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Analysis of fire resistance of concrete with polypropylene or steel fibers

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HIGHLIGHTS

- Concrete with steel fibers achieve greater compression strength than without addition.
- Concrete with polypropylene fibers reaches higher strength than with steel fibers.
- Steel fiber concrete reach higher temperatures to fire than concrete without addition.
- Polypropylene or steel fibers concrete to fire cool more slowly than without addition.
- Temperatures 200 °C, compressive strength with fiber is greater than without addition.

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ABSTRACT

The decrease in concrete resistance and the expansion generated in reinforced concrete structures by direct exposure to fire at 400 °C maximum temperature serves as the basis for the present research. The aim is to improve these problems by the addition of steel fibers or of polypropylene fibers in concrete. From the results analysis of compression fracture tests on cylindrical concrete specimens, it can be concluded that concrete with addition of polypropylene fibers or steel fibers are a good alternative to traditional concrete, because both its strength, and its behavior in case of fire are improved, delaying the appearance of fissures and explosive concrete spalling.

1. Introduction

Given the importance of concrete as a structural material and the significance of preserving its stability in case of fire, advancing in the research of materials and systems that improve their behavior has become a need, because fire reduces concrete resistant capacity and rigidity and generates deformations imposed during the fire and the cooling phase [1,2].

Concrete subjected to early stages of fire has no noticeable loss of qualities, and rather, it increases its mechanical strength when up to 280 °C, maintaining a grey appearance. From 280 °C onwards, the mechanical ability of concrete decreases, reaching a compressive strength loss of 15% at around 400 °C. This decisively influences the way to work and the type of exposure to fire of the structural element [3].

In addition to resistance, the decrease of the longitudinal elasticity module of concrete is of utmost importance, decreasing up to 75%, when the temperature rises from 20 °C to 400 °C. In addition, this thermal gradient produces expansion differences between the different faces of the structural element regarding their exposure to fire, resulting in differences in strain and high tensile stresses, that produce concrete cracking [4–7].

The addition of steel fibers modifies the nonlinear behavior of structural concrete, especially its tensile strength, preventing the opening and propagation of cracks and increasing its ductility [8–12].

Concrete reinforced with polypropylene fibers, due to the physical and mechanical properties of the fibers, reduces the permeability and capillar porosity blocking the pores in the concrete. These improvements are achieved with the optimal amount of polypropylene of 0.7 kg/m^3 [13–16].

The addition of metallic fibers in concrete, when subjected to fire, produces a positive influence, improving energy absorption and reducing cracking [17–19]. In the case of the addition of polypropylene fibers, the ability to reduce cracking is due to fact that concrete permeability increases suddenly between 80 °C and 130 °C, and polypropylene, once it has reached the melting point, flows through the cracks and produces channels allowing the

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water vapor and gases to be evacuated releasing the pore pressure [20–28]. Although there are numerous research works on the behavior of concrete elements to fire, no literature has been found about concrete elements subjected to compression in the range of temperatures studied in the present work, neither when subjected to a direct fire test, nor comparisons performance to fire of concrete with steel and polypropylene fibers.

Based on the above premises, the aim of this research is to compare the mechanical behavior of concrete with addition of metallic fibers, with concrete with polypropylene fibers, when exposed to direct fire action, with maximum temperatures of around 400 °C. Likewise, the mechanical behavior of these concretes will be compared with concrete without fibers, both exposed to fire and at room temperature.

2. Experimental testing

2.1. Materials

For the development of the experimental work, the following equipment and materials listed below were used.

Materials used:

- Cement type CEM II/BL 32,5 for the three batches, according to the standards UNE-EN 197-1:2011 and RC-08 [29,30].
- Washed fine river sand with 0–4 mm granulometry fraction, of washed siliceous nature, according to the standard UNE-EN 13139/AC:2004 [31].
- Coarse aggregate with 4–20 mm granulometric fraction, of washed siliceous nature, and a maximum aggregate size of 12 mm, according to the standard UNE-EN 12620:2003 +A1:2009 [32].
- Water from the Canal de Isabel II of Madrid water supply system, since it meets the technical requirements established for structural concrete.
- Straight drawn steel fibers with hooks at the edges of each fiber (Sika Fiber CHO65/35 NB). They comply with the standard ASTM A 820-Type 1.
- Monofilament polypropylene fibers (SIKA Sikafiber M-12). They comply with the standard UNE 14889-2: Polymer fibers for concrete. Class 1-a: “Monofilament Microfiber”.
- No additives have been used.

The proportions used in the various batches are shown in Table 1.

Fig. 1 shows the appearance of the steel and polypropylene fibers employed and the fiber characteristics are shown in Table 2.

2.2. Testing program

In order to achieve the objective of the present research, we have studied the behavior in compression in concrete specimens without additions and with different percentages of fibers of steel and polypropylene, in accordance with Spanish Structural Concrete standard, annex 14 of the EHE [33], for manufacturing fiber-reinforced concrete. A group of specimens has initially been tested to fire, and later tested to fracture in compressive strength, in order to compare it with the performance of specimens not subjected to thermal aggression, and to establish results of strength, resistance, strain and energy density deformation, both maximum and ultimate ones.

Table 1
Proportions of the batches and material content according to addition.

Type of concrete	HM-25				
Batch	1	2		3	
Type of addition	No addition	Steel fibers	Steel fibers	Polypropylene fibers	Polypropylene fibers
N° of specimens	6	6	6	6	6
Cement (kg)	4.088	4.088	4.088	4.088	4.088
Sand (kg)	8.472	8.472	8.472	8.472	8.472
Gravel (kg)	14.616	14.616	14.616	14.616	14.616
Water (l)	2.040	2.040	2.040	2.040	2.040
Addition (%)	0	1	2	1	2

To perform the analysis, 30 cylindrical test pieces have been made, 100 mm in diameter and 200 mm in height, according to the standard UNE-EN 12390-1:2013 [34]. The testing program was organized in three batches; with the first one, 6 specimens of concrete without additions were made. With the second batch, 12 specimens were elaborated with addition of steel fibers, of which 6 were made with 1% proportion of steel fiber in cement weight, and the other 6 specimens, with 2% addition. With the third and last batch, another 12 specimens were produced; in this case incorporating polymeric fibers of polypropylene: 6 of them with 1% addition and the other remaining 6 with 2% of polypropylene fibers per cement weight. From each of the specimen groups performed, 50% specimens were tested directly to fracture by compression, according to the standard UNE-EN 12390-3:2009 [35], while the remaining 50%, were first subjected to the direct fire test in accordance to the fire resistance tests of materials used by the Fire Prevention and Extinction Service of Madrid Autonomous region and the standards UNE-EN 1363-1:2012, UNE-EN 1363-2:2000 and UNE-EN 1365-4:2000 [36–38]. Once cooled, they were also tested in compression.

The nomenclature and the tests carried out on the specimens can be seen in Table 3.

2.3. Experimental process

Firstly, and before starting the manufacture of the concrete specimens, materials necessary for the preparation of the test specimens listed in Table 1 were kept 24 h in laboratory conditions. Gravel was sifted through a mechanical sieve, in order to ensure that there was no aggregate larger than 12 mm. Each of the materials used, cement, sand, gravel, fibers and water were separately weighed, with a dial type industrial scale and with a digital scale, according to the required precision.

Kneading of the specimens batches was carried out in a planetary mixer of vertical axis IBERTEST CIB-701 model, upgraded to IB32-040V0, where the materials were introduced in the following order: gravel, cement, and finally, sand, while specimens with additions were individually manually mixed, to ensure a perfect distribution of the fibers.

Once all materials were incorporated in the mixer, except water, the mixing process began with the help of the rotary blades of the mixer, mixing the dry materials for approximately 2 min in order to homogenize the batch. Later, water was progressively poured, taking into account the moisture content of the aggregate until a plastic consistency of concrete was reached, for approximately 5 min.

Once the concrete for each of the 3 batches was finished, the molds were filled up, according to the fresh concrete testing standard UNE-EN 12390-2 [39]. And after each mold was filled with three concreting lifts, they were compacted with a compactor steel bar. Specimens were made up to volume and were kept for 24 h at laboratory temperature of approximately 22 °C (±3 °C) and an approximate relative humidity of 60%, before they were unmolded.

After 24 h, specimens were unmolded and kept in a curing chamber at 20 °C (±2 °C) temperature and relative humidity ⩾95% for 28 days, for curing, hardening and for performing the subsequent study of fracture compression tests and fire tests,