90days show higher flexural strength as compared to the SIFCON produced with respective mono fibers. SIFCON produced with hybrid fibres with the combinations (SF+HDPF), (SF+PPF), (SF+WPF) and subjected to sulfate attack show 38.14%, 13.57% and 12.88% increase in flexural strength as compared to SIFCON produced with respective mono fibres.

It is observed that the shear strength of SIFCON produced with hybrid fibers and subjected to the sulfate attack for 90days show higher shear strength as compared to the SIFCON produced with respective mono fibers. SIFCON produced with hybrid fibres with the combinations (SF+HDPF), (SF+PPF), (SF+WPF) and subjected to sulfate attack show 19.31%, 16.58% and 4.99% increase in shear strength as compared to SIFCON produced with respective mono fibres.

It is observed that the impact strength of SIFCON produced with hybrid fibers and subjected to the sulfate attack for 90days show higher impact strength as compared to the SIFCON produced with respective mono fibers. SIFCON produced with hybrid fibres with the combinations (SF+HDPF), (SF+PPF), (SF+WPF) and subjected to sulfate attack show 6.71%, 7.73% and 9.18% increase in impact strength as compared to SIFCON produced with respective mono fibres.

CONCLUSIONS

The following conclusions may be drawn based on the experimentations conducted on the behavior of SIFCON produced with hybrid fibres under sulfate attack.

- SIFCON produced with hybrid fibers with the combinations (SF+HDPF), (SF+PPF), (SF+WPF) show 7.85%, 10.85% and 8.04% increase in compressive strength as compared to SIFCON produced with respective mono fibres.
- SIFCON produced with hybrid fibers with the combinations (SF+HDPF), (SF+PPF), (SF+WPF) show 14.02%, 14.39% and 15.71% increase in tensile strength as compared to SIFCON produced with respective mono fibres.
- SIFCON produced with hybrid fibers with the combinations (SF+HDPF), (SF+PPF), (SF+WPF) show 10.17%, 4.30% and 9.55% increase in flexural strength as compared to SIFCON produced with respective mono fibres.
- SIFCON produced with hybrid fibers with the combinations (SF+HDPF), (SF+PPF), (SF+WPF) show 21.69%, 6.77% and 13.00% increase in shear strength as compared to SIFCON produced with respective mono fibres.
- SIFCON produced with hybrid fibers with the combinations (SF+HDPF), (SF+PPF), (SF+WPF) show 9.95%, 10.33% and 13.52% increase in impact strength as compared to SIFCON produced with respective mono fibres.
- SIFCON produced with hybrid fibers with the combinations (SF+HDPF), (SF+PPF), (SF+WPF) and subjected to sulfate attack show 5.36%, 8.73% and 5.63% increase in compressive strength as compared to SIFCON produced with respective mono fibres.
- SIFCON produced with hybrid fibers with the combinations (SF+HDPF), (SF+PPF), (SF+WPF) and subjected to sulfate attack show 15.76%, 12.90% and 11.04% increase in tensile strength as compared to SIFCON produced with respective mono fibres.
- SIFCON produced with hybrid fibers with the combinations (SF+HDPF), (SF+PPF), (SF+WPF) and subjected to sulfate attack show 38.14%, 13.57% and 12.88% increase in flexural strength as compared to SIFCON produced with respective mono fibres.
- SIFCON produced with hybrid fibers with the combinations (SF+HDPF), (SF+PPF), (SF+WPF) and subjected to sulfate attack show 19.31%, 16.58% and 4.99%increase in shear strength as compared to SIFCON produced with respective mono fibres.
- SIFCON produced with hybrid fibers with the combinations (SF+HDPF), (SF+PPF), (SF+WPF) and subjected to sulfate attack show 6.71%, 7.73% and 9.18% increase in impact strength as compared to SIFCON produced with respective mono fibres.

ACKNOWLEDGEMENT

The authors would like to thank Dr. Jagadish G. Kori, Head of the Civil Engineering Department, teaching and non-teaching staff of Government Engineering College, Devagiri, Haveri for giving all the encouragement needed which kept the enthusiasm alive.

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