INFLUENCE OF COOLING METHOD ON STEEL FIBER REINFORCED CONCRETE EXPOSED ELEVATED TEMPERATURES

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Abstract- The objective of this study is to understand the effect of extinguishing building fires with water jets and how the presences of steel fibers in concrete influence the performance. This paper presents the findings with regard to the influence of cooling method adopted to cool steel fiber reinforced concrete which was exposed to elevated temperatures. In order to create the temperatures in a real fire environment, a total of 102 cube specimens with a dimension of 150 mm were cast and heated from 100 to 800°C with an interval of 100°C. The specimens were steadily exposed for 3 hours after attaining their respective temperature and were cooled by their assigned method. (i.e. air cooling and water quenching). The cubes were tested with the help of a compressive testing machine and the results were discussed.

Keywords: Steel fiber, concrete, temperature, fire, compressive strength

I. Introduction

In the modern age of engineering, the aspects of structural safety have been updated with time. The building resistance and the safety measures are in par with man made disasters like building fires. Although, fire protection measures like advanced fire extinguishing systems, better response of emergency services do facilitate safety, there were many cases of structural collapse post fire accident which resulted in life loss. The usage of water jets to terminate building fires is a common practice, but a notable effect of this extinguishing method on heated concrete is overlooked. In other words, the method of terminating the fire has a major impact on the strength of the building, if the extinguishing is done by water jets the heated concrete on sudden cooling undergoes a thermal shock which directly affects the strength of the concrete in addition to the already weakened concrete due to heat. The use of steel fibers in plain concrete has revealed substantial enhancement in strength, and in reinforced concrete it has always shown improved results in terms of compression, tension and shear forces. Studies proposed that there is a 10% rise in the compressive strength of steel fiber reinforced concrete with reference to ordinary concrete [2,3]. But, in this study fibers were added to investigate the performance of steel fiber reinforced concrete heated from 100 to 800°C for a duration of 3 hours and cooled through different cooling techniques namely air cooling and water quenching (which is meant to imitate the water jet extinguishing in real scenarios). A study determined that adding steel fibers develops the bond strength and prevents brittle failure of concrete [1]. The addition of steel fibers not only improves the mechanical characteristics and strength of concrete [4], but also improved load carrying capacity and enhanced resistance to deformation and cracking [5].

II. Material and method

The experimental programme is split in to the following sections: material selection, specimen details and test setup.

Material selection: Cement, Fine Aggregate, Coarse Aggregate

The concrete is of M20 grade with mix proportions [6] of 0.48:1:1.3:3.33 attained by following IS 10262–2009. Ordinary Portland cement (OPC) which is of 43 grade corresponding to IS 8112–1989 is used [7]. Crushed stone which passed through IS 20 mm sieve and held on IS 4.75 mm sieve is used as coarse aggregate [8] while river sand compatible to grading zone II of IS 383-1970 is used as fine aggregate [8].

Fibers

Fibers chosen for this research were flat crimped fibers made of steel with an aspect ratio of 60. Studies have shown that fibers having lower aspect ratio can easily be pulled out of the matrix which jeopardizes the bond strength [9]. The presence of fibers develops the tensile strength, lowers the spalling and increases heat endurance [10, 11]. In addition to that the inclusion of steel fibers increases the deformation capability which in turn results in reduction of spalling. The dimensions of fiber used in this study is 42 mm in length and 0.7 mm in thickness denoted in Figure 1. The quantity of steel fibers used is 1% by volume of concrete.

Fig 1 Flat crimped steel fibers

Specimen Details

A total of 102 cube specimens were cast using iron molds. The dimensions of the cube specimen are 150 mm by 150 mm by 150 mm, for the test setup. Out of 102, 48 specimens were cast with steel fiber, 48 without steel fibers and 6 control cube specimens for each case. For every temperature, cooling method and mix, three cubes specimens were assigned to find an average.

Test Set-up

The cast cubes were cured for 28 days and were arranged for heating in an electrical furnace that was built as per ISO 834 stipulations [12]. The furnace is separated into three sections of which one is a control panel which regulates the temperature. The remaining two sections are the chamber and a retractable bed which lies on a track. The chamber is fixed with coils on three sides while the base is covered with refractory bricks. The Figure 2 shows the furnace with the specimens on the refractory bed and the control panel. Cube specimens in sets of 3 were heated to each temperature of 100, 200, 300, 400, 500, 600, 700 and 800°C. The cubes were then steadily exposed for 3 hours after attaining the assigned temperature. Later the specimens were cooled according to their respective cooling method i.e. by air cooling and water quenching. Compression Testing Machine of 100 kN capacity is employed to find the compressive strength of the cube specimen exposed to elevated temperatures with fiber reinforcement with regard to its parallel ordinary cube specimens. The Figure 3 shows the placing of specimen into the compression testing machine for the test.

Fig 1 Electric Furnace and control panel

Fig 3 Placing of cube specimen in compressive testing machine

III. Results and discussions

The results are expressed in percentage of compressive strength gained or lost by steel fiber reinforced cubes with reference to the control cube specimen and their corresponding plain concrete cement cubes in table 1. The variation of strength of specimens cooled by air and water is depicted in the same table for comparison. The results are further discussed in detail explaining the performance and behavior of specimens.

Table 1 Variation of compressive strength of steel fiber reinforced specimens

Temperature (°C)	Variation of compressive strength for air cooled cubes (in %)		Variation of compressive strength for water quenched cubes (in %)	
	Control specimen vs SFRPCC specimen	PCC specimen vs SFRPCC specimen	Control specimen vs SFRPCC specimen	PCC specimen vs SFRPCC specimen
27	14.0	14.0	14.0	14.0
100	33.9	2.3	23.8	6.1
200	24.4	13.0	15.2	14.5
300	16.1	10.2	9.5	13.2
400	15.8	15.1	4.5	15.5
500	-1.8	27.9	-2.7	51.4

600	-15.8	41.5	-29.2	42.5
700	-54.2	6.9	-59.5	43.2
800	-60.4	3.1	-69.6	52.2

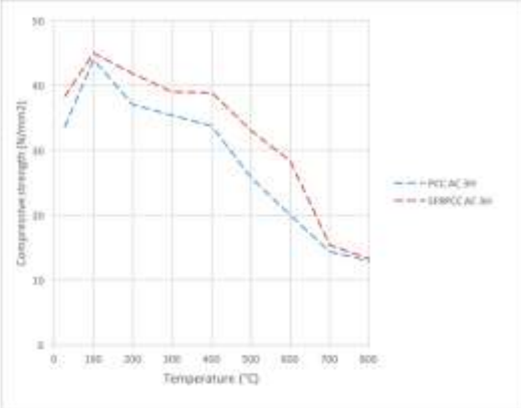

Fig 4: Variation of compressive strength with temperature for air cooled cube specimens exposed for 3 hours

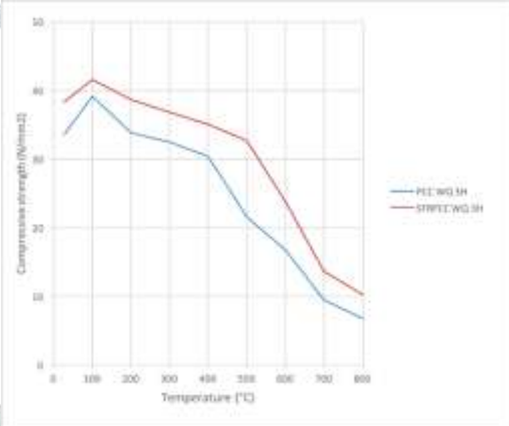

Fig 5: Variation of compressive strength with temperature for water quenched cube specimens exposed for 3 hours

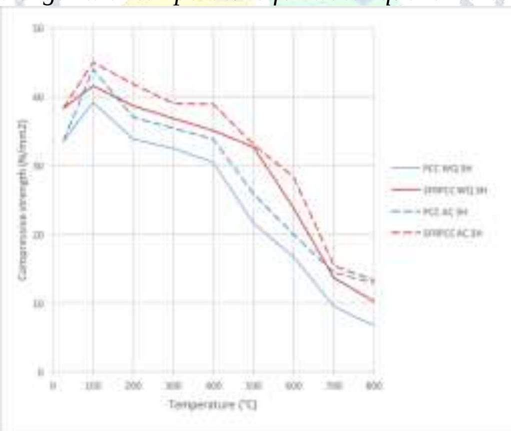

Fig 6: Variation of compressive strength with temperature for air cooled and water quenched cube specimens exposed for 3 hours

For the results it is evident that there is an improvement in compressive strength of steel fiber reinforced specimens at room temperature by 14%. For air cooled cube specimens, with increase in temperature there a surge in strength by 33.9% with reference to the control specimen, this surge can be attributed to the accelerated curing effect at 100°C. Moving on, the rise in the strength gradually minimized with increase in temperature from 200 to 400°C with 24.4%, 16.1% and 15.8% respectively. But at temperatures beyond 500°C and up to 800°C the percentage of strength loss gradually increased by 1.8, 15.8, 54.2, and 60.4% with reference to the control specimen. However, the when steel fiber reinforced specimens compared to their heated PCC counterparts, the results were promising. With 2.3, 13, 10.2, 15.1, 27.9, 41.5, 6.9 and 3.1% improvements at temperatures 100, 200, 300, 400 ,500, 600, 700 and 800°C respectively. It can be clearly seen that the addition of steel fibers has improved the compressive strength of concrete by some degree. The presence of steel fibers in concrete helps to slow down strength loss at elevated temperatures this behaviour was similar to other studies [13, 14]. The variation is depicted in a graphical form in figure 4.

For specimens that were water quenched, a rise in compressive strength with reference to control specimens was observed up to 400°C with increments of 23.8, 15.2, 9.5, 4.5% at 100, 200, 300 and 400°C respectively. In contrast to that the strength started to decrease rapidly at 500, 600, 700 and 800°C with -2.7, -29.2, -59.5 and -69.6% loss. This loss in strength could be due to the occurrence of a thermal shock. At higher temperatures the intensity of the shock would be greater thereby leading to rapid strength loss. However, on comparing the steel fiber reinforced specimen to their heated PCC specimens, there was a significant improvement in strength beyond 500°C and a notable increase below 400°C that was observed previously [13]. With 6.1, 14.5, 13.2, 15.5, 51.4, 42.5, 43.2 and 52.2% at 100, 200, 300, 400, 500, 600, 700 and 800°C respectively. The graphical depiction is show in figure 5 below.

On the other hand, when the compressive strength of the specimens made with steel fiber and plain concrete that were air cooled are compared to that of the water quenched ones, it is clearly evident from figure 6 that there is a notable contrast between the two cooling methods. For PCC specimens that were air cooled exhibited better strength than the water quenched ones. A similar trend is seen in steel fiber reinforced specimens. This loss in strength is accredited to the phenomenon of thermal shock due to sudden cooling. The uneven contraction of concrete on cooling results in occurrence of micro cracks. This directly has an influence on strength of the concrete. It should be noted that steel fiber reinforced cube specimens when quenched in water perform similar to and even better than the air cooled PCC specimens at 500 and 600°C. It can be deduced that the addition of fiber in concrete not only strengthens concrete but also resists thermal shock. This resistance is offered by the bonding formed by the steel fibers in between the concrete matrix which helps in controlling the cracks [1].

IV. Conclusions

The following conclusions are drawn from the experimental study conducted.

1. Steel fiber reinforced concrete performed better than plain concrete at room temperature
2. The performance of steel fiber reinforced concrete is at its best between 400 to 600°C range compared to the other temperatures.
3. Water quenching of the fiber reinforced specimens showed less loss in strength compared to that of plain concrete ones especially considering the occurrence of a thermal shock.
4. The cooling done water quenching has a significant effect on concrete, however, supplementing concrete with steel fibers helped in gaining strength by resisting the thermal shock.
5. The addition of steel fibers in specimens that were cooled by water quenching showed strengths that were similar to and greater than the plain concrete specimens that were cooled by air.
6. Lastly, the specimens reinforced with steel fibers that were air cooled showed the best performance with regard to compressive strength compared to all other scenarios.

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