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Hybrid Fiber Reinforced HPC at Elevated Temperatures

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Abstract

This study is trying to provide a better understanding on the behavior of high performance concrete with fiber addition, under elevated temperatures. A cocktail of 0.80% steel fibers and 0.22% polypropylene fibers were added to the mix. The specimens were subjected to different temperatures. An electric furnace was used to heat the specimens up to 200 °C, 400 °C and 600 °C. The mass loss, the initial and residual compressive strength were determined. The spalling phenomenon was also observed. The low permeability of the high strength concrete was found responsible for the reduction of the residual strength. The results showed also a slight change of color on the heated concrete.

Rezumat

Acest studiu încearcă să ofere o mai bună înţelegere asupra comportamentului betonului de înaltă performanţă cu adaos de fibre supus la temperaturi înalte. Ca şi adaos de fibre a fost folosit un mix oţel-polipropilenă constând într-un procent volumetric de 0.80% fibre de oţel şi 0.22% fibre de polipropilenă. Probele de beton au fost supuse la 200 ° C, 400 ° C şi 600 ° C, utilizând un cuptor electric. Au fost determinate pierderea de masă şi rezistenţa la compresiune iniţială şi reziduală. A fost urmărit de asemena şi fenomenul de exfoliere. Scăderea rezistenţei reziduale a fost pusă pe seama permeabilităţii reduse a betonului. S-a observat o uşoară schimbare a culorii betonului încălzit.

Keywords: high performance concrete, steel fibres, polypropylene fibres, spalling, compressive strength

1. Introduction

High performance concrete structures have been studied in various aspects. Recently, more attention has been paid to the mechanical properties of concrete at high temperature, or the residual properties of concrete after exposure to elevated temperatures [1,2]. Although HPC has shown a number of advantages when used in concrete structures, it suffers from one major weakness: higher

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brittleness. When exposed to high temperatures, high performance concrete exhibits more serious degradation than normal concretes does, such as spalling and cracking [3,4]. Many investigations have confirmed that high strength concrete is more likely to exhibit explosive spalling [5]. It has been found that a number of fibers can also improve the residual properties of concrete after exposure to elevated temperatures. Polypropylene fibers were used to reduce spalling and steel fibers to reduce cracking and to enhance the residual strength [6,7].

2. Experimental program

2.1 Materials and mix proportions

Ordinary Portland cement, CEM I 52.5R and microsilica were the cement based materials. The coarse aggregate was crushed gravel and had two nominal sizes 4-8 mm and 8-16 mm. As fine aggregate, river sand with the nominal size of 0-4 mm was used. To achieve a good workability, superplasticizer was added to the mix. The steel fibers used in this study had hooked ends, were 25 mm in length, with a diameter of 400 μm. Polypropylene fibers were 12 mm in length with a diameter of 15 μm. Table 1 is presenting the properties of the used fibers and Table 2 the mix proportions of the high performance concrete.

Table 1**:** Fibers properties

Properties/types of fibers	Steel	Polypropylene
Length [mm]	25	12
Diameter [μm]	400	15
Specific gravity [kg/m³]	7.85	0.91
Shape	With hooked ends	Straight, multifilament
Tensile strength [MPa]	1000	300-400
Elastic modulus [GPa]	210	3.6
Melting point [°C]	1500	170

Table 2**:** Mix proportions

Specimens name	RB
Cement [kg/m³]	520
Microsilica [kg/m³]	52
Superplasticizer [l/m³]	15.6
Water [l/m³]	130.68
Sand 0-4 [kg/m³]	771.9
Coarse aggregate 4-8 [kg/m³]	258.80
Coarse aggregate 8-16 [kg/m³]	688.01
Steel fibers [kg/m³]	62.80
Polypropylene fibers [kg/m³]	2.00
w/cm	0.28

2.2 Specimens preparation

Crushed aggregates was first added to the mixer, followed by approximately two-thirds of the water in which were added the polypropylene fibers. After 5 min. of mixing, the cement, the microsilica and the remaining water with the superplasticizer were added gradually to the running mixer. In the end, after the homogenization, were added the steel fibers. The curing of the specimens was carried out in accordance with RILEM-Technical Recommendation for Testing and Use of Construction Materials [8]. During the curing the specimens were kept in water with the temperature of 20±2 ºC for 28 days. After removing from water, the specimens were left to dry naturally.

2.3 Tests

An gas-fired furnace was used to heat the specimens up to 200 °C, 400 °C and 600 °C. The temperature time curve is presented in Fig. 1. The loading rate was 1.4 °C/min, maintaining for 3 h the target temperature for each batch. After having reached the target temperature, the specimens were cooled down to the room temperature within the furnace.

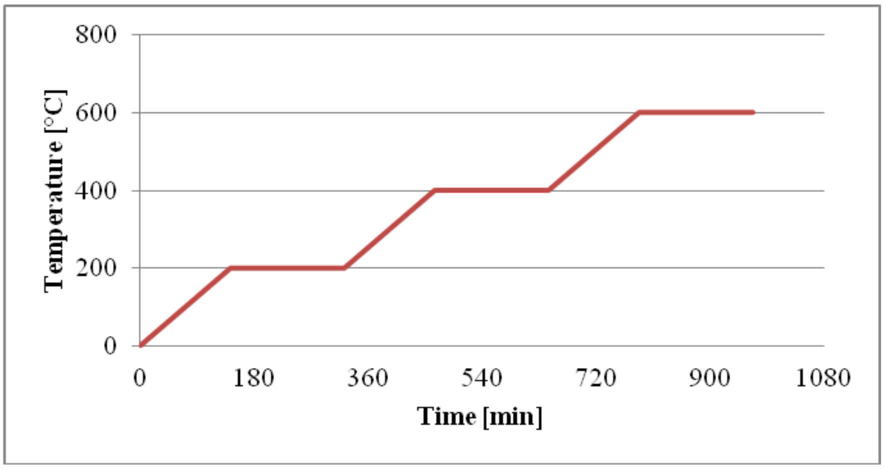

Figure 1. Temperature-time curve

Compressions tests were carried out in accordance with CEB-FIB Model Code [9] prescriptions on 100 mm cubes, using a test machine with a 3000 kN capacity, at 28 days. The load rate was 1 MPa/sec. The testing procedure is ilustrated in Fig. 2.

Figure 2. Compression test

The addition of fibers has a negative effect on the mass loss [10]. To determine the influence of polypropylene fibers on the mass loss and the relationship between the exposure temperature and the residual compressive strength the equations propused by J. Xiao and H Falkner were used [11].

For mass loss:

$$\Delta m^T / m^{20} = 0.0001T - 0.0009 \quad (1)$$

For relative compressive strength:

$$f_{cu}^{T} / f_{cu}^{20} = 0.002(T/100)^3 - 0.04(T/100)^2 + 0.11(T/100) + 0.9638 \quad (2)$$

$$f_{cu}^{T} / f_{cu}^{20} = 1.011 - (T/1900) \qquad ,T \leq 400^{\circ}C \quad (3.a)$$

$$f_{cu}^{T} / f_{cu}^{20} = 1.440 - (T/625) \qquad ,400^{\circ}C \leq T \leq 900^{\circ}C \quad (3.b)$$

3. Results and analysis

During heating, no explosive spalling phenomena occurred. However, it was observed a slight cracking of the heated specimens. The maximum crack was 0.10 mm and it was measured on the specimens heated at 600 °C. The change of concrete color (from grey to a tint of yellow) can be attributed to the change in texture and composition, expansion and crystal destruction during the heating [12].

3.1 Mass loss

The mass loss was determined by weighing the specimens before and after they were subjected to high temperatures. Fig. 3 shows the mass fluctuation of the high performance concrete specimens at different levels of temperature. The measured and determinated relative mass losses are summarized in Fig. 4.

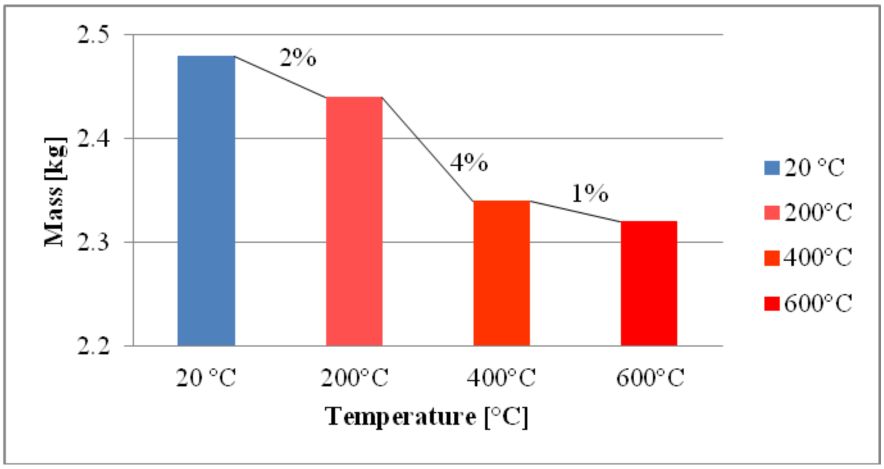

Figure 3. Mass loss

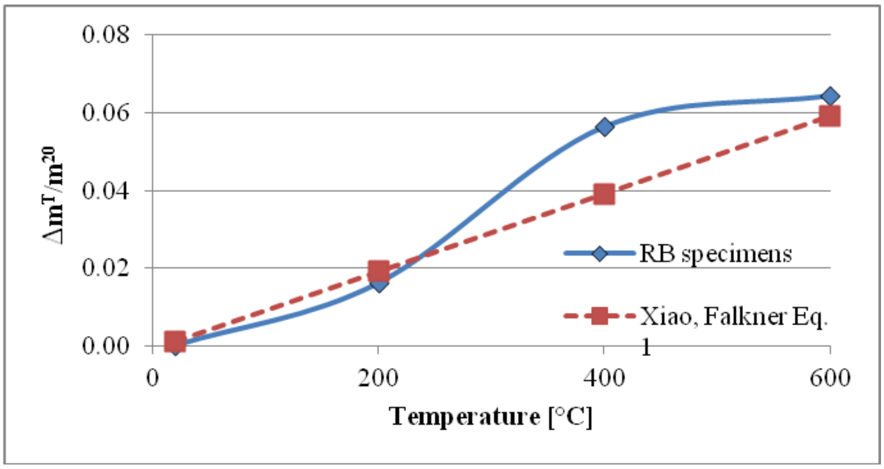

Figure 4. Regression for mass loss

3.2 Residual compressive strength

Results are presented in Fig. 5. The measured and determinated relative compressive strength are summarized in Fig. 6. It was noticed a gain of strength between 20 °C and 200 °C . Above this temperature, the specimens progressively lost their compressive strength, which has decreased with about 33 % at 600 °C, towards the strength measured to the room temperature.

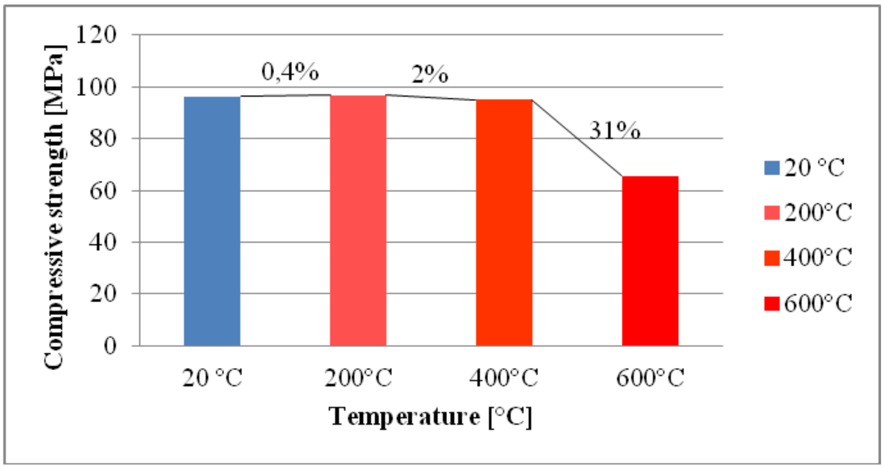

Figure 5. Compressive strength

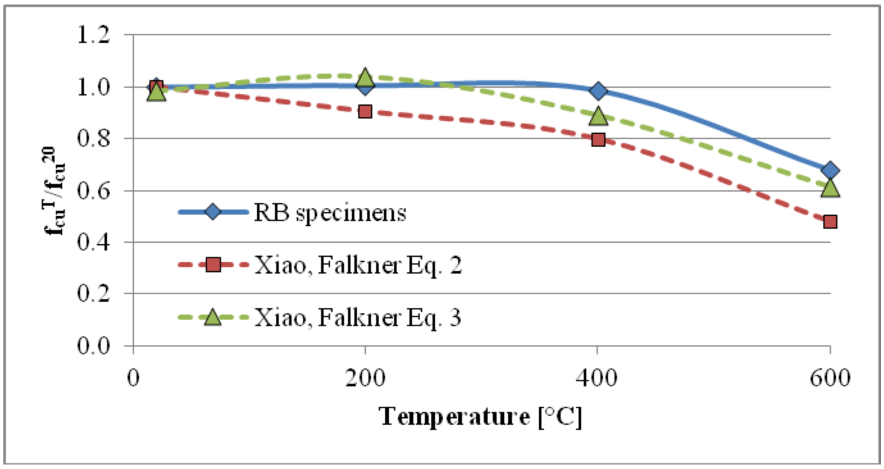

Figure 6. Regression for compressive strength

5. Conclusions

Based on these results, several conclusions may be drawn:

1. No explosive spalling occurred up to 600 ºC. The absence of this phenomenon reconfirms the beneficial effect of polypropylene fibers on heated concrete, by avoiding or reducing explosive spalling.
2. Up to 200 ºC the mass loss of the high performance fiber reinforced concrete is relatively small, while between 200 ºC and 400 ºC it becomes double. After 400 ºC, the mass loss slows down up to 1%.
3. The specimens retained about 98% of their compressive strength up to 400 °C, but this was reduced to 65% after they were expodes to 600 °C. We can observe a falling point between 400 °C and 600 °C, as other authors had concluded as well [11,13].

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