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TOUGHNESS OF STEEL FIBER REINFORCED CONCRETE AT VARIOUS ELEVATED TEMPERATURE

Mahesh Prabhu[1], Vivek Bindiganavile[2], Narayana Suresh[3]

[1]Assistant Professor, Department of Civil Engineering, Government Engineering College, Ramanagara 562159

[2]Associate Professor, Civil & Environmental Engineering, University of Alberta, Edmonton, Canada T6G 2W2

[3]Professor & Director, Building Fire Research Centre, National Institute of Engineering, Mysore 570008

Abstract: **This experimental investigation was focused on the study of compressive behavior of steel fiber reinforced concrete (SFRC) subjected to different sustained elevated temperature ranging from 100^{0} C to 400^{0} C. In order to evaluate the effect of elevated temperature on M40 grade SFRC steel fibers of length 30 mm were used. Specimens were casted by using 0%, 1%, and 2% volume fractions. Data obtained from laboratory test results showed that residual strength varied inversely with the quantity of fibers at all levels of sustained elevated temperatures. The compressive toughness of SFRC was also evaluated to investigate the mechanical properties of SFRC at sustained elevated temperatures of 100^{0} C, 200^{0} C 300^{0} C and 400^{0} C. Test results showed that increase in the volume of steel fibers does not have significant variation in compressive strength at room temperature whereas it is observed that there is a decreasing trend in the residual compressive strength of SFRC up to sustained elevated temperature of 400^{0} C.**

Keywords: **steel fiber reinforced concrete (SFRC), residual strength, mechanical properties.**

1. INTRODUCTION

Fibre reinforced concrete is increasingly being used for various civil infrastructure applications worldwide. Various research investigations on the compressive behavior of Steel Fiber Reinforecd Concrete have concluded that the toughness of Steel Fiber Reinforced Concrete increases with the reinforcing index or fiber factor which is defined as product of the volume fraction (or weight fraction) and the aspect ratio of the fibers Ezeldin and Balaguru 1992 [7]; Hsu and Hsu 1994 [8]; Mansur et al. 1999 [9]. The information on the effect of fiber on compressive strength of concrete after subjecting to elevated temperature is limited. In 2016, the effect on concrete was studied when polyester fiber is added in different proportions that has been subjected to sustained elevated temperatures [10]. This paper presents the results of the laboratory investigations on the properties of hardened cement concretes with steel fibers (30 mm long hooked-end) for 0%, 1% and 2% volume fractions.

2. EXPERIMENTAL PROGRAM

Materials

Portland pozzolanic cement of specific gravity 3.15, natural river sand of specific gravity 2.6 and confirming to zone - II as per IS: 383 – 1970 , coarse aggregate of 12.5 mm and down size of specific gravity 2.62 were used for cement concrete matrix. Water cement ratio was 0.45, Steel fibers of 30mm length hooked end type were incorporated in the concrete. Conplast sp430 water reducing superplasticizer was used to improve the workability of the steel fiber reinforced concrete matrix. The steel fibers used in this study were hooked at both ends is as shown in Figure 1. Diameter (ϕ) of 0.6 mm and a length (l) of 30 mm steel fiber which has an aspect ratio l / ϕ of 50 was used.

Figure 1: Hooked end steel fibers

TABLE I: INGREDIENTS OF CONCRETE MIXTURE

Ingredient	quantity	unit
water	147.68	Litres
Cement	369.2	Kg/m^3
Fine aggregate	976.69	Kg/m^3
Coarse aggregate	908.5	Kg/m^3
Superplasticizer	40	Litres

The effects of mixing steel fibers of various percentage were investigated for reinforcing indices (RI_v) of 0, 0.5 and 1.0. The reinforcing index RI_v is defined by Eq. (1). In which V_f = volume fraction of fibers.

$$RI_v = V_f \, l / \phi. \qquad (1)$$

Mix proportions

Table I shows the proportions of ingredients for mix design of 1 m^3 of concrete batch used in the experimental program. The plain concrete was designed for a 28-day cube compressive strength of 40 MPa. The mixture was designed to obtain a cohesive and workable mixture [1].

Preparation of specimens

In the process of preparing the fiber reinforced concrete specimens care was taken to achieve uniform fiber distribution and gap-grading of the aggregates was avoided. The mixtures were prepared using a conventional mixer. The ingredients of concrete were first dry mixed in a concrete mixer for about 60 seconds followed by addition of steel fibers into the mixing drum and continued with mixing for another one minute, lastly water and superplasticizer were introduced into the mixer and the ingredients were mixed thoroughly for another 120 seconds. The fresh concrete was poured into the 150 mm x 150 mm x 150 mm cube moulds in its fresh state with and without steel fibers. Totally 45 numbers of specimens with 0%, 1%, and 2% volume fraction of 30 mm length hooked end steel fibers were prepared as given in Table II. A typical steel fiber reinforced concrete at its fresh stage is shown in Figure 2. All the specimens were demoulded after 24 hours and water cured until 28 days.

TABLE II: SPECIMENS FOR ASSESSMENT OF STRENGTH

Type	Dimensions (mm)	Volume of fibers	Number of cube specimens
SFRC0	150 x 150 x 150	0 %	15
SFRC1	150 x 150 x 150	1 %	15
SFRC2	150 x 150 x 150	2%	15

Figure 2: Steel fibers in fresh concrete

Temperature test

The temperature tests were carried out after 28 days water curing for the concrete specimens at Building Fire Research Centre, the steel fiber reinforced concrete specimens was subjected to sustained elevated temperature thermal tests. A high temperature capacity electric oven was used and temperature time history for this electric oven is plotted in Figure 7.

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Three specimens for each series of concrete mix were placed inside the oven and these specimens were heated to 100°C, 200°C, 300°C & 400°C and after reaching the targeted temperature it was maintained at this constant level for 120 minutes of duration. Then the electric oven was turned off so that the heated specimens were cooled at room temperature. During these test procedures moisture in the test specimens were allowed to escape freely.

Compression test

The post thermal residual compressive strength tests for concrete specimens subjected to different sustained elevated temperatures were respectively tested after they were gradually cooled down to room temperature. For each series of concrete specimens (0 %, 1%, 2% fibers) three number of specimens were tested and the average value for them was designated as the compressive strength value of the respective series of specimens. The compressive strength tests were conducted according to IS 516 – 1959 [2]. A typical fiber reinforced concrete cube under compression load is shown in Figure 3. The failure mode of a typical tested cube specimen is as shown in Figure 4. The variation of compressive strength of concretes with different sustained elevated temperatures is plotted in Figure 5. The stress v/s strain of concretes after subjected to sustained elevated temperatures of 100°C, 200°C, 300°C and 400°C and subsequent cooling are plotted in Figure 8 to Figure 11.

Figure 3: Specimen under Compression

Figure 4: Typical failure mode of specimen

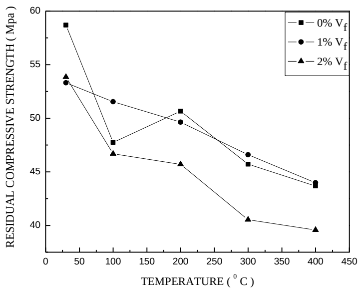


Figure 5: Residual compressive strength

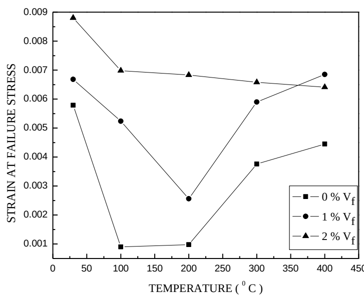


Figure 6: Variation of strain with temperature

3. RESULTS AND DISCUSSION

Table III presents the test results, in which f_{ca} = compressive strength of concrete; ε_{ca} = strain that corresponds to the compressive strength; and TI = toughness index, defined by Eq. (2). in which ED = energy absorption capacity of SFRC or the area under the stress-strain curve, as shown in Figure 12; and ED_c = energy absorption capacity of the control specimen. Both ED and ED_c are defined up to a strain of 0.015 (Ezeldin and Balaguru 1992).

$$TI = \frac{ED}{ED_c} \qquad (2)$$

From Figure 5 it is understood that the residual compressive strength for all the series of cubes fluctuated as the sustained elevated temperatures increased. At room temperature the compressive strength of 1 % fibers specimens shows 9.18% decrease compared to that of Control specimens, whereas 2 % fibers specimens show 8.26 % decrease. At 100°C sustained elevated temperature and subsequent cooling the compressive strength of 1 % fibers specimens shows 12.19 % decrease compared to that of room temperature strength. Whereas at the same temperature 2 % fibers specimens show 20.47 % decrease which is likely due to the fibers present in the concrete which can be observed from Figure 6 where strain at peak stress values for higher fiber content specimens are greater in comparison with that of the control specimens. Similar development happens at 200°C except for 0 % fiber specimen series as it is observed that there is increase in the compressive strength by 4.96 % of earlier ones.

TABLE III: RESIDUAL COMPRESSIVE STRENGTH TEST RESULTS

Specimen	Stress N/mm^2 f_{ca}	Strain ε_{ca}	RI_v	TI	Temperature ^0c
SFRC0	47.750	0.0009	0	0.99	
SFRC1	51.540	0.00524	0.5	1.45	100^0C
SFRC2	46.689	0.00698	1.0	2.16	
SFRC0	50.667	0.00098	0	2.17	
SFRC1	49.640	0.00256	0.5	1.37	200^0C
SFRC2	45.703	0.00683	1.0	1.55	
SFRC0	45.710	0.00376	0	1.89	
SFRC1	46.593	0.00590	0.5	1.72	300^0C
SFRC2	40.530	0.00158	1.0	1.43	
SFRC0	43.670	0.00445	0	1.98	
SFRC1	43.984	0.00685	0.5	2.01	400^0C
SFRC2	39.570	0.00671	1.0	0.97	

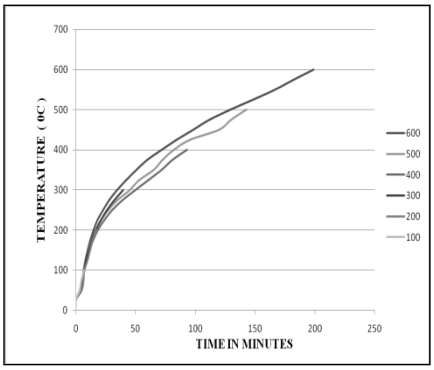


Figure 7: Time v/s Temperature for Electric Oven

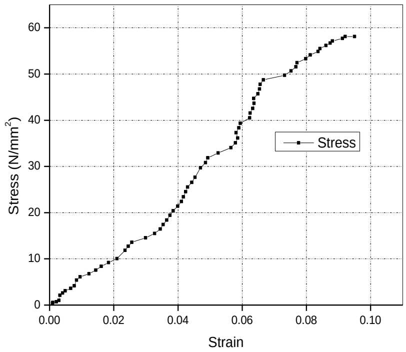
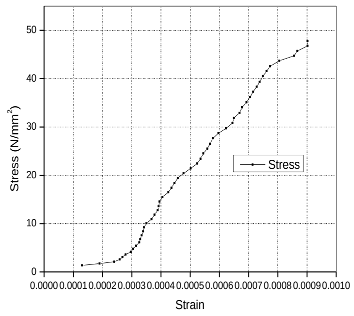


Figure 8: Stress v/s Strain for Control specimen

Also 1% fibers series of specimen's shows 6.70 % increase against 2 % fiber specimens at this level of elevated temperature which reflects the performance of 1 % series better than 2 % series specimens. Subsequently for the concrete specimens at 300°C and beyond the compressive strength of 1 % fibers specimens retains better strength compared to that of 0 % and 2 % fiber specimens, which is higher by 1.5 % and 10.30 % at 300^0 c in comparison with that of 0 % and 2 % volume fractions. Similarly the compressive strength is 0.51 % and 7.51 % higher at 400^0 c in comparison with that of 0 % and 2 % volume fractions. This clearly shows that the residual compressive strength is inversely proportional to the quantity of fibers in M40 grade concrete at all levels of sustained elevated temperatures except at 300^0 c and beyond where the percentage difference is marginal.



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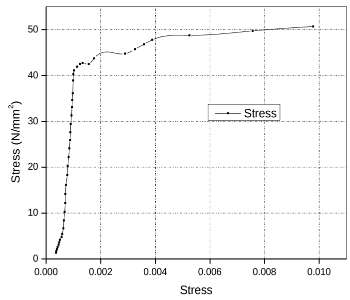

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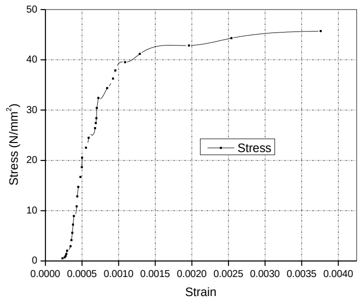

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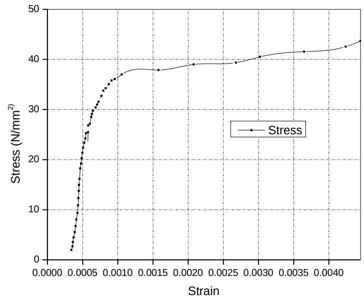
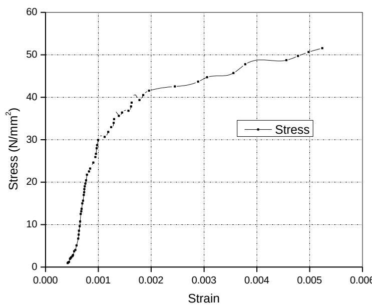


(d)

Figure 9: Stress v/s Strain for RI_V = 0: (a) 100^0C (b) 200^0C (c) 300^0C (d) 400^0C



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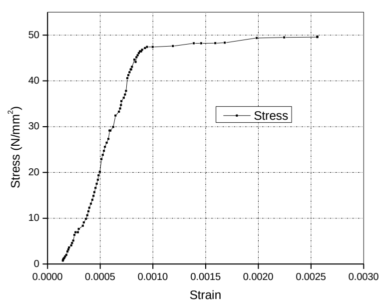

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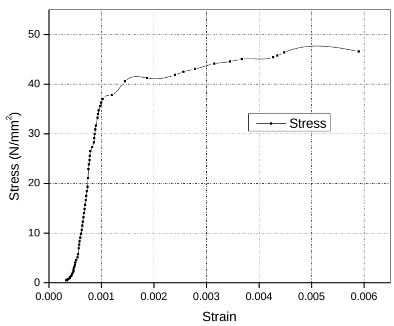

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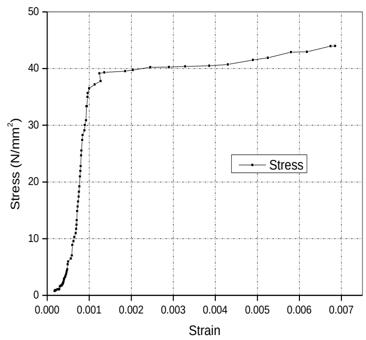

(d)

Figure 10: Stress v/s Strain for RI_V = 0.5: (a) 100^0C (b) 200^0C (c) 300^0C (d) 400^0C

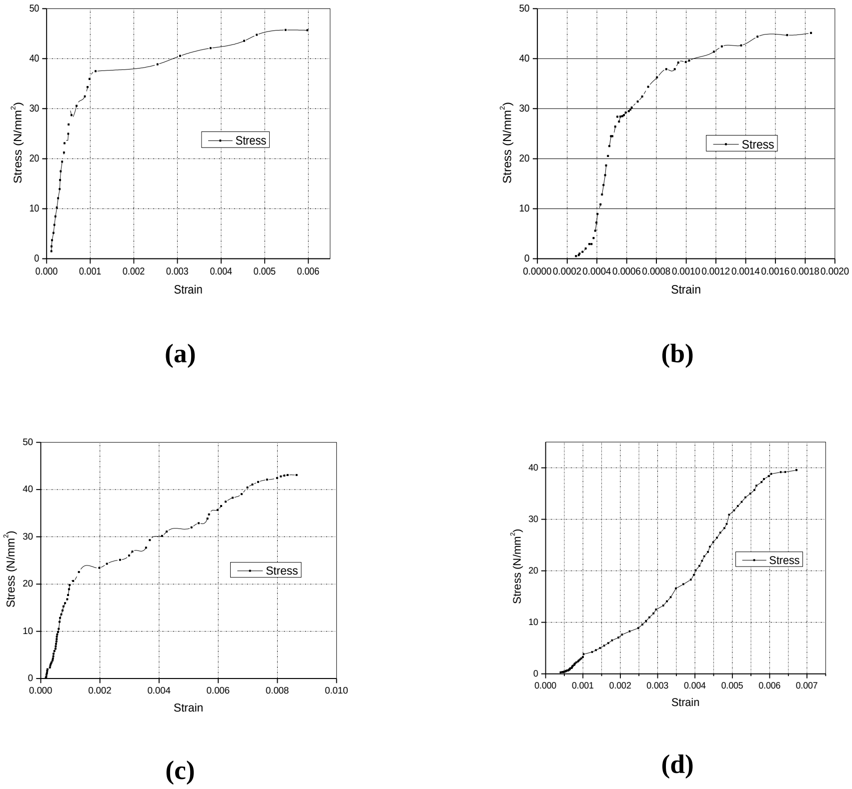

Figure 11: Stress v/s Strain for RI_V = 1.0: (a) 100^0C (b) 200^0C (c) 300^0C (d) 400^0C

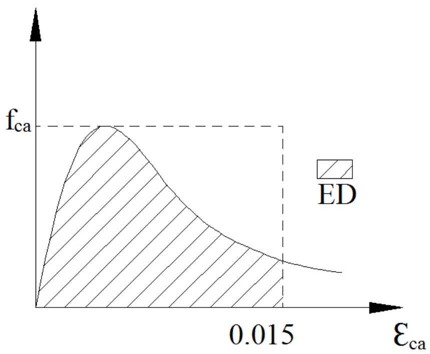

Figure 12: Definition of Toughness Index

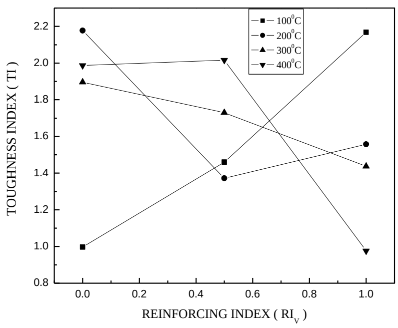

Figure 13: Variation of Toughness Index

Figure 13 shows the variation of toughness index of M40 grade steel fiber reinforced concrete for various sustained elevated temperatures. It is observed that compressive toughness of SFRC at 100^0 C sustained elevated temperature increases for reinforcing index upto 1.0. Whereas at 200^0 C the compressive toughness is found to be decreased upto 0.5 reinforcing index, and then increases for reinforcing index of 1.0 which clearly shows the fluctuations in its variations. The influence of steel fibers on compressive toughness of concrete at 300^0 C and 400^0 C sustained elevated temperature is found to be of decreasing trend with respect to increase in reinforcing index, in which a gradual reduction of compressive toughness is noticed at 300^0 C, whereas the rate of reduction is high at 400^0 C sustained elevated temperature.

4. CONCLUSIONS

The most important conclusions are summarized below.

1. The presence of steel fibers in M40 grade concrete decreases its compressive strength at room temperature and residual compressive strength at sustained elevated temperature upto 400^0 C which is inversely proportional to its volume.

2. Addition of steel fibers had little effect on the residual compressive strength enhancement for the sustained elevated temperature range between 300^0 C to 400^0 C.

3. Adding steel fibers to M40 grade concrete increased both its compressive toughness and its strain at the peak stress. However, this improvement is observed to be limited for 100^0 C sustained elevated temperatures for all the fiber volume fractions.

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