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Research Article

COMPRESSIVE AND FLEXURAL BEHAVIOUR OF ULTRA HIGH PERFORMANCE CONCRETE WITH HYBRID STEEL FIBER

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ABSTRACT

This experimental studyinvestigated the effects of hybrid steel fiber of different size (0.2 and 0.5 mm)diameter andshape (smooth and corrugated steel fiber) on the compression and flexural performance of ultra-high performance concrete (UHPC).The compressive strength of UHPC with water-cementitious ratio of 0.23 exceeded 150 MPa after oven curing. The flexural stress-strain graph of UHPC shows a linear-elastic behaviour up to failure, which is unique from that of conventional concrete. The failure pattern, load – deflection relationship, stress–strain relationshipand toughness under UHPC mixture with no fiber and five UHPC mixtures with hybrid steel fiber content of 2% by volume of UHPC, were examined. This examination provides a detailed report of experimentaltest results for the compressive and flexural behaviour of Ultra High Performance Concrete, with increased strength and modulus of toughness. An UHPC mixture with 1.5% of 0.2 diameter and 0.5% of 0.5 diameter fiber showed the best compressive and flexural behavior, whereas those with 2% of 0.5 diameter fiber exposed the worst properties. Based on the attained peak stress, strain at peak stress, and modulus of elasticity, compression and flexural toughness index. UHPC showed high performance under compression and flexural loading. High peak load carrying capacity shows well toughness index and reinforcing properties of the hybrid steel fiber. UHPC has very high mechanical performance.

INTRODUCTION

Concrete is widely used composite material now-a-days, which gained popularity during 18th century. From then, several studies were done on increasing the strength of concrete and its durability. The Ultra High Performance Concrete (UHPC) is based on greater strength and durability characteristics. This (UHPC) concrete is developed to overcome the inadequate strength of traditional concrete by making use of natural resources like silica fume, Quartz sand.

Basically a four step principle is followed suggested by (Shi, *et al*., 2015; Wang; *et al*.; 2015) Improving the microstructure, Boosting up the toughness, lowering the porosity and improving the homogeneity. The combination of reduced water/cement ratio, lowering of Cao to SiO_2 along with the steel fibres makes a conventional concrete into a ultra high performance concrete. The addition of tiny steel fibre makes this concrete superior over the other due to its high toughness and strength (Park, *et al*., 2012; Prabha, *et al*., 2010; Liu, *et al*., 2012; Habel, *et al*., 2006; Wu, *et al*., 2016a). The UHPC can be used in the construction of bridges, reinforced columns, and precast piles.

The UHPC has been the most interested field by the researchers across the world for the past two decades. Though the old-conventional concrete is very low cost efficient, but the problem pertaining

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to it is poor inflexural and tensile strength. One of the special type of concrete known as Reactive Powder Concrete, known for its superior strength greater than 150 MPa, good in tension, improved compressive strength characteristic and bending. From the previous studies of the selection of material for design specification for better strength result is unclear. Some of the few research proved the addition of thin fibres had a massive impact on the behaviour of concrete such as little impact on precracking and significant impact on post cracking characteristics.

(Harish, *et al*., 2013) discussed about the thermal curing of ultra high strength mortars and thus evaluating the stress strain characteristic, in which the high stress peak, strain peak noticed. Another research discussed about the UHPC of reaching the strength 90% at 14^{th} day (Prem, *et al*., 2012; Mansur, *et al*., 1999). The role of fibre such as its content, type and mixing directly affects the stress-strain characteristic. However, these study deals with the monofibre and study on the hybrids fibre are rare.

This research elaborately discuss about the stress-strain characteristic of Ultra high performance concrete including the use of hybrid fibre. The utilization of hybrid fibre in the concrete for increased tensile and flexural strength makes this study unique. In this study, the compressive, flexural strength along with stress-strain relationship and toughness index were determined (Markovic, 2006; Yu, *et al*., 2014; Carreira and Chu, 1985; Ezeldin and Balaguru, 1992).

EXPERIMENTAL PROGRAM

Raw materials

The Ordinary portland cement (OPC) complying with the Indian Standard (IS 12269:1987) Grade 53 and specific gravity of 3.15 was used of particle size 31µm to 7.5 µm. The Silica fume (ASTM C1240 – 97b) standard with anaverageparticle size of 5 µm to 15 µm andspecific gravity of 2.25 was used. A quartz powder of specific gravity 2.59, whose particle size range lies between 15 µm to 50 µm was used. Two steel fibres with the different diameters and shapes smooth (0.2 mm), corrugated (0.5 mm) but same length 13 mm, were used. Their tensile strength of smooth steel fibre was 2, 400 MPa and corrugated was 1800 MPa. The sand used in this experiment are Grade I Coarse, Grade II Medium of particle size range (0.6-2.36) mmand (0.075-0.15) mm respectively. A raw polycarboxylate-based superplasticizer (SP) was preferred. Chemical properties of material given in Table 1.

Mixing

The mixing of concrete was done in a mixer known as Shear pan mixer machine. The advantage of using the shear pan mixture was that it could rotate in both the directions in order to ensure the uniformity in mixing of materials. The water/cement ratio was maintained about 0.24 in this research. The materials are then put into the mixer one by one and allowed to mix for duration of 10 minutes. After starting the mixer, (20% to 30%) water and SP (superplasticizer) were added and the intensity of mixing was improved for a further duration of 10 minutes. The water and SP (50%) were again added into the mix and allowed the mixer to rotate again for 15 minutes. Moreover, the hybrid steel fibres were incorporated into the concrete mix manually. Finally, the remaining 20% of water and super plasticizer were added and the mixer was allowed to rotate for 20 minutes.

Casting and curing

A standard cube, beam, and cylinder mould of 100 × 100 × 100 mm, 100 × 100 × 500 mm and 200 × 100 mm respectively were used. A total of eighteen cubes, eighteen beam and eighteen cylinders were casted for different mix mentioned in Table 2. During casting, the mix was filled into the respective mould in three layers providing some vibration to ensure the uniform distribution of steel fibre. The demoulding was done after 48 hours. The mix M1 to M5 steel fibres having an aspect ratio of 65 and 26 was chosen, length being 13mm, diameter 0.2 mm and 0.5 mm and then total percentage of the steel fiber 2.0% in the concrete volume. The batch M6 is mixed with no fibres.

The curing of the UHPC included hot oven curing. Finally after de moulding the specimens were kept in water curing take for 3 days after which they were kept into hot electric oven at 200°C for duration of

Table 1. Chemical element composition and their density

Chemical composition	CaO (%)	SiO_3 (%)	Al_2O_3 (%)	Fe_2O_3 (%)	SO_3 (%)	MgO (%)	Na_2O (%)	K_2O (%)	C (%)	Density (kg/m^3)
Cement	65.4	20.5	4.5	0.56	2.75	2.45	0.78	-	-	1440
Silica fume	0.30	94.3	0.09	0.10	-	0.43	0.27	0.83	-	650
Quartz powder	0.04	99.00	0.15	0.064	-	0.98	0.54	0.23	-	1201

Table 2. Mixture proportions of UHPC

Trial Mix	Cement (kg/m³)	Quartz powder (kg/m³)	Silica fume (kg/m³)	Sand (kg/m³)	Water (l/m³)	super plasticizer (l/m³)	Smooth fiber (%)	Corrugated fiber (%)
M1	788	315	197	866	189.12	14.77	2.0	0
M2	788	315	197	866	189.12	14.77	0	2
M3	788	315	197	866	189.12	14.77	1.5	0.5
M4	788	315	197	866	189.12	14.77	0.5	1.5
M5	788	315	197	866	189.12	14.77	1	1
M6	788	315	197	866	189.12	14.77	0	0

12 hours. Once the hot curing finished, the specimen were cured under water for 28 days.

EXPERIMENTAL METHODS

Compression test

According to ASTM C109, Compressive strength of UHPC was measured on cube size of 100 cu.mm and then the average strength of UHPC was calculated at after 28 days. The mean value of tested three cubes were finalised the compressive strength of concrete. The compressive strength of cube was carried out in 200 T loading capacity machine. The compressive loading is carried out at the nominal rate of 2.5kN/sec. The peak compressive load was calculated after the specimen failed to withstand the ultimate load, then ultimate loads are observed, and compressive strength is calculated.

Split tensile test

According to BS 1881: 1983, Cylinder (200 × 100) mm samples were used. During the production of concrete, tensile strength is the most important properties in design of the building. Comparing to other steel alloys, concrete is very weak in tension due to its brittle nature and very low withstanding against direct tension. Tensile strength results are very important parameter to analyse of building components which subject to temperature, longitudinal torsion, shrinkage and transverse shear effects. For testing the method vertical lines are sketched on each circumference ending of the cylinder then that lines were in the plane of sample. The cylinders were kept on the wood strip and that the axial lines marked on the ends are upright and placed over the wood strip. Another wood strip and the load bearing bar were kept longitudinally, where the cylinders were tested on a universal testing machine of 2000 kN loading machine. The loading rate was maintained constantly up to the splitting tensile failure occurs in the cylinder. For each mix, three samples of samples were tested at the period of 28 days.

Flexural strength

According to ASTM C1609, The flexural strength of UHPC is measured using the standard size of the specimen for hybrid steel fibre concrete using various factors obtain from the load vs deflection curves such as resilience, toughness and ductility of material. The flexural behaviour is calculated by testing the prismatic beam with four-point loading using a servo hydraulic pressure controlled testing equipment. The flexural performance of UHPC is observed by the standard ASTM C1609 method. From the load-deflection curve several parameters were derived. The flexural behaviour is measured by testing a simply supported beam (SSB) under four-point loading using a hydraulic load testing equipment. Flexural strength shall be calculated by the equation below.

$$\sigma_b = \frac{Pl}{bh^2}$$

Where σ_b : flexural strength (N/mm²)

P : maximum load on specimen (N)

L : span (mm)

h : height of the beam (mm)

Flexural toughness

According to JSCF-SF4, The standard method for flexural toughness of steel fiber reinforced concrete identified by JSCF-SF4. The deflection measuring equipment used for computing the load Vs deflection curve of a samples are connected with electrical linear variable differential transformers (LVDT) and capable of observing the deflection with high accuracy. Load will be applied to the sample constantly without having any impact. The loading rate up to ultimate load failure shall follow JIS A1106 method of the test for flexural strength of UHPC. The ultimate load obtained by the testing system up to failure of the specimens. Flexural toughness shall be expressed by flexural toughness factor. Flexural toughness will be calculated from the area under the load-deflection curve until the observed deflection 1/150 of the span (l). Flexural toughness was expressed by flexural toughness index or factor, formula for the flexural toughness factor given below.

$$\overline{\sigma_b} = \frac{T_b}{\delta_{tb}} * \frac{l}{bh^2}$$

Where, $\overline{\sigma_b}$: flexural toughness factor (N/mm^2)

T_b: Area under the load vs deflection curve (J)

δ_{tb}: Ultimate deflection (mm)

b : Width of the beam

h : Height of the beam

Ductility

The fracture energy of a concrete could be determine by the load – deflection curve in the specimen. It is used to measure of the resistance of the material elements or structure components to change in volume of concrete during the transformation of the elastic limit to the plastic limit until failure. That can be also used measure the fracture energy of the structural members. In common the ductility of specimen could be calculated through the ductility index, it shall also expressed in term of the ductility index, where μ represent the deflection ductility index of the components, Δ_u indicates the deflection of the components at the failure load and Δ_y means the deflection of a components at the elastic load, Equation of the ductility index showing in below.

$$\mu = \frac{\Delta_u}{\Delta_y}$$

RESULTS AND DISCUSSION

Compressive strength

The compressive strength of mix (M1-M6) evaluated 28 days are shown Table 3. In experimental studies show which the samples reach 80% of the compressive strength at the age of 14 days. In general the various mix proportion having identical fibre volume regardless of aspect ratio made 20% increase in compressive strength. While the outcome result demonstrated that compressive strength not depends too greatly on the reinforcement index of hybrid fibre. This impact might be portrayed by long- term pozzolanic responses (result of cement hydration). The compressive strength of concrete specimen attains 80% strength at 14 days and remaining 20% achieves in 28 days from casting of specimen.

Split tensile strength

The split tensile strength result are brings out on the cylinder specimens are shown in Table 3. Comparing to the conventional concrete UHPC shows there is a better amount of improvement in that split tensile loading strength of the concrete up to adding of hybrid steel fibers. In experimental values are improved around 200% at the hybrid steel fiber capacity of 2% Corrugated fibres exhibited a very low tensile strength than smooth fibres. In considering one of the most important part adding hybrid steel fiber in UHPC is to increase its split tensile strength. A hybrid fibers utilized in this research had attained the objective of concrete.

Flexural strength

Flexural behavior of specimen was observed at the age of 28 day and result show in Table 3. The mix ratio of concrete show (M1-M6). The mix M3 show better result than other the batch mixes results exhibited a linear relationship.

Flexural toughness

This test investigation examines the flexural behaviour, toughness and flexural toughness factor ratio of hybrid steel fiber reinforced concrete using JSCF-SF4. The (Fig. 1 and 2) show the load – deflection curve for (M1-M6). From the load - deflection curve parameter are calculated in Table 4. The first-ultimate stress describes the flexural property of the steel fiber concrete until initial cracking, while yield strength at indicated deflections characterizes the yield capability after initial cracking. Flexural toughness is an amount of the energy absorption capacity of the test on prismatic beam. The initial crack, yield state and toughness obtained by the test method return the strength of steel fiber concrete under flexural loading.

Ductility

Ductility index shows the fracture energy of the

Table 3. Mechanical properties of concrete

Mix	Compressive strength (MPa)	Split tensile strength (N/mm^2)	Flexural strength (N/mm^2)	Flexural toughness (J)	Flexural toughness Factor (N/mm^2)	Ultimate strain in beam (mm)	Ultimate deflection in beam (mm)
M1	162	10.47	21.8	18380	7821.87	0.0164	0.94
M2	151	11.23	18.4	20820	7114.05	0.0271	1.21
M3	183	13.8	27.2	21520	12069.57	0.0210	1.17
M4	172	10.48	20	18160	8446.51	0.0154	0.86
M5	161	10.42	18	9430	6083.87	0.0124	0.91
M6	110	9.65	12.8	8660	5972.41	0.0184	0.58

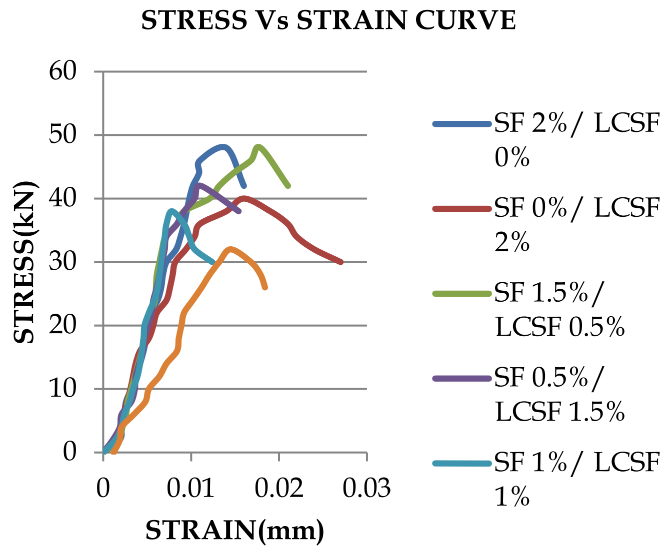

Fig. 1 Strain-Strain curve for beam. SF: Smooth Steel Fiber, LCSF: Low Carbon Steel Fiber (Corrugated SF: Smooth Steel Fiber, LCSF: Low Carbon Steel Fiber (Corrugated Steel Fiber).

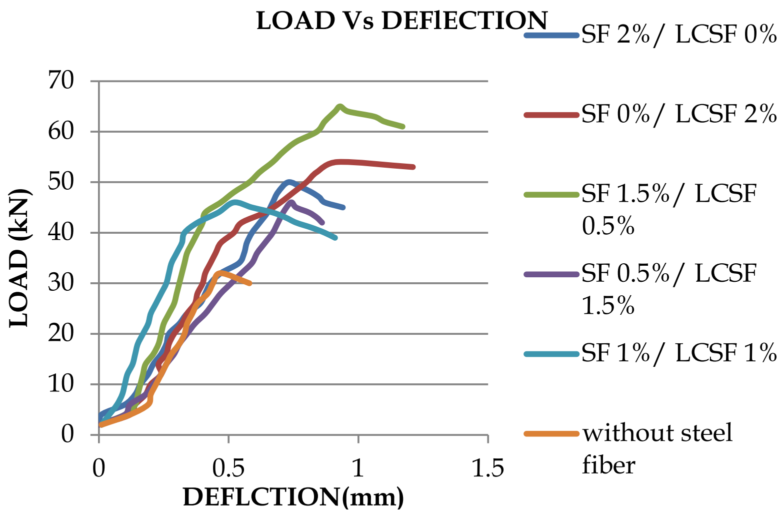

Fig. 2 Load vs. deflection for beam.

Table 4. Ductility index

Beam Specimens	Initial Cracking		Yielding State		Peak State		Ultimate Deflection	Ductility Index	
	P_{cr}	Δ_{cr} (mm)	P_y	Δ_y (mm)	P_p	Δ_p (mm)	Δ_u (mm)	Δ_p/Δ_y	Δ_u/Δ_y
M1	25.9	0.35	38	0.57	50	0.73	0.94	1.28	1.64
M2	26.7	0.41	42	0.56	54	0.92	1.21	1.64	2.16
M3	32.5	0.32	52	0.54	65	0.93	1.17	1.72	2.16
M4	22.41	0.38	34	0.62	46	0.74	0.86	1.19	1.38
M5	23.4	0.31	38	0.28	46	0.52	0.91	1.85	3.25
M6	16.14	0.24	-	-	32	0.62	0.58	-	-

concrete, the higher the energy absorption capacity of the concrete (J), the higher the ductility property of concrete. Comparing to normal concrete UHPC having higher fracture energies due to the fiber capacity to bond between the cracks. The fracture energy can be determine the various setup such as splitting, flexural and direct tests. Mix M3 show better fracture energy than other controlled mix.

CONCLUSION

The following conclusions were pulled out from this research,

- The mechanical properties were evaluated and it is been found that the compressive strength of 28 days was in the strength of 110-183 Mpa for M1 to M6 mix of concrete respectively. The flexural and splitting tensile strength were about 27.2 to 12.8 MPa and 9.65 to 13.8 MPa respectively, were similar to compressive strength result, thus confirming the effectiveness of utilizing the fibre, silica fume and quartz sand.
- From the pre-peak region the stress-strain relationship a linear ascending segment is seen and also the increment in the strain is visible at peak stress with higher strength of concrete and reinforcement index. A gradual post peak curve was observed due to the addition of fibrecontent which shows the positive impact of fibre on the concrete.

Therefore, UHPC which makes use of hybrid fibres and natural resources paved way for new revolution in construction field and can be used in the construction of tall towers, piles and bridges.

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