International Journal of Innovative Research in Advanced Engineering (IJIRAE) ISSN: 2349-2763
Issue 08, Volume 3 (August 2016) www.ijirae.com

EXPERIMENTAL STUDY ON THE PERFORMANCE OF HYBRID FIBRE REINFORCED CONCRETE AT ELEVATED TEMPERATURES

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Abstract— The main objective of this study is to understand the fundamental behaviour of FRC when it is exposed to elevated temperatures. However, rather than relying on one type of fibre, this study proposed of mixing two different types of fibre in concrete which will then be exposed to elevated temperatures from normal temperature i.e. 27 °C (room temperature) to 200°C, 400 °C and 600 °C for one hour and cooled to room temperature before testing. The two types of fibres used, steel and Recron 3s (polyester) fibres, have different characteristics. The study is mainly focused on the experimental work. Concrete mixes prepared are without fibre, with either or both steel fibre and Recron 3s fibres. Dosage of steel fibre is 1% by volume of concrete and Recron 0.1% by volume of concrete. The study deals with the comparison of residual strength of hybrid fibre reinforced concrete with fibre reinforced concrete. Experimental work was carried out to study the impact of elevated temperatures on the compressive strength, tensile strength and ultrasonic pulse velocity.

Keywords— Steel Fibre, Polyester Fibres, Elevated Temperature, Hybrid Fibre Reinforced Concrete, Residual Compressive Strength, Residual Split Tensile Strength

I. INTRODUCTION

Plain concrete possesses a very low tensile strength, limited ductility and little resistance to cracking. Internal micro cracks are inherently present in the concrete and its poor tensile strength is due to the propagation of such micro cracks, eventually leading to brittle fracture of the concrete. The addition of small, closely spaced and uniformly dispersed fibres to concrete would act as crack arrester and would substantially improve its static and dynamic properties. This type of concrete is known as Fibre Reinforced Concrete [1]. Fire has become one of the greatest threats to concrete structures and during fire concrete gets exposed to elevated temperatures. High temperatures influence the durability of concrete structures and may result in undesirable structural failures.

Addition of steel fibres minimise the degradation of compressive strength for concrete after exposure to elevated temperatures. Polypropylene fibre reinforced concrete showed reduced energy absorption capacity of concrete after exposure to 800°C whereas steel fibre reinforced concretes showed highest energy absorption capacity after exposure to high temperatures [2]. On heating polypropylene fibre reinforced concrete up to 170°C, fibre readily melts and volatilise, creating additional porosity and small channels in the concrete [3]. SFRC with 1% steel fibre on exposure to temperatures up to 400°C, loss in compressive strength is relatively small. SFRC performs better than non-SFRC for maximum exposure temperatures below 1000°C, even though the residual strength was very low [4].

Relative compressive strength of concrete containing PP fibres is higher than those without PP fibres. Presence of PP fibres is more effective for compressive strength than split tensile strength above 200°C [5]. Addition of PP fibres is very effective in mitigation of spalling and build-up of pore pressure inside heated HSC. Addition of steel fibres plays some role in pore pressure reduction at relatively higher pressures in deeper regions of concrete during fast heating [6]. The addition of steel fibres is helpful in preventing spalling, and significantly improves the ductility and the cracking behaviour of recycled aggregate concrete (RAC) after exposure to high temperatures [7]. Incorporating two or more type of fibres in concrete can increase its resistance to loss of strength and explosive spalling when exposed to elevated temperatures. This study deals with the effect of steel fibre and polyester fibre on residual mechanical strength of concrete when exposed to elevated temperatures.

II. EXPERIMENTAL INVESTIGATION

Specimens used for this were standard size cubes (150 mm) and cylinder (150 mm diameter and 300 mm height). The mix design for M30 grade concrete was done as per IS 10262:2009. All materials were batched separately by weight. The ingredients of concrete were mixed thoroughly in mixer machine till the uniform consistency was obtained. Concrete was poured into the mould, compacted and the top surface was finished by means of a trowel. The specimens were removed from the mould after 24 hours and water curing was done for a period of 28 days. After curing, the specimens are subjected to heating to required temperature. The tests were conducted after cooling the specimens to room temperature. Tests were done as per the relevant Indian standard specifications.

A. Material Details

The materials used in the investigation are:

1) *Cement: Cement used was 53 grade OPC cement having a specific gravity of 3.14*
2) *Fine Aggregate: Manufactured sand (M-sand) has been used for the present investigation. It conforms to Zone II of IS 383 with a specific gravity of 2.62 and fineness modulus 2.76.*
3) *Coarse Aggregates: The maximum size of the aggregates used was 20mm and 12mm. The specific gravity of coarse aggregates is 2.67.*
4) *Water: In the present study potable water was used for mixing and curing conforming to IS:456-2009.*
5) *Superplasticizer: Superplasticizers helps to reduce the water content, thereby effectively controlling the water-cement ratio to achieve the design strength. BASF Master Glenium Sky 8233 was used in this study. And it was purchased from Century Private Limited, Kakkanad.*
6) *Steel fibres: In this study, steel fibres were collected from Jeetmull Jaichandlal Madras Pvt ltd. Steel fibres used are hooked fibres with 30mm length, 0.5mm diameter and aspect ratio of 60. Density of steel fibre is 7860Kg/m^3*
7) *Recron 3S fibre: Recron 3S is a secondary reinforcement product for construction developed by Reliance Industries Limited. 12mm Polyester Triangular Fibre (type CT 2024) is used in this study. Dosage of Recron fibre is 900g/m^3 (0.1% by volume of concrete).*

TABLE 1: MIX PROPORTION OF M30 CONCRETE

MIX DESIGNATION	C00	C10	C11	C01
W/C RATIO	0.43	0.43	0.43	0.43
CEMENT (KG)	388	388	388	388
FA (KG)	670	670	670	670
CA (KG)	1200	1200	1200	1200
WATER (L)	167	167	167	167
ADMIXTURE (L)	1.37	1.37	1.37	1.37
STEEL FIBRE(% BY VOLUME OF CONCRETE)	0	1	1	0
RECRON 3S FIBRE(% BY VOLUME OF CONCRETE)	0	0	0.1	0.1

B. Heating of Specimens

The specimens are heated using an electrically heated air circulating furnace (fig. 1). The inside of the oven is cylindrical in shape with 400mm internal diameter and 600mm deep. In the present study, unstressed residual strength test has been conducted. The specimens are heated without preload at a prescribed rate to the target temperature which is maintained until thermal steady state is achieved and the specimens are cooled to room temperature and following tests were conducted.

C. Tests on Concrete

1) *Compressive Strength Test:* Compressive strength test was conducted on cube of size 150 mm as per IS 516:1959.The test was done after 28 days of water curing and heating. Specimens were tested only after cooling it to room temperature.
2) *Split Tensile Strength Test:* Split tensile strength test was conducted on cylinders of size 150 mm diameter and 300 mm height as per IS 5816:1999 after exposure to high temperatures and cooled to room temperature.
3) *Ultrasonic Pulse Velocity test:* Non- destructive ultrasonic pulse velocity test values are used to determine the properties of concrete. Tests were conducted on cubes as per IS 13311: 1992 (Part 1).

Fig. 1 Electrically Heated Air Circulating Furnace

III. RESULTS AND DISCUSSIONS

A. Residual Compressive Strength

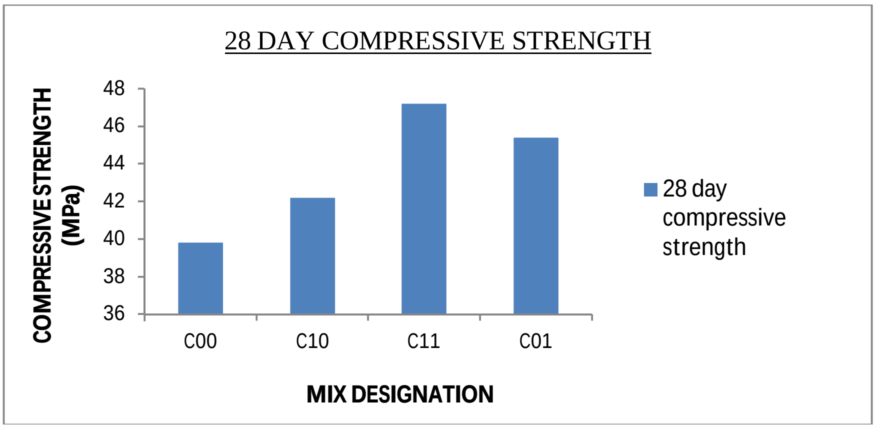

Fig. 2 28 day Compressive Strength

Addition of fibres increases the compressive strength. 28day compressive strength increased about 20% on addition of hybrid fibre. Recron fibre incorporation increased about 14% while steel fibre increased compressive strength about 6%. Results show that addition of hybrid fibre gives higher compressive strength than individual fibres.

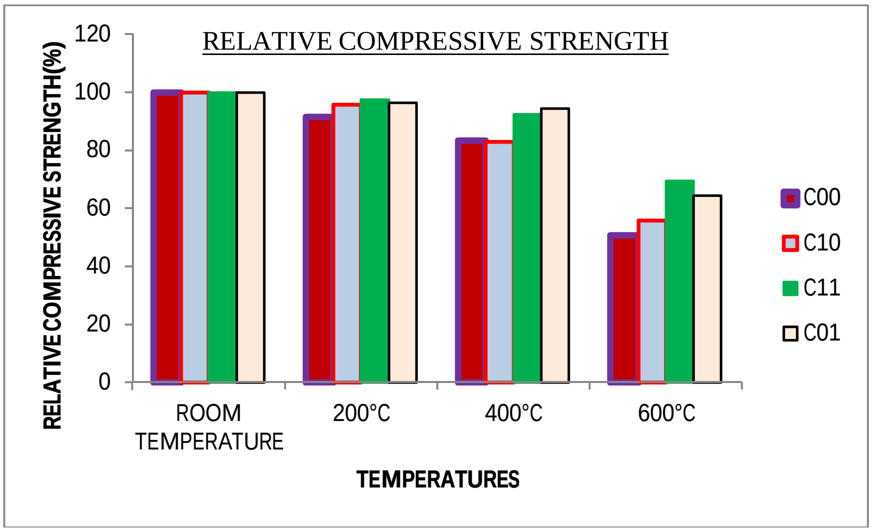

Fig. 3 Relative Residual Compressive Strength

There is a considerable loss of strength when exposed to 600°C. Hybrid fibre reinforced concrete shows more resistance to loss of compressive strength. Loss of strength increases with increase in exposure temperature. Relative residual compressive strength is the ratio residual compressive strength at elevated temperature to the compressive strength at room temperature. Fig. 3 represents the relative residual compressive strength of each mixes at different temperatures. Presence of fibres retained 95% of strength when exposed to 200°C compared to control mix having 90% of initial strength. Strength loss up to 400°C is gradual. Hybrid fibre reinforced concrete retained about 69% of initial strength. Addition of hybrid fibre reduced about 18% strength loss at 600°C.

B. Residual Split Tensile Strength

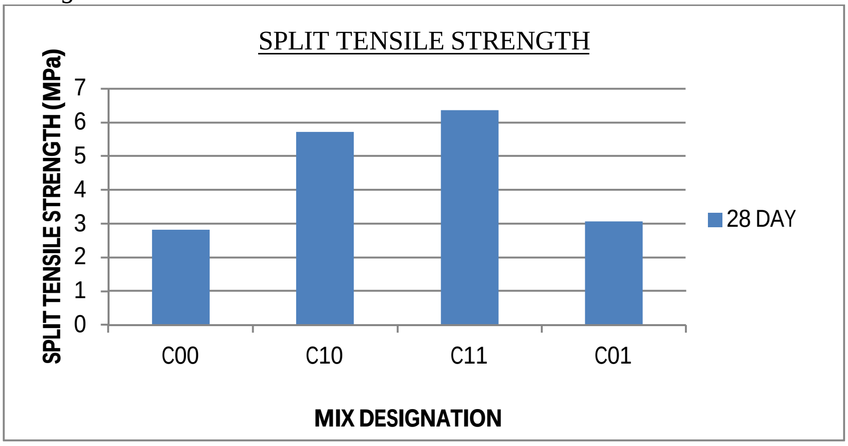

Fig. 4 28 day Split Tensile Strength

The variation of split tensile strength is similar to that observed in case of compressive strength, except for C01. Addition of Recron fibre increased the compressive strength but split tensile strength does not increased significantly. Split tensile strength doubled on addition of steel fibre. Addition of hybrid fibre gave the maximum split tensile strength of 6.36MPa.

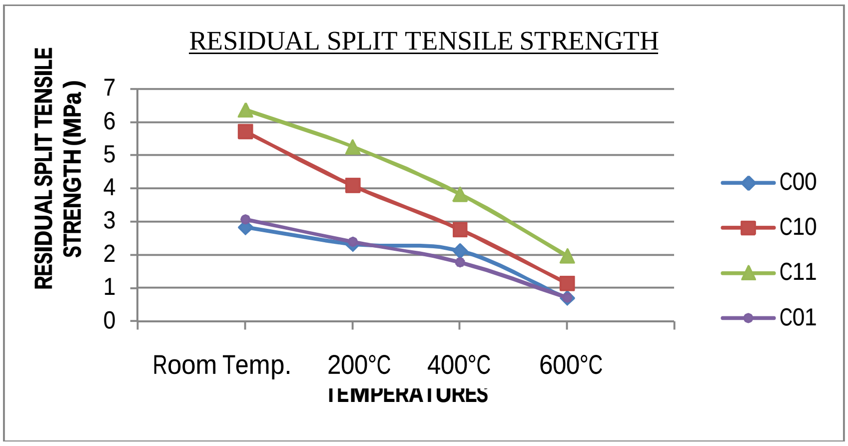

Fig. 5 Residual Split Tensile Strength

The loss of split tensile strength is considerably sharp when compared to loss of compressive strength. This is because that tensile strength is more sensitive to cracks either on macro or on micro scale caused by the elevated temperature. Loss of tensile strength in case of C01 shows similar pattern as that of control mix. Mixes having steel fibres shows more sharp loss of strength compared to control mix. Hybrid fibre reinforced concrete has higher residual tensile strength compared to other mixes.

Fig 6 represents the relative residual split tensile strength of the mixes at elevated temperatures. Loss of tensile strength was highest for C10 mix. At 200°C, control mix and C11 mix retained about 80% of its initial strength. At 400°C, C11 has undergone more strength loss. When exposed to 600°C, C11 retained max strength of about 25% of initial strength.

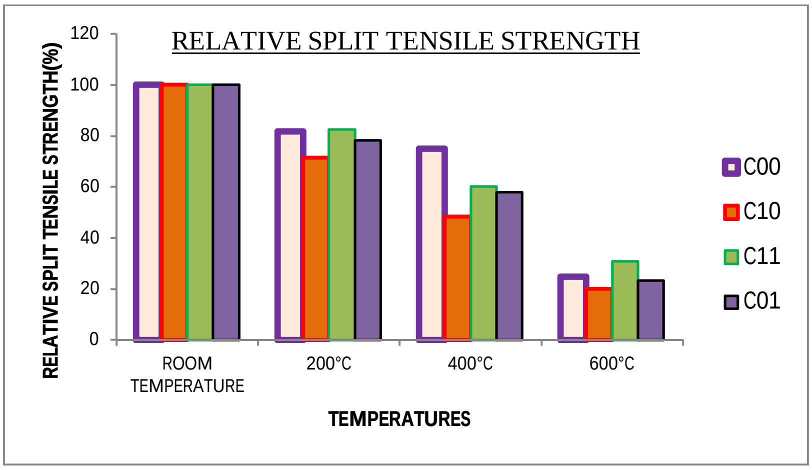

Fig. 6 Relative Residual Split Tensile Strength

C. Ultrasonic Pulse Velocity

UPV is used as a relative measure of concrete quality.

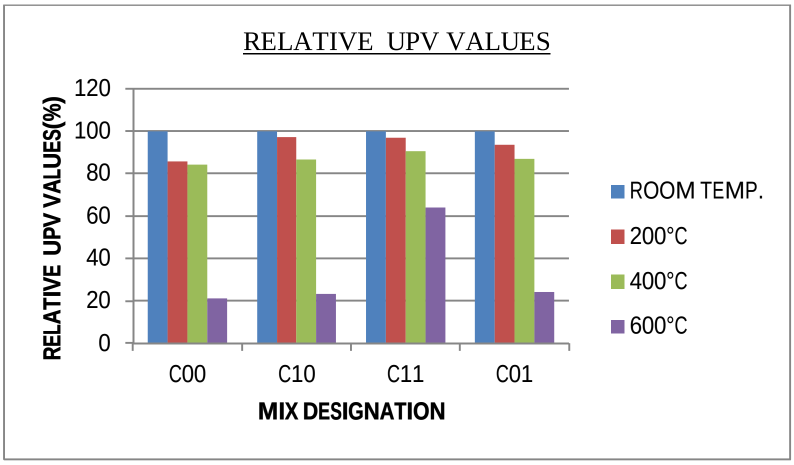

Fig. 7 Relative Residual UPV

After exposure to 600°C, C11 has a residual UPV value of about 60% of initial value. Other mixes have a significant loss of UPV values when exposed to 600°C. IS 13311(Part 1): 1992 classification of the quality of concrete based on UPV measurements at room temperature is presented in Table 2. Accordingly, C10 and C11 are classified as excellent and C00 and C01 are classified as good at 200°C. All the mixes are classified as good at 400°C and all the mixes except C11 are classified as poor at 600°C

TABLE 2 : PULSE VELOCITY RATINGS FOR CONCRETE QUALITY GRADING (AS PER IS 13311(PART1):1992)

PULSE VELOCITY(KM/S)	> 4.5	3.5- 4.5	3.0 - 3.5	< 3.0
QUALITY	EXCELLENT	GOOD	FAIR/MEDIUM	POOR

IV. CONCLUSIONS

Based on the results of this experimental study, the following conclusions can be drawn:

1) *Strength loss increases with increase in exposed temperature. Addition of Recron 3s fibre has little influence on split tensile strength but 14% increase in compressive strength while addition of 1% steel fibre increased compressive strength to 6%. Addition of hybrid fibre doubled split tensile strength and 18% increase in compressive strength.*
2) *Relative residual compressive strength of C11 and C01 were 64% and 69% respectively at 600°C. There is a gradual strength reduction up to 400°C for both C11 and C01 mixes. C11 exhibited maximum relative residual compressive strength.*
3) *The loss of split tensile strength is considerably sharp when compared to loss of compressive strength. This is because that tensile strength is more sensitive to cracks either on macro or on micro scale caused by the elevated temperature.*

4) *After exposed to 200°C, C11 retained about 82.5% of its unheated split tensile strength on average, which further reduced to 60.2% and 30.9% after exposure to 400°C and 600°C respectively. All other mixes retained only about 20-25% of its initial strength when exposed to 600°C.*
5) *Combined effect of steel and Recron fibre can be seen in hybrid fibre reinforced concrete with 18% increase in compressive strength and more than double the split tensile value.*
6) *UPV value decreases with increase in exposure temperature due to formation of cracks.*
7) *UPV values of all mixes except C11 converges to a range of 1-1.2km/s, being classified as of poor quality*
8) *At 600°C, C11 retains about 64% of initial UPV value at room temperature.*
9) *C11 exhibits better resistance to effects of temperature compared to other mixes.*

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