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Comparative analysis on strength and stress-strain behaviour of slurry infiltrated fibrous reinforced concrete

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ABSTRACT

The effects of steel mesh and steel fibre orientation on strength properties and stress- strain behaviour of Slurry Infiltrated Fibre Reinforced Concrete (SIFCON) have been studied. In this research, steel mesh of 0.62 mm diameter and aspect ratio of steel fibers 50 mm were used for preparing the specimens. Steel mesh of different percentages (5%, 10% and 15%) was added in parallel orientation and steel fibers were added with 5%, 10% and 15% in both random and parallel orientation. The results of SIFCON and FERRO cement were compared with the normal cement mortar. FERRO cement and SIFCON showed better results on strength parameters and stress-strain behaviour compared to normal cement mortar.

1. INTRODUCTION

Concrete is strong in compression and weak in tension. Since 1970, the Fibre reinforced cementitious composites (FRCC) has been used widely into the concrete to improve the performance of conventional concrete not only in strength parameters but also crack resistance and stiffness. With these benefits, FRCC has been used in many civil engineering structures. In addition to normal FRCC, Slurry Infiltrated Fibre Reinforced Concrete (SIFCON) was developed by Lankard in the year 1984. SIFCON concrete is produced by cement slurry, aggregate, superplasticizers and water over a layer of steel fibers. SIFCON is a high-performance and high-strength concrete consisting of high percentage of steel fibre volume compared to Steel Fibre Reinforced Concrete (SFRC). There are four major design influences that should be typically considered in SIFCON. These include fibre alignment, fibre volume, type and strength of the slurry. Compressive strength, modulus of elasticity and tensile strength of hardened slurry influences the performance of the SIFCON concrete. Fibre orientation (i.e. Parallel or random to the applied load) also has a significant impact on the SIFCON concrete [1].

Sonebi et al (2004, 2005) worked o a statistical approach to improve fresh and hardened performance of SIFCON concrete incorporating lime stone powder or silica fume. They found that SIFCON concrete with silica fumes shows the lesser workability properties compared to lime stone powder but the hardened properties of SIFCON concrete has been decreased with the addition of these mineral admixtures [2]. In addition, the durability and strength properties of SIFCON tension members were examined to develop a model for force-displacement interactions by Zeng and Murakami (1998).

In the present research, an attempt was made to a comparative study on the effect of steel mesh and steel fibre orientation (Parallel and random) in conventional concrete. The parameters like workability, strength (Split tensile strength and Compressive strength) and stress-strain behaviour (SIFCON Vs FERRO CEMENT) were examined.

2. EXPERIMENTAL PROGRAM

2.1 Materials

The concrete mix was made with OPC cement of 53 grades as a binder. For all sample preparations tap water was used in the set water/cement proportion (w/c) of 0.3. The fine aggregate (4.75 mm downgraded) is used as filler materials. OPC is tested as per Indian Specifications IS: 12269 – 1987 [3]. The fine aggregate is tested as per Indian Specifications IS 2386 (Part 1, 3 & 4) – 1963 [4]. Polycarboxylate ether was used as high range water reducers and 0.4% was in this research. A square steel mesh of diameter 0.62 mm with spacing 5 mm and steel fibre with aspect ratio 50 (diameter of 0.6 mm x length of 30 mm) conforming to ASTM A 820 Type 1 was used for the making of SIFCON.

2.2 Fabrication of SIFCON mixes

The concrete mix has been designed and prepared in accordance to guidelines laid down in IS: 10262-2009 [5]. The concrete is drenched into steel moulds and left to harden. After 24 hours these cubes are exiled from the moulds for curing. A total of three altered mixes with varying percentage of steel fibers (5%, 10% and 15%) and steel mesh at 0.30 w/c ratio have been prepared.

2.3 Fabrication of SIFCON mixes

Compressive strength was evaluated from cube specimen of size 150 mm and split tensile strength was carried out on cylinder specimen of 150 mm x 300 mm on a compression testing machine (2000kN capacity) as per IS: 516-1959 with curing period of 28 days [6,7].

2.4 Stress-strain behaviour

Stress-strain behaviour was observed for normal cement mortar, varying percentage of steel fibers in SIFCON (parallel and random orientation) and varying percentages of steel mesh in FERRO CEMENT.

3 RESULTS AND DISCUSSION

3.1 Stress-strain behaviour

The compressive strength results of concrete with the addition of steel fibers and steel mesh (i.e., 5%, 10% and 15%) at a curing period of 28 days are shown in Figure 1. The strength enhancement of SFCON with the random orientation of steel fibers was more compared to parallel orientation because steel fibers act as a bridge between the slurry particles and improve the concrete strength.

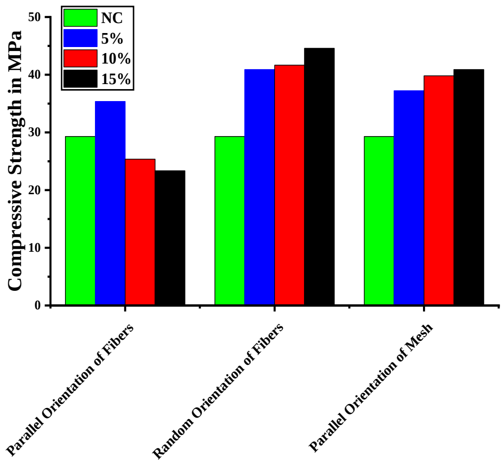

Figure 1. Compressive strength of SIFCON and FERRO cement at 28 days

- Experimental observations establish an increase in compressive strength by 30%, 39.6% and 43% in comparison with conventional cement mortar when 5%, 10% and 15% of hooked steel fibres addition in parallel manner.
- It is observed that there is an increase in compressive strength by 43%, 46%, 55%, in comparison with conventional cement mortar when 5%, 10% and 15% of hooked steel fibres addition in random manner.
- It is evident from the study that there is decrease in compressive strength by 12%, 20% in comparison with conventional cement mortar when 10% and 15% of steel mesh addition in parallel manner and by adding 5% of hooked steel fibres addition in random manner there is increase in compressive strength by 40%.

Decrease in compressive strength is due to the obstruction of mesh which is added by 3 layers in cylinders. Due to this, cylinder is divided into four zones. The top most layer and bottom most layer is taking the load and middle two layers are not taking the load due to obstruction of mesh. Mesh is preventing the load transfer from layer to layer [8].

3.2 Split tensile strength

The shrinkage and thermal stresses results in the development of tension in concrete due to which early age cracking happens. Generally, these stresses are more than concrete's tensile strength which is very low at initial ages. Therefore, it's very much essential to evaluate the tensile strength of concrete. Split tensile strength of cylindrical specimens were recorded at 28 days for 0.3 W/B ratios as shown in Figure 2. From the results, it is clearly observed that the tensile strength with random orientation of steel fibers showed higher tensile strength values than the parallel orientation of steel fibers and parallel orientation of steel mesh. The tensile strength of concrete gets gradually enhanced upto 10% addition of steel fibers or steel mesh after that the tensile strength was decreased drastically [9].

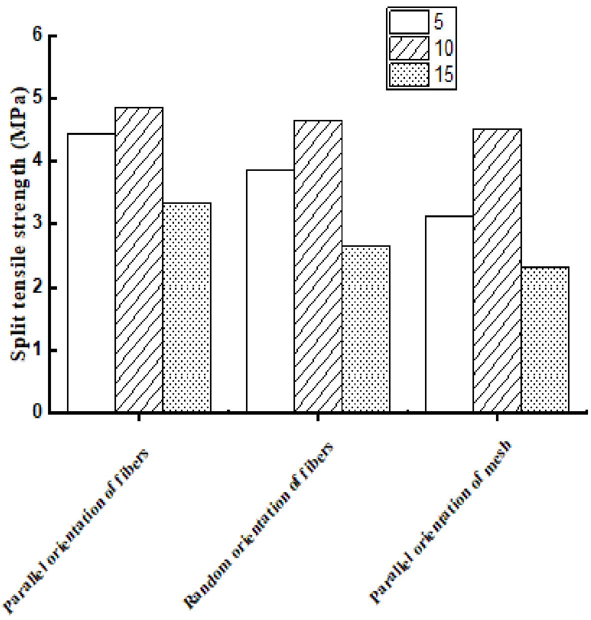

Figure 2. Split tensile strength of SIFCON and FERRO cement at 28 days

- Observations concluded that the tensile strength of conventional cement mortar with 5%, 10% and 15% of hooked steel fibres addition in parallel manner got decreased by 1.91%, 20%, 31%when compared with conventional cement mortar.
- It is established that the tensile strength of conventional cement mortar with 5%, 10% and 15% of hooked steel fibres addition in random manner got increased by 1.67%, 5%, 6.93% when compared with conventional cement mortar.

- Computations established that the tensile strength of conventional cement mortar with 5%, 10% and 15% of steel mesh addition in parallel manner got decreased by 22%, 46.8%, 49.76% when compared with conventional cement mortar.

It is observed that the tensile strength of SIFCON with parallel orientation of fibres and FERRO CEMENT got decreased when compared with conventional cement mortar. The decrease in strength is due to alignment of fibres to the direction in which load is applied. We are applying the load in perpendicular direction to the fibres in spilt tensile strength test, this is because we have to place the cylinders in horizontal direction to perform spilt tensile test.

Table 1. Toughness and young's modulus for all mixes

Mix		Compressive strength	Maximum strain	Strain to peak stress	Toughness	Young's modulus
Normal Cement Concrete		29.29	0.058	0.0043	0.10285	9953
Parallel orientation of Steel Mesh	5%	35.36	0.0082	0.0059	0.21153	8485.7
	10%	25.36	0.0074	0.0050	0.12856	7063.6
	15%	23.35	0.0068	0.0043	0.11743	11352
Random orientation of steel fibers	5%	40.89	0.0067	0.0043	0.18156	12563
	10%	41.65	0.0084	0.0068	0.20895	5315.3
	15%	44.58	0.0068	0.0052	0.18232	7064.3
Parallel orientation of steel fibers	5%	37.23	0.0073	0.0046	0.17420	7002
	10%	39.82	0.0083	0.0078	0.20955	7779
	15%	40.89	0.0068	0.0043	0.19564	8518.3

3.3 Stress-strain behaviour

Stress-strain relationship of concrete with varying percentage of steel fiber in parallel and random orientation is shown in Figure 3 and 4. The stress-strain relation with varying percentage of steel mesh into FERRO cement is shown in Figure 5. In this research, it can be obtained that the steel fiber addition was enhanced the strain after ultimate stress and thus increase the area under the stress-strain curve when fibers are introduced in normal cement mortar. The cement mortar with parallel orientation of steel fibers showed lesser stress and strain values compared to random orientation. With the addition of 5%, 10% and 15% steel fibers parallel orientation showed enhancement in peak stress by 30.72%, 39.58% and 44.05% compared to normal cement mortar, respectively [10-11].

The same pattern was observed with random orientation of steel fibers into cement mortar. The peak stress was increased by 44.195%, 46.68% and 55.94% at 5%, 10% and 15% steel fibers in random orientation compared to normal cement mortar, respectively. The normal cement mortar with random orientation of steel fibers showed more stress values compared to parallel orientation. The parallel orientation of steel mess was added into the cement mortar at different proportion. The peak stresses was increased with 5% steel mesh addition by 31.18% but beyond that the peak stresses were decreased by 11.09% and 19.70% at 10 and 15% steel mess addition compared to normal cement mortar, respectively. In comparison, the cement mortar with random orientation of steel fibers showed more peak stress compared to parallel steel fiber orientation and parallel steel mesh orientation at all percentage variations. It can also be calculated the toughness and young's modulus for steel fiber and steel mesh volume with different orientations are shown in Table 1.

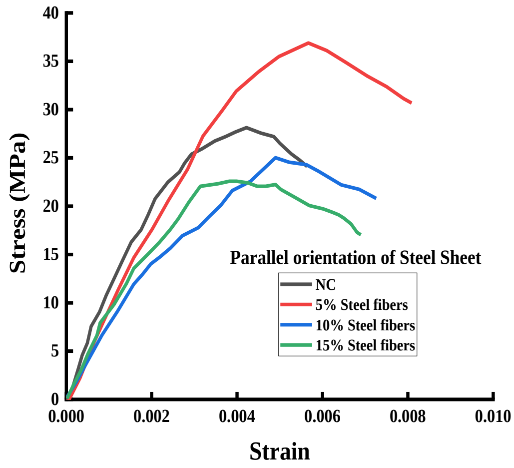

Figure 3. Stress-strain curve of SIFCON with varying percentage of steel fibers in parallel orientation

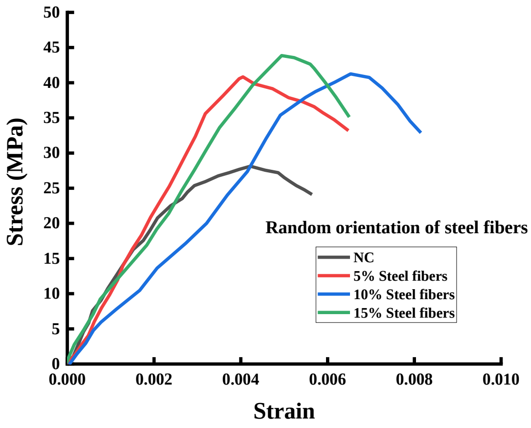

Figure 4. Stress-strain curve of SIFCON with varying percentage of steel fibers in random orientation

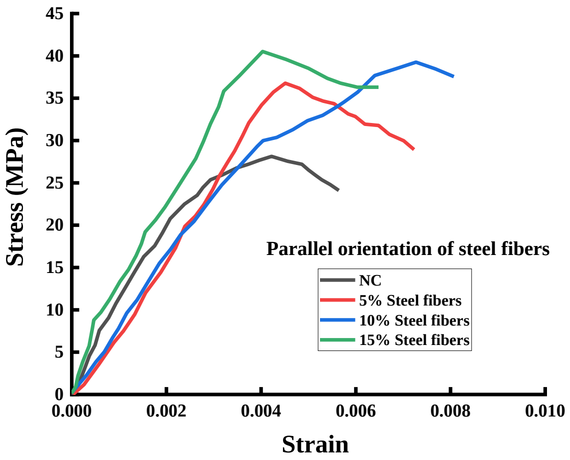

Figure 5. Stress-strain curve of FERRO cement with varying percentage of steel fibers in random orientation

4 CONCLUSION

The following outcomes are drawn from the experiments on stress-strain behaviour, split tensile strength and compressive strength

- SIFCON showed maximum compressive strength values compared to FERRO cement and normal cement mortar because steel fibers act as bridge to the cement and aggregate particles.
- With 10% addition of steel fiber (parallel or random orientation) or steel mesh showed maximum split tensile strength values in all mixes.
- SIFCON and FERRO cement showed similar stress-strain relation compared to normal cement mortar.
- With more percentage of fiber volume showed harsh mix in the concrete.
- Young's modulus of FERRO cement and SIFCON showed more enhancements compared to normal cement mortar.
- Toughness parameter has improved because of fiber addition.

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