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Tensile Behaviour of Concrete with Steel Fibers Subjected To High Temperatures

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Abstract : The present study aims at comparing the split tensile and flexural strengths of plain concrete and steel fibre reinforced concrete subjected to high temperatures. The grade of concrete designed for investigation is M30. The fibres used for investigations are hook end steel fibres with aspect ratio 50. The dosage of fibres added was 3% by weight of cement. The specimens of size 150 mm diameter and 300 mm length cylinders and 100 x 100 x 500 mm prisms are cast for testing. The samples are cured for 3, 7, 28 and 56 days. The specimens are air dried and then exposed to 27, 100, 200, 300 and 400°C for duration of one hour and cooled to room temperature and then the cylinders are tested under 2000 kN digital compression testing machine and the prisms are tested under 1000 kN digital universal testing machine. When exposed to elevated temperatures, standard concrete with steel fibres performs better than the plain concrete without steel fibres. All the results and observations are analysed and presented in the paper.

Key words: Steel fiber reinforced concrete, split tensile strength, flexural strength and air cooling.

I. INTRODUCTION

Concrete is widely used as a primary structural material in construction due to numerous advantages, such as strength, durability, ease of fabrication, and non combustibility properties, it possesses over other construction materials. concrete is a material widely used for the construction, due to its low thermal conductivity and high specific heat. With the increase incidents of major fires and fire accidents in buildings; assessment, repair and rehabilitation of fire damaged structures has become a topic of interest.

Exposure of concrete to elevated temperature affects its mechanical and physical properties. Physical and chemical transformations takes place in concrete during first heating which can result in significant loss in strength. Concrete structural members when used in buildings have to satisfy appropriate fire safety requirements specified in building codes.

This is because fire represents one of the most severe environmental conditions to which structures may be subjected; therefore, provision of appropriate fire safety measures for structural members is an important aspect of building design.

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II. LITERATURE REVIEW

Hadad et al [9] conducted experimental investigation of the residual bond strength of fiber reinforced concrete at elevated temperatures. The types of fibers used in the experiment were brass coated steel fibers, hook end steel fibers and polypropylene fiber with constant volumetric fraction of 2%.a the test was conducted on heat exposure of 350, 500, 600 and 700°C. It was concluded that the loss of bond between the fibers and surrounding concrete decreased with increase in temperature. Steel fibers effectively reduce the cracks in the concrete. Hook end steel fiber produced the better results when concrete is heated upto700°C compared to other fibers.

Sofren Leo et al [8] studied the behaviour of spalling resistance with varying fiber volume fraction, fiber length and fiber material. The test was conducted at 200 and 400°C for two hours exposure duration. It was found that addition of steel fiber were effective in bridging the cracks, and also polypropylene fibers developed more pores in the concrete. The effect of fiber length, longer fiber would tend to reduce permeability performance.

Gayathri et al [2] studied on performance of PVA(poly vinyl alcohol) fiber reinforced concrete. The physical properties of PVA fibers were 6mm length, 38um dia, 1400Mpa tensile strength, 41.7 Gpa young's modulus and 1.3 specific gravity. The volume fractions of fibers used were 0.15%, 0.3% and 0.45%. The grade of concrete designed is M30. The sizes of cubes used are 100x 100x 100 mm. The size of prisms used are 500x 100x 100 mm. The specimens are tested for the age of 28 days. The inclusion of PVA fibers resulted in on increment in the flexural strength. As fiber percentage increases, the flexural strength got improved, at 0.15% volume of fibers the flexural strength increased to 17.15 %, at 0.3% volume fibers the flexural strength increased to 30.3 % and at 0.45% volume of fibers the flexural strength increased to 40% when compared to conventional concrete.

Arun kumar et al [1] studied on performance of micro steel polypropylene fiber reinforced concrete. The grade of concrete designed for the investigation is M50. The micro steel fibers (1%) with aspect ratio 28 (12.5mm length and 45mm dia), The micro polypropylene fibers (0.25% & 0.5%) with aspect ratios 120 (12mm length and 0.1mm dia) and 67 (20mm length and 0.3 mm dia) were used for the study. The split tensile strength improved by 47% to 57% at 28 days and 40% to 68% at 90 days respectively. The high split strength was due to presence of steel and polypropylene fibers that increased the ultimate load and also the concrete matrix that was visually to be dense with the bridging of fibers with in cracks.

III. EXPERIMENTAL PROGRAMME

A. Materials used:

Cement: Portland pozzolana cement (PPC) used in this study conforms to IS 1489-1:1991.
Sand: Locally available river sand with specific gravity 2.57 conforming to grading zone II of IS 383:1970 is used.
Water: Potable water is used for the present study.
Coarse aggregate: Coarse aggregate having specific gravity 2.78 is used.
Steel fibres: Hook-end type with aspect ratio 50 is used.
Mix proportions (M30): 1:1.82:3.35 with w/c ratio 0.45 (IS 10262:2009)

B. Casting and curing of specimens:

The specimens of 150 mm diameter and 300 mm length cylinders are used to find split tensile strength of concrete. The specimens of 500mm X 100mm X 100mm beams are used to find flexural strength of concrete. The specimens were demoulded after 24 hours from the time of casting and the specimens are kept under water till the time of testing i.e., 3, 7, 28 and 56 days.

C. Testing of specimens:

After completion of curing period, these cylinders and beams are exposed to temperatures 27, 100, 200, 300 and 400°C for one hour in the oven. After specified temperature exposure is completed, the specimens are removed from oven and allowed to cool and then tested.

D. Split tensile strength test:

After the completion of curing period, the cylinders are tested on digital compression testing machine (2000 kN) according to IS 5816-1999. Each sample comprising of 3 cylinders was tested and average value is reported.

Fig. 1 Tensile strength test

E. Flexural strength test:

After the completion of curing period, the beams is tested on digital universal testing machine (1000 kN) according to IS 516-1959. Each sample comprising of 3 beams are tested and the average value is reported.

Fig. 2 Flexural strength test

Fig. 3 Hot air oven

IV TEST RESULTS AND DISCUSSIONS

A. Tensile strength

Plain concrete when exposed to high temperatures is subjected to physical changes leading to the evaporation of moisture which is useful for the process of hydration. This in turn reduces the strength and thereby develops internal stresses which lead to micro cracks. This problem is restricted by the addition of steel fibres which arrests the development of micro cracks, increasing the strength. In the present investigation, splitting tensile strength and flexural strength of controlled concrete without fibres i.e., 0% fibres of M30 grade is compared with that of steel fibre reinforced concrete. On comparing the results, tensile strengths of steel fibre reinforced concrete were on higher side than that of controlled concrete without fibres in both the factors of age and temperature.

a. Effect of temperature on tensile strength

To study the effect of temperature the variation of percentage relative tensile strength with temperature is plotted in Fig. 4 to Fig. 7.

Table 1 Percentage relative tensile strength for different temperature exposures at different ages.

S. No.	Fiber content (%)	Age of test (days)	Percentage relative Tensile strength (N/mm²)				
			27°C	100°C	200°C	300°C	400°C
1	0	3	52.14	54.64	62.5	43.21	30.71
	3		57.14	62.5	64.24	47.86	37.5
2	0	7	52.86	60	64.29	46.43	42.86
	3		61.79	72.86	66.07	49.64	45.00

3	0	28	100	80	72.14	65.36	57.5
	3		125.4	88.6	80	75	72.14
4	0	56	117.1	83.57	93.93	86.07	77.65
	3		136.1	91.79	97.14	90.71	79.64

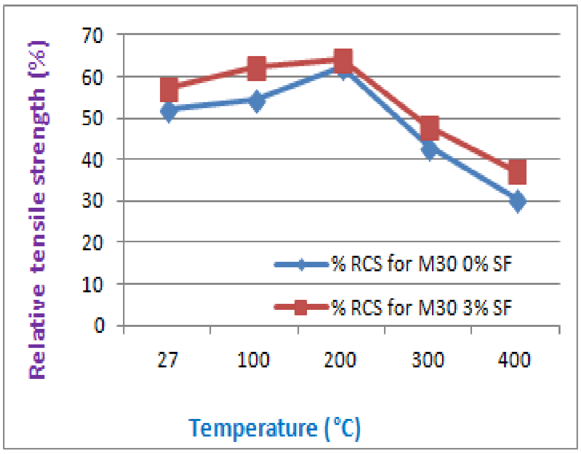

Fig. 4 Variation of relative tensile strength with temperature at the age of 3 days

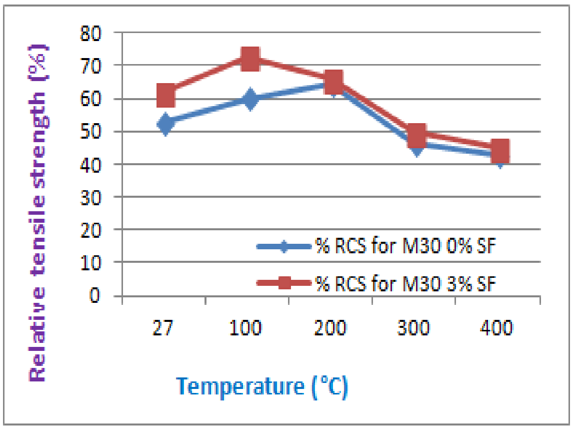

Fig. 5 Variation of relative tensile strength with temperature at the age of 7 days

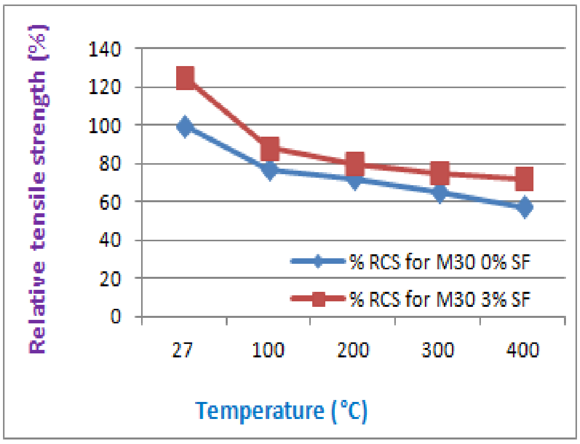

Fig. 6 Variation of relative tensile strength with temperature at the age of 28 days.

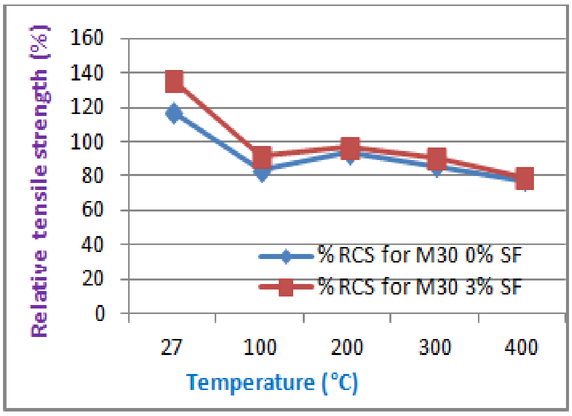

Fig. 7 Variation of relative tensile strength with temperature at the age of 56 days.

Referring Fig. 4 to 7, it is noticed that the obtained split tensile strengths of M 30 standard controlled concrete are appreciably less compared to that of steel fiber reinforced standard concrete mix for all exposure temperatures. This can be attributed to the low tensile strength of plain concrete. The low tensile strengths lead to the propagation of internal micro cracks, which causing brittle failure of concrete.

It is observed that there is a significant rise in tensile strength at 200°C at 3 days for both M30 controlled concrete and M30 steel fiber reinforced concrete.

It is observed that there is a significant rise in tensile strength at 100°C at 7 days for M30 controlled concrete and there is a significant rise in tensile strength at 200°C at 7 days for M30 steel fiber reinforced concrete.

It is observed that there is a significant rise in tensile strength at 27°C at 28 and 56 days for both M30 controlled concrete and M30 steel fiber reinforced concrete.

It is observed that M30 steel fiber reinforced concrete shows better strengths than M30 controlled concrete at high temperatures for all ages.

b. Effect of age on tensile strength

To study the effect of age, the variation of % relative tensile strength with age for different temperatures is plotted. For the present work 3, 7, 28 and 56 days curing periods are considered.

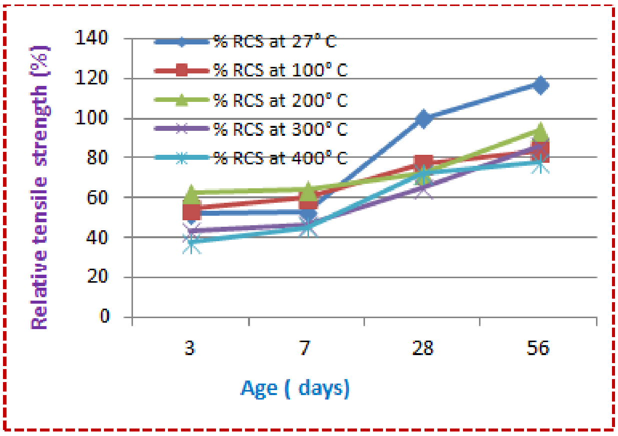

Fig. 8 Variation of relative tensile strength with age for concrete without fibres

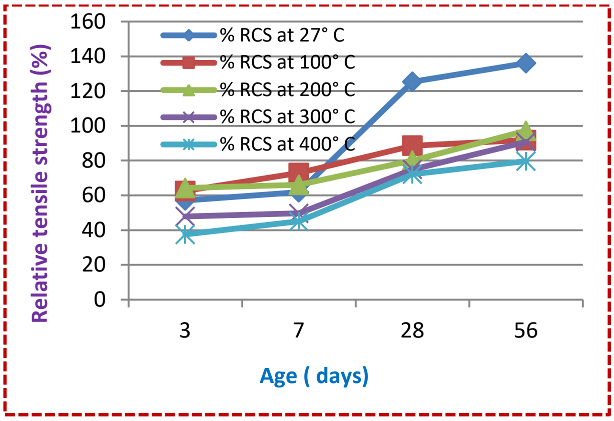

Fig. 9 Variation of relative tensile strength with age for concrete with 3% steel fibres

It is observed that as the age of concrete increases, the tensile strength also increases gradually for all temperatures for both M30 controlled concrete and M30 steel fiber reinforced concrete. Steel fibers in concrete reduce the internal pore pressure by absorbing the heat and help in arresting the bursting of concrete. Referring to Fig. 8 and Fig. 9, it is noticed that the age effect is predominant for M30 standard concrete and M30 steel fiber reinforced concrete tested under room temperature. Referring to Fig. 8 , for M30 standard concrete, a steep rise in strength is observed between 7 and 28 days age at all temperatures. A steady rise in strength was observed beyond 28 days age.

Referring to Fig. 9, for M30 steel fiber reinforced concrete, a steep rise in strength is observed between 7 and 28 days age at all temperatures. Above 28 days age, the strengths are almost remaining constant at all temperatures except at room temperature.

B. Flexural strength

Table 2 Percentage relative flexural strength for different temperature exposures at different ages

S. No.	Fiber content (%)	Age of test (days)	Percentage relative flexural strength (N/mm²)				
			27°C	100°C	200°C	300°C	400°C
1	0%	3	61.28	62.19	52.56	46.54	44.43
	3%		75.63	76.73	52.76	49.85	46.24
2	0%	7	68.41	70.01	58.38	54.86	54.16
	3%		83.55	84.25	58.98	57.67	56.37
3	0%	28	100	100.8	57.27	56.07	53.16
	3%		108.2	112.7	61.69	58.38	53.66
4	0%	56	104.8	115.1	62.89	61.99	61.38
	3%		112.2	118.7	70.41	63.39	61.99

a. Effect of temperature on flexural strength

To study the effect of temperature, the variation of percentage relative flexural strength with temperature at a particular age has been plotted in Fig. 10 to Fig.13.

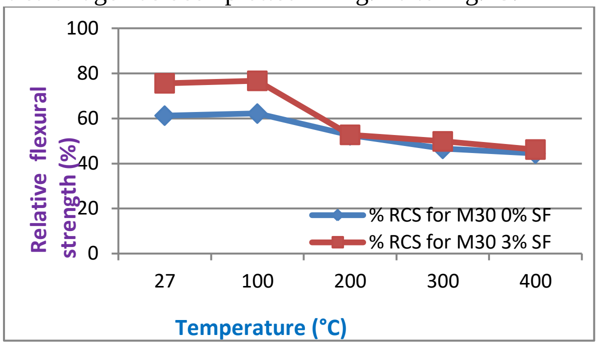

Fig. 10 Variation of relative flexural strength with temperature at the age of 3 days

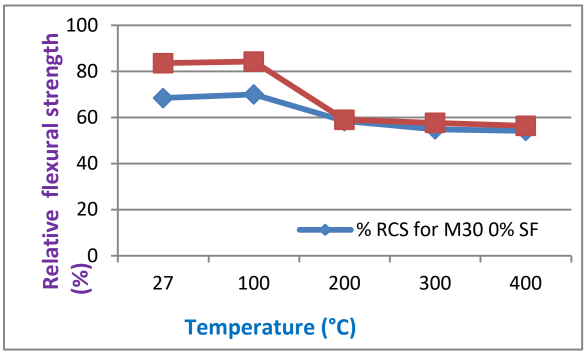

Fig. 11 Variation of relative flexural strength with temperature at the age of 7 days

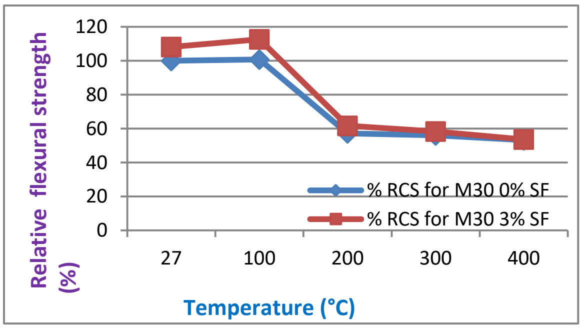

Fig. 12 Variation of relative flexural Strength with temperature at the age of 28 days

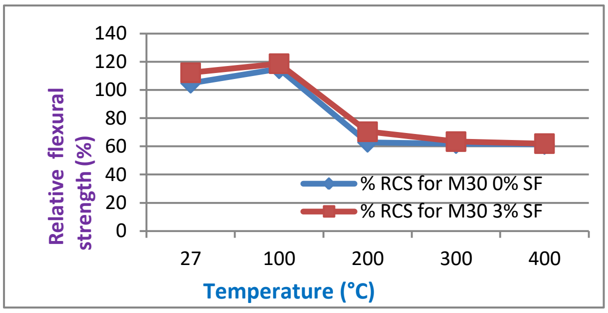

Fig. 13 Variation of relative flexural strength with temperature at the age of 56 days

Referring Fig. 10 to Fig. 13 it is noticed that the flexural strengths of M 30 standard controlled concrete are less compared with the strengths obtained after adding steel fibers for all exposure temperatures. This can be attributed due to the brittle nature of concrete. The brittle nature increases with increase in temperature leading to fracture and low flexural strengths.

Referring to Fig. 10, it is observed that there is a significant rise in flexural strength at 100°C at 3 days for both M30 controlled concrete and M30 steel fiber reinforced concrete.

Reefing to Fig. 11, it is observed that there is a significant rise in flexural strength at 100°C at 7 days for both M30 controlled concrete M30 steel fiber reinforced concrete.

Referring to Fig. 12 and Fig. 13, It is observed that there is a significant rise in tensile strength at 100°C at 28 and 56 days for both M30 controlled concrete and M30 steel fiber reinforced concrete.

It is observed that there is a significant rise in flexural strength at 100°C and then there is a gradual decrease at 3, 7, 28 and 56 days for both M30 controlled concrete and M30 steel fiber reinforced concrete.

b. Effect of age on flexural strength

To study the effect of age, the variations of relative flexural strength (%) with age for different temperatures are plotted. For the present work 3, 7, 28 and 56 days curing periods are considered.

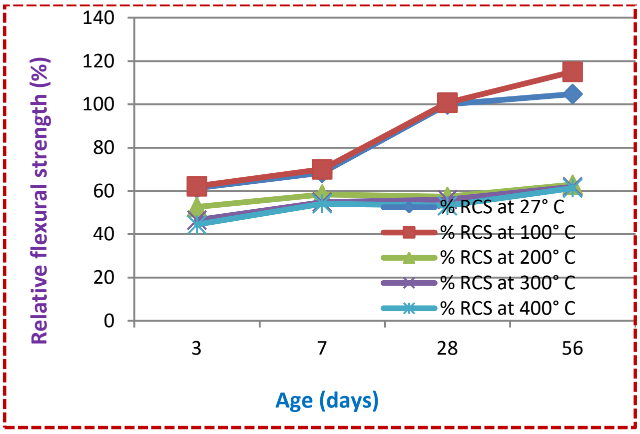

Fig. 14 Variation of relative flexural strength with age for concrete without fibers.

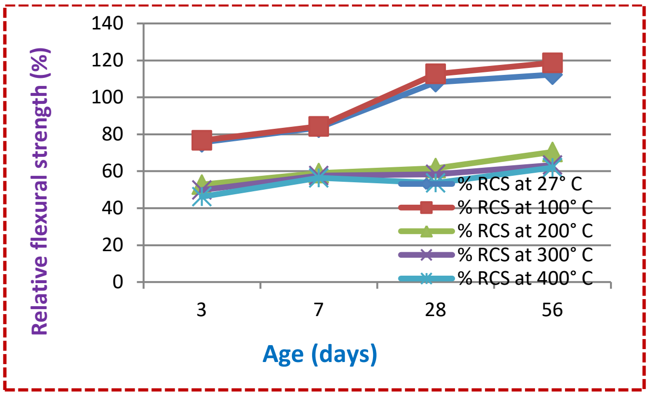

Fig. 15 Variation of relative flexural strength with age for concrete with 3% steel fibres.

It is observed that as the age of concrete increases, the flexural strength also increases gradually for all temperatures for both M30 controlled concrete and M30 steel fiber reinforced concrete.

Improved flexural strengths in standard steel fiber reinforced concrete is an indication of improved ductile nature of concrete on addition of steel fibers in concrete.

Referring to Fig.14 and Fig.15, it is noticed that the age effect is predominant for M30 standard concrete and M30 steel fiber reinforced concrete tested under room temperature.

Referring to Fig.14, for M30 standard concrete, a steep rise in strength is observed between 7 and 28 days age at temperatures of 27 and 100°C. A steady rise in strength was observed beyond 28 days age for all temperatures.

Referring to Fig.15, for M30 steel fiber reinforced concrete, a steep rise in strength is observed between 7 and 28 days age at temperatures of 27 and 100°C. Above 28 days age, the strengths are almost remaining constant at all temperatures.

V. CONCLUSIONS

1. At 400°C, steel fiber reinforced standard concrete shows an increase of 25.4% in split tensile strength compared to M30 controlled concrete at the of 28 days.
2. It is concluded that as the age of concrete increases, the tensile strength also increases gradually for both M30 controlled concrete and M30 steel fiber reinforced concrete exposed to temperatures up to 400°C.
3. At 100°C temperature, steel fiber reinforced standard concrete shows an increase of 11.8% flexural strength compared to M30 controlled concrete at the age of 28 days.
4. It is concluded that as the age of concrete increases, the flexural strength also increases gradually for both M30 controlled concrete and M30 steel fiber reinforced concrete exposed to temperatures up to 400°C.

From the results of the present study, it can be concluded that performance of steel fiber reinforced standard concrete is better than M30 controlled concrete in terms

of split tensile strength and flexural strength.

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