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The behavior of hybrid reinforced concrete after heat resistance

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ABSTRACT
This study is trying to provide the behavior of concrete when additional fibers are added under the effect of evaluated temperatures. Three types of polypropylene fibers are used with different length respectively 3 mm, 6 mm and 12 mm and two types of steel fibers are used of length respectively of 3cm and 5 cm. Hybrid specimens of concrete are prepared by using two different combinations: 0.5% steel fibers in combination with 0.2% polypropylene fibers by the volume of concrete; and 0.25% of steel fibers in combination with 0.1% polypropylene fibers by the volume of concrete. The specimens were subject to different temperatures. An electric furnace was used to heat the specimens up to 200 ^{0}C, 400 ^{0}C and 600 ^{0}C. The mass loss and compressive strength were determined by using twelve different mixtures.
Keywords – steel fiber, polypropylene fiber, temperature, compressive strength, mass loss

I. INTRODUCTION

The explosive spalling of pieces of concrete from the heated surface is considered to be the most dangerous effect of damaging the concrete subject to intense fire attack, especially when it occurs in restricted areas such as underground tunnels [1].

Explosive spalling occurs during the early part of a fire, usually within the first 30 minutes. It can occur at an early stage just above 150 ^{0}C and it is characterized by pieces of concrete being violently expelled from the surface [2].

Spalling is often restricted to the unreinforced part of the section and usually does not proceed beyond a reinforcing layer [3]. Different studies have been conducted and a reduction in physical and mechanical properties of concrete after heat exposure has been concluded [4].

For the cement matrix, thermal treatments in high temperature cause a reduction in the amount of chemically bonded water in the hydrate phase [5]. In particular, with an increase in temperature, gel-like hydration products are decomposed followed by a removal of hydroxide from the calcium hydroxide [6].

Moreover, the concrete is compound of some percentage of water that when exposed to high temperatures, evaporate the water within the internal concrete structures to the gaseous state, resulting in an increase of pressure in the concrete voids [7]. If the concrete offers resistance to the escape of the water vapor, high pressures will be developed in the internal concrete structure, which will lead to very brittle concrete failure [8].

The use of fibers reduces the effect of explosive spalling which arises mainly from the vapor pressure build-up mechanism [9]. This applies especially to the distribution in the cement paste matrix, the development of channels after being melted and evaporated and their inter-chains with microcracks in the cement matrix [10].

To begin with, the fibers in general expand at different rates than the matrixes, causing small fissures or openings to be formed between the cement matrix and fibers [11]. Research work shows that these fissures are enough to allow some relief of the vapor pressure that builds up in the pores of the concrete [12].

Furthermore, as the heating continue to grow and the temperature reaches the range of 165 ^{0}C -171 ^{0}C, the fibers begin to melt, and when the temperature reaches 360 ^{0}C the fibers evaporate [13].

The disappearance of the fibers provides passageways or channels along in which the water vapor can dissipate by avoiding the build –up of pressure [9].

These two effects enhance the stresses that are suddenly developed by the vapor pressure, which subsequently reduce the explosive spalling and increase the comprehensive strength of concrete [14], [15].

II. MIX DESIGN

This study investigates the relationship between compressive strength and loss in weight of steel fibers and polypropylene reinforced concrete, treated at 200 ^{0}C, 400 ^{0}C and 600 ^{0}C.

12 series of concrete were cast using CEM II 32.5 R, local sand and local gravel with maximum size of 25 mm. Each series contained the same mix, ratio aggregate/cement of 2.67 and water/cement of 0.5. The main difference between the above series is the volume fraction of steel fiber and polypropylene fibers. The hooked end steel fibers are 0.7 mm in diameter, and 30 and 50 mm in length with an aspect

ratio of 67 and 47. Also, three different types of PP (polypropylene) fibers are used with different length of 3mm, 6 mm and 12 mm. The percentages of steel fibers used in the mixtures are 0, 25% and 0.5% by the volume of concrete. The percentage of PP fibers used in the above experiments is respectively 0.1% and 0.2% by the volume of concrete.

III. FIGURES AND TABLES

The mix proportion of concrete is shown in Table 1. Some of the properties of steel fibers and polypropylene fibers used in this study are shown in Table 2 and Table 3.

Table 1: Mix proportions of concrete

Contents	Specific gravity kg/m^3
Sand	900
Cement	400
Coarse Aggregate 10-25 mm	670
Coarse Aggregate 5-10 mm	300
Water	200
Superplasticiziers	1
Ratio aggregate : cement	2.67
Ratio water : cement	0.5

Table 2: Properties of hooked-end steel fibers

Symbols of steel fibers	SF1	SF2
Fiber Length	50 mm	30 mm
Fiber Width	0.75 mm	0.75 mm
Aspect Ratio	67	44
Tensile Strength	>1100MPa	>1450 MPa

Table 3: Properties of polypropylene fibers

Symbols of polypropylene fibers	PP1	PP2	PP3
Fiber Length	12 mm	6 mm	3 mm
Modulus of Elasticity	3900 N/mm^2	3700 N/mm^2	3500 N/mm^2
Extensibility	400 N/mm^2	370 N/mm^2	320 N/mm^2
Melting Point	170 ^{o}C	170 oC	170^{0}C
Elictrical Conductivity	Zero	Zero	Zero

In the figures below are shown images from steel fibers and polypropylene fibers used in the study.

Figure1: Steel Fiber 5 cm in length (SF1) and steel fiber 3 cm in length (SF2)

Figure 2: Polypropylene fibers 12 mm (PP1); 6 mm (PP2); 3 mm (PP3)

IV. EXPERIMENTAL WORK

The specimens were prepared by using cubic molding of 10cm X 10 cm. The specimens were heated in three different temperatures 200 ^{0}C, 400 ^{0}C, 600 ^{0}C by using an electrical furnace. The specimens were heated slowly at a constant rate of 2^{0}C/ min. Once the required temperature was attained, samples were cooled down until the time of testing for about 20-24 hours. In figure no.3, the following procedures are shown to describe the preparation of samples in the mixing machine as per ASTM C 1116-91 standards [16].

Figure 3: Mixing of samples in the mixture machine

Figure 4: Compressive strength test on compressive test machine

The loss in weight and the compressive strength of twelve mixtures are recorded in four different temperatures respectively 20 ^{0}C, 200 ^{0}C, 400 ^{0}C, 600

^{0}C. The below pictures represent the different samples after heat exposure in 200 ^{0}C, 400 ^{0}C and 600 ^{0}C.

Figure 5 : Samples after heat expose in 200^0 C, 400 ^{0} C and 600 ^{0}C

Below are shown the results of compressive strength and loss of weight for 12 mixtures of hybrid reinforced concrete.

Table 4: Compressive Strength of mixture of 0. 5 % of steel fiber with 0.2 % polypropylene fibers by the volume of concrete

Mixing Ratio	R1 N/mm^2 20 ^{0}C	R2 N/mm^2 200 ^{0}C	R3 N/mm^2 400^{0}C	R4 N/mm^2 600 ^{0}C
Standard Concrete without fibers	33.52	32.09	27.8	26.81
SF1-P1	37.1	36.1	35.1	33.9
SF1-P2	34.1	33.3	30.3	28.65
SF1-P3	35.9	31.41	30.9	30.06
SF2-P1	31.9	31.51	30.5	29.78
SF2-P2	36.29	27.52	26.8	25.5
SF2-P3	36.39	34.16	32.3	31.7

Table 5: Mixture of 0.25 % of steel fibers with 0.1% polypropylene fibers by the volume of concrete

Mixing Ratio	R1 N/mm^2 20 ^{0}C	R2 N/mm^2 200 ^{0}C	R3 N/mm^2 400^{0}C	R4 N/mm^2 600 ^{0}C
SF1-P1	28.83	26.04	27.1	28.2
SF1-P2	35.04	31.63	31.19	30.92
SF1-P3	35.25	30.93	29.7	28.38
SF2-P1	30	28.7	26.67	22.42
SF2-P2	32	29.3	28.3	27.67
SF2-P3	32.5	31.9	28.1	23.57

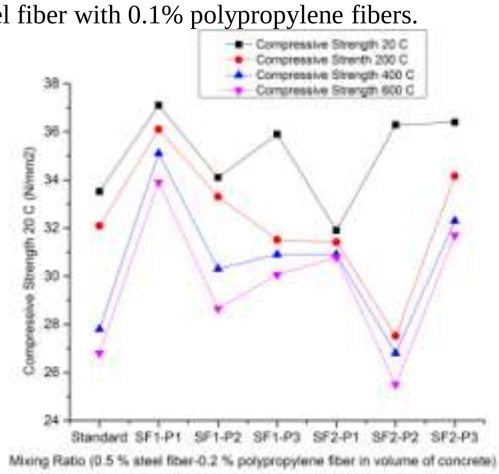
Table 6: Percentage Loss in weight of mixtures with 0.25 % steel fibers and 0.5% of polypropylene fibers by the volume of concrete

Mixing ratio	% loss of weight 200 ^{0}C	% loss of weight 400^{0}C	% loss of weight 600 ^{0}C
SF1-P1	5.95	6.12	7.83
SF1-P2	6.63	6.74	7.18
SF1-P3	5.78	6.35	7.13
SF2-P1	5.4	5.7	6.6
SF2-P2	3.4	4.7	5.9
SF2-P3	6.34	6.7	7.97

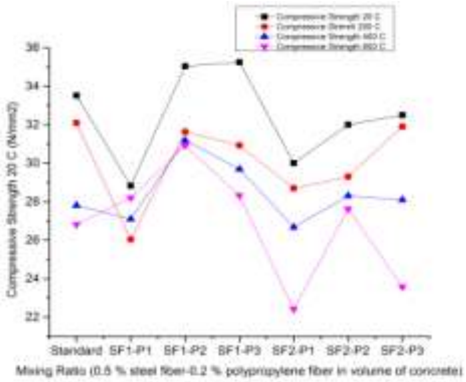
Table 7: Percentage Loss in weight of mixtures with 0.1 % of steel fibers with 0.25% of polypropylene fibers by the volume of concrete

Mixing ratio	% loss of weight 200 ^{0}C	% loss of weight 400^{0}C	% loss of weight 600 ^{0}C
SF1-P1	9.27	9.73	10.12
SF1-P2	6.76	6.81	7.38
SF1-P3	4.85	6.11	7.33
SF2-P1	2.44	4.5	7.69
SF2-P2	6.34	6.8	7.12
SF2-P3	4.55	5.8	7.7

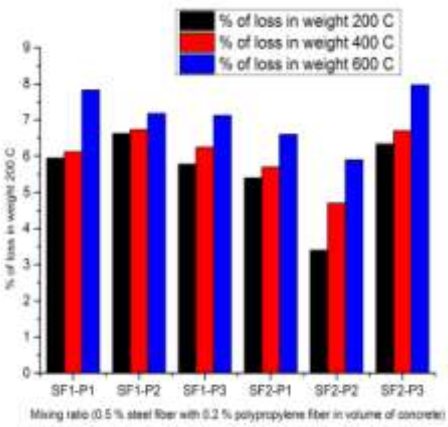
The graph below shows the results of compressive strength and loss of weight on 200 ^{0}C, 400 ^{0}C and 600 ^{0}C for two different mixing ratios. Graph no.1 shows the results of compressive strength of mixing ratio of 0.5 % steel fibers in combination with 0.2 % polypropylene fibers. Moreover, graph no.2 reflects the results of compressive strength in four different temperatures of mixing ratio of 0.25 % steel fiber with 0.1% polypropylene fibers.



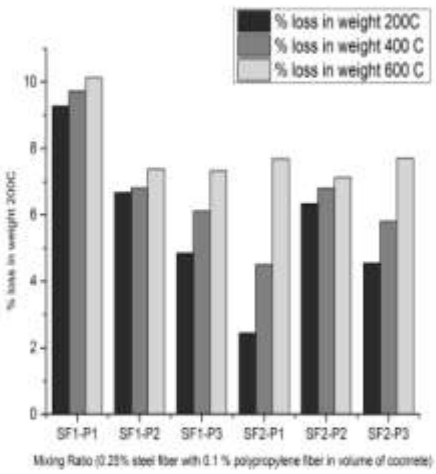
Graph 1 : Compressive strength of mixing ratio of 0.5 % steel fibers in combination with 0.2 % polypropylene fibers in four different temperature 20^{0}C, 200 ^{0}C, 400^{0}C, 600^{0}C.



Graph 2 : Compressive strength of mixing ratio of 0.25 % steel fibers in combination with 0.1 % polypropylene fibers in four different temperature 20^0C, 200 ^{0}C, 400 ^{0}C, 600 ^{0}C.



Graph 3 : Loss in weight of mixing ratio of 0.5 % steel fibers in combination with 0.2 % polypropylene fibers in three different temperatures, 200 ^{0}C, 400 ^{0}C, 600 ^{0}C.



Graph 4 : Loss in weight of mixing ratio of 0.25 % steel fibers in combination with 0.1 % polypropylene fibers in three different temperatures 200 ^{0}C, 400 ^{0}C, 600 ^{0}C.

V. CONCLUSIONS

1. The behavior of reinforced concrete at evaluated temperature is similar to that of the plain concrete.

2. The compressive strength of fiber-reinforced concrete was higher than that for the plain concrete for all heating temperature up to 600 ^{0}C.

3. Fiber-reinforced concrete with 1% steel fibers 5 cm in length in combination with 0.2 % polypropylene fibers 12 mm in length has a superior behavior after exposure to a high temperature.

4. Fiber-reinforced concrete with 0.5 % steel fiber SF2 3cm in length in combination with 0.1 % polypropylene 12 mm in length has shown the lowest value of compressive strength after heat exposure.

5. For all the samples tested, a significant loss in weight was founded which varies from 3-10 % after the sample have been treated in 200 ^{0}C.

6. The loss in weight of samples treated in 400 ^{0}C and 600 ^{0}C has not shown a significant difference compared with the ones treated in 200 ^{0}C.

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