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BEHAVIOUR OF STEEL FIBER REINFORCED CONCRETE COLUMNS HEATED UP TO 400^{O}C

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Abstract-The present work is aimed to study the behaviour of reinforced concrete columns containing one percent of flat crimped steel fibers by volume heated up to 400^{o}C. Reinforced concrete columns of M20 grade concrete with dimensions 150 mm X 150 mm X 1200 mm were cast and cured for 28 days. They were heated to different temperatures ranging from 100 to 400°C with a steady exposure for one hour and then air cooled to room temperature. Later the columns were tested for ultimate loads and Young's modulus and the results were analysed. The columns with steel fibers performed well in compression due to more resistance against load. In addition to that the Young's modulus was better for columns with steel fibers.

Keywords: steel fibers, temperature, columns

I. INTRODUCTION

With the increase in the complexity of the structure, the chances of mitigating fire accidents in structures are very less. Due to this, building and other structures should not only be designed for strength, but they must also be designed to resist high temperatures. The affect of fire on building depends upon the intensity and duration of exposure. The depth of damage due to fire on a particular building depends on several factors like the performance of the structure, fire extinguishing techniques and type of construction material.

Concrete is an excellent fire-resistant material. One of the main advantages of concrete over other construction materials is its natural fire resisting properties and low thermal conductivity. During fire accident, different parts of the building may be exposed to various intensities of temperature. As the temperature is changing continuously, there will be a change in the behaviour of concrete due to the development of thermal properties, which in turn affects its mechanical properties. These changes alter the deformation behaviour and load-bearing capacity of the structural member. Concrete, when exposed to high temperatures, undergoes changes in physical structure, chemical composition and moisture content. These changes are primarily observed at the cement paste and then at the aggregates. With the increase in temperature and exposure duration, the compressive strength decreases. Temperatures up to 95^{o}C have little effect on the strength and other properties of concrete. The actual reduction in strength starts from temperature 100^{o}C and above. At 100^{o}C, water starts evaporating from C-S-H gel. As the temperature reaches 105^{o}C all evaporable water gets evaporated depending on the duration of exposure. Beyond 105^{o}C, chemically combined water (hydrated water) and physically adsorbed water is lost gradually. The loss is intense from temperature 120^{o}C; water starts expelling from gel pores resulting in the coarsening effect. When the temperature reaches 150^{o}C, dehydration of tobermorite gel starts and a complete dehydration occurs at 180^{o}C resulting in shrinkage of paste thereby losing its cementing ability. At 200^{o}C, dehydration of calcium silicate is the leading cause for the decrease in strength. These hygrothermal changes result in the change of pore structures of concrete where initially free moisture is lost; that is followed by physically absorbed water and finally chemically combined water of hydrated cement products causing progressive strength loss. These changes may lead to weakening the interfacial bond between paste and aggregate, which may result in cracking and finally reducing the strength of concrete.

When concrete is exposed to high temperatures, its load bearing capacity is reduced. The rise in the temperature causes a decrease in the strength and modulus of elasticity or both concrete and steel reinforcement. However, the rate at which the strength and modulus decrease depends on the rate of increase in the temperature of the fire and the insulating properties of concrete.

Steel Fiber reinforced concrete (SFRC)

Steel Fiber reinforced concrete (SFRC) is defined as concrete made with hydraulic cement containing fine and coarse aggregate and discontinuous discrete fiber. Steel fiber is usually added to concrete mixtures to improve plastic cracking characteristics, tensile and flexural strength, impact strength and control cracking. However, at elevated temperature steel fibers could improve the fire resistance of the concrete structures.

There are different types of steel fibers available namely 1) Straight fiber, 2) Crimped fiber, 3) Stranded fiber, 4) Hooked fiber, 5) Twisted fiber as shown in the Fig 1.

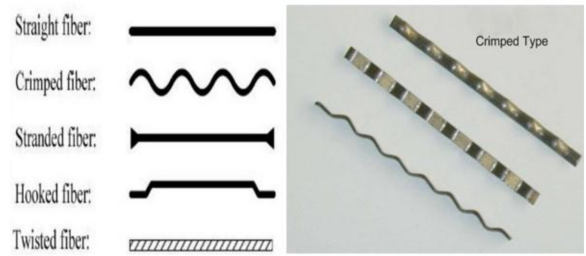

Fig.1 Types of steel fibers

In SFRC, thousands of small fibers are dispersed and distributed randomly in the concrete during mixing improve concrete properties. SFRC is increasingly used to improve static and dynamic tensile strength, energy absorbing capacity and better fatigue strength. The addition of steel fiber increases the ultimate strength and ductility. Steel fibers are used to enhance the compressive strength and ductility of concrete. The addition of fibers to concrete enhance its toughness and strength and peak stress, but can slightly reduce Young's modulus.

II. EXPERIMENTAL PROGRAMME

The specimens were cast in wooden moulds where five columns were cast without steel fibers of which one being a control column and other four columns were cast with 1 percent of flat crimped steel fibers by volume.

The dimensions of RC columns are 150 mm X 150 mm in cross section and 1200 mm in length with reinforcement of four main bars of 8 mm diameter for longitudinal reinforcement and 6 mm stirrups with a spacing of 42.5 mm center to center at the ends and 85 mm center to center at the middle of the column for shear reinforcement.

The clear cover provided for the columns is 20mm which was maintained using cover blocks. Cover blocks were kept inside the column moulds at the bottom and sides. The reinforcement cage was placed in the mould (as shown in Fig. 2). The column moulds were filled with concrete. Each layer was compacted using a needle vibrator (as shown in Fig 3)

Fig. 2 Reinforcement cage placed in moulds

The grade of concrete is M20 with mix proportions of 1: 1.3: 3.33 as per IS 10262-2009 and with water cement ratio of 0.48. The cement used was ordinary Portland cement (OPC) conforming to IS 8112-1989. The coarse aggregate used was crushed stone passing IS 20mm sieve and retained on IS 4.75 mm sieve. The fine aggregate used was river sand conforming to zone-II of IS 383-1970. Flat crimped steel fibers of length 42mm and thickness 0.7mm with an aspect ratio of 60 are used.

Fig.3 Specimen plastering and vibrating

Fig.4 Curing of columns

Fig.5 Specimen in CTM

The column specimens were demoulded after 24 hours of casting and were cured in a water tank for a period of 28 days (as shown in Fig.4). After a curing period of 28 days, the specimens are heated to temperatures 100, 200 300 and 400^{o}C exposed for 1 hour at each temperature.

Fig. 6 Cooling of columns

The specimens after the exposure to high temperatures were left in the open to cool down to room temperature by air (as shown in Fig. 6.) The specimens were then inspected for visual changes followed by compression test shown in Fig. 5. The ultimate load of columns with steel fibers and without steel fibers at different temperatures and Young's modulus of columns with steel fibers and without steel fibers at various temperatures are presented.

III. RESULTS

Physical changes:

There is no significant color change in the columns subjected to temperatures below 300^{o}C but light yellowish color was observed in the case of columns exposed to 400^{o}C after cooling them to room temperature. In addition to that minute cracks were observed on the surface of the columns exposed to 300^{o}C and 400^{o}C.

Ultimate Load

In Table 1, it is shown that the columns without steel fibers exposed to temperatures 100^{o}C, 200^{o}C, 300^{o}C, 400^{o}C exhibited 117.41, 99.04, 69.52, 65.30 % residual strength of the companion column respectively.

Table-1 Variation of ultimate load of RC columns without steel fibers with temperature

Temperature °C	Ultimate load (kN)	Ultimate load in percentage with respect to companion specimen
27	735	100
100	863	117.41
200	728	99.04
300	511	69.52
400	480	65.30

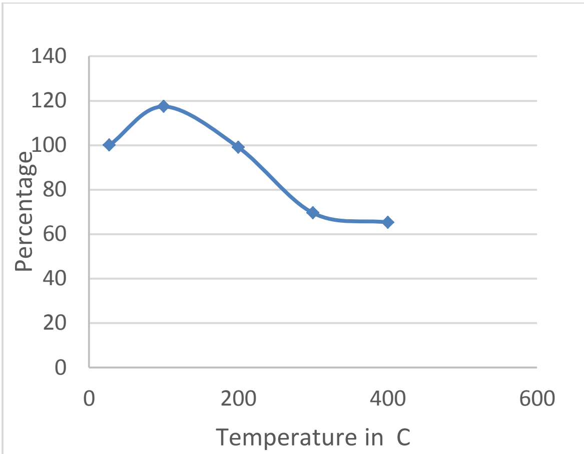

Fig.7 Variation of ultimate load in percentage with companion specimen load with Temperatures from 27°C to 400°C for RCC Columns without steel fibers

The Fig.7 shows a graphical depiction of the results of residual strength with temperatures of each column specimen heated from 27 to 400°C respectively. It is observed from the results that there is an increase in the ultimate load of column without steel fibers exposed to 100°C, by 17.41 % compared to the ultimate load of the companion specimen. From there on the ultimate loads decreased with increase in the temperature up to 400°C.

Table 2 Variation of ultimate load of RC columns with 1% steel fibers with temperature

Temperature °C	Ultimate load (kN)	Ultimate load as percentage with respect to ultimate load of companion specimen
27	735	100
100	887	120
200	767	104.35
300	590	80.27
400	525	71.42

Table 2 shows that there is an increase in the ultimate load of column with steel fibers exposed to 100°C, by 20.00 % compared to the ultimate load of the companion specimen (27°C). However, the ultimate loads gradually decreased with further increase in the temperature to 400°C which is depicted in the Fig. 8.

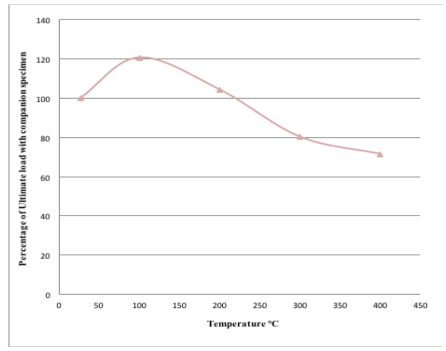

Fig. 8 Variation of ultimate load in percentage with companion specimen with Temperatures from 27 to 400°C for RCC Columns with 1.0 % steel fibers

Table 3 Variation of ultimate load of each column without and with steel fibers with respect to companion column

Temp °C	Ultimate load (kN) without steel fibers	Ultimate load (kN) with steel fibers
27	735	863
100	863	887
200	728	767
300	511	590
400	480	525

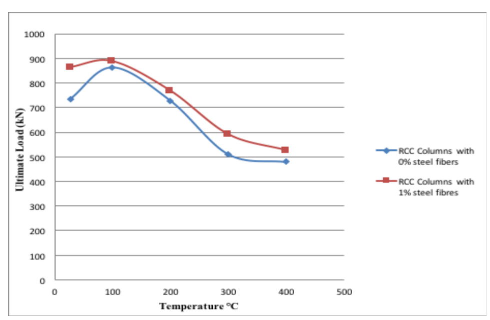

Fig. 9 Variation of Ultimate loads of RC Columns with Temperatures from 27 to 400°C without steel fibers and with 1% steel fibers

Table 3 shows the comparative results of the columns with and without steel fibers, the ultimate load of columns with steel fibers columns performed well in compression when compared to columns without steel fibers exposed to 100 to 400°C for 1 hour because of the presence of flat crimped steel fiber by 1 % volume of concrete. Fig. 9 represents the curves of ultimate loads with corresponding temperatures for columns without steel fibers and with steel fibers with respect to the results achieved.

Young’s Modulus

Table 4 Young’s Modulus, E with temperatures for Columns without steel fiber

Temperature °C	**Young’s Modulus, E (N/mm^2)**
27(Control)	2106.16
100	2432.70
200	1779.01
300	1647.34
400	1783.06

From Table 4 it was observed that there is slight increase in Young’s modulus for column exposed to 100°C compared to companion column. From the Young’s modulus results it was observed that increase in temperature will decrease the Young’s modulus. Fig.10 shows the curve representing Young’s modulus with corresponding temperatures ranging from 100 to 400°C.

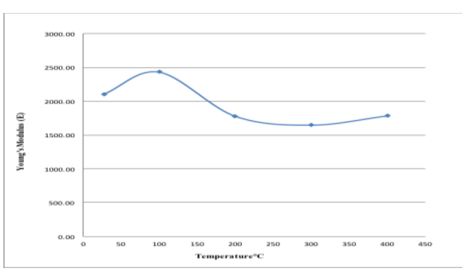

Fig.10 Variation of Young's Modulus with Temperatures from 27 to 400°C of RCC Columns without steel fibers

Table 5 Young’s Modulus, E with temperatures for Columns with steel fiber

Temperature in °C	**Young’s Modulus, E (N/mm^2)**
27	3268.94
100	3400
200	3490
300	2796.95
400	2700

In Table 5 it can be seen that there is slight increase in Young’s modulus for column with steel fibers exposed to 100°C and 200°C compared to companion column. However, it was observed that increasing the temperature above 200°C will decrease the Young’s modulus. Fig. 11 shows the curve representing Young’s modulus with corresponding temperatures ranging from 100 to 400°C.

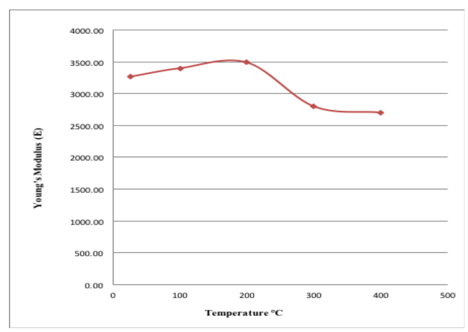

Fig. 11 Variation of Young's Modulus with Temperatures for RCC Columns with 1 percent steel fibers

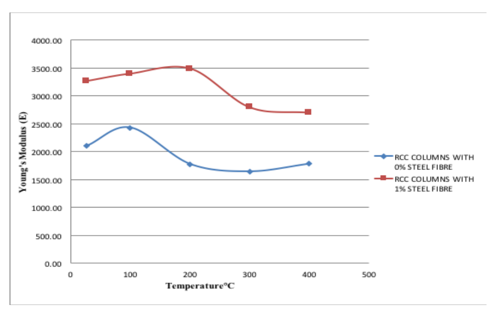

Fig.12 Variation of Young's Modulus with temperatures for RCC Columns without and with steel fibers

From the results (Table 4 & Table 5) obtained after tests, it is clear that Young's modulus will be decreasing with the increase in temperature i.e., from 200°C temperature exposure onwards for both of the columns without steel fiber and with steel fiber. Fig. 12 clearly shows the curves of Young's modulus with temperatures for columns without steel fibers and columns with steel fibers with their corresponding achieved results. It can be stated from the graph that Young's modulus of columns with steel fibers is high compared to that of columns without steel fibers.

IV. CONCLUSIONS

The column without steel fibers exposed to 100°C for 1 hour exhibited 17.4% increase in residual strength than that of companion column, whereas the column exposed to 200°C showed only 1% decrement in its residual strength. In addition to that the columns exposed to temperatures of 300°C and 400°C exhibited a decrement of 31.5% and 34.7% of residual strength compared to the strength of companion column respectively.

1. Load carrying capacity of all the heated columns without steel fibers was lower than that of companion column except for the column exposed to 100°C.
2. The column with 1% steel fibers exposed to 100°C for 1 hour exhibited 20.6% increase in residual strength than that of companion column, whereas the column exposed to 200°C showed only 4.35% increment in its residual strength. In addition to that the columns exposed to temperatures of 300°C and 400°C exhibited a decrement of 19.7% and 29.6% of residual strength compared to the strength of companion column respectively.
3. Load carrying capacity of all the heated columns with steel fibers was lower than that of companion column except for the column exposed to 100°C.
4. There was no change in the colour of the specimens exposed up to 300°C but for 400°C light yellow colour change was observed.
5. Columns with steel fibers performed well in compression after heating as their failure loads are more when compared to columns without steel fibers.
6. Surface cracks on the specimens were observed when exposed to a temperature of 300°C and above.
7. The Young's Modulus, (E) for all the columns linearly decreased with increment in temperatures compared to companion specimen both in the case of columns without and with steel fiber and also Young's modulus of columns with steel fibers were better when compared to columns without fiber exposed to 100 to 400°C for 1 hour.

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