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# COMPRESSIVE BEHAVIOUR OF A TIRE RECYCLED STEEL AND TEXTILE FIBER CONCRETE SUBJECTED TO FIRE

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## ABSTRACT

The use of rubber aggregates, steel and textile fibres recycled from tires in concrete is a solution that it is being studied by several authors around the world. A few works have been carried out at room temperature but very scarce at high temperatures. This paper presents the results of a research with the aim to evaluate the behaviour at high temperatures of a concrete made with different amounts of recycled textile and steel fibres from tires. The study considered five concrete compositions, with the same water/cement ratio (W/C=0.43), differing only in the type and quantity of fibers incorporated in the mixture. Thus, a reference composition (0% fiber), two compositions with 30 and 70kg/$m^3$ of steel fibers and a composition with 2 and 4kg/$m^3$ of textile fibers from tires were tested. The concrete was tested for a load level of 0.5$f_{cd}$ and different maximum temperature levels (20, 300, 500 and 700ºC).

**Keywords:** concrete, steel fibers, textile fibers, recycled tires, high temperatures, compressive strength.

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## 1. INTRODUCTION

The studies carried out by different authors have shown that the strength of the concrete, even the normal, degrades with increasing temperature [1-4]. These reductions on the mechanical properties are however more pronounced for high strength concretes. The high strength concretes are also more susceptible to spalling than the normal ones due to their higher compactness and the existence of pores of smaller diameter that difficult the release of the water vapour generated inside the concrete in case of fire [5-7]. On the other hand the addition of ultrafine particles in the cements used in these compositions and even the adjuvants make the concrete compact and with pores closed to the point of creating difficulties to the water vapour realising to outside [8].

Bazant and Kaplan also noted that the fact the coefficients of thermal expansion of aggregates and cement paste are not equal, leads to thermal differential movements between them, which translate into micro-cracks and spalling on the concrete matrix [9].

Khoury has developed important studies in this area studying the mechanical properties of concrete at high temperatures. The author found that the mixing proportions of aggregates with cement and water has a major impact on mechanical properties of concrete with temperature because usually important chemical and physical changes occur, with losing of cohesion, that lead to its degradation [10].

Bayramov et al conducted a study to optimize the amount of steel fibers on high strength concrete to achieve higher ductility and increase its energy absorption capacity. The steel fibers used in the compositions presented a relation length/diameter between 55 and 80. The authors studied the effect of distribution of fibers in the concrete composition because they thought to have influence. The results showed that the diameter and orientation of steel fibers had an important role in the compressive strength of concrete. The steel fibers have been introduced with the aim of strengthening the concrete, reducing cracking and spalling. [11].

Lau and Anson carried out a study to characterize the mechanical properties of normal and high performance concretes subjected to different temperatures. They also studied the effect of add 1% of steel fibers as reinforcement for both types of concrete. In this study the authors found that as higher is the increasing rate of temperature lower is the permeability of concrete and higher the risk of spalling of the concrete. The addition of steel fibers improves the performance of concrete in fire regardless the mixture and maximum temperature reached. Thus, the authors found that the addition of steel fibers in the concrete improves its compressive strength [12].

Çavdar studied the effect of four different types of fibers on the concrete compressive strength at high temperatures. The fibers tested were polypropylene (PP), carbon (CF), glass (GF) and polyvinyl alcohol (PVA). The amounts used were 0.0%, 0.5%, 1.0%, 1.5% and 2.0% in volume, and the temperatures tested were 20, 100, 450 and 650ºC [13].

Çavdar found that with the increasing of temperature the cement matrix change in a way that at 450ºC damages and some cracking and at 650ºC extensive cracking and deterioration of concrete occur, respectively. He has also concluded that the compressive strength decreases with the temperature, being the value for the mixtures with PP and GF fibers about 40-50% at 450ºC and 55-70% at 650ºC of the resistance at ambient temperature. The mixtures with CF and with PVA fibres reduce about 3-8% at 450ºC and 50-60% at 650ºC of the compressive strength at ambient temperature. The reduction in compressive strength is lower when the amount of CF fibres added to the mixture is between 0.5 and 1.5% in volume for any temperature in study [13].

Bangi and Horiguchi studied the influence of the length, diameter and fiber type in reducing the internal water vapor pressure of the high strength concretes subjected to high temperatures. In this study were tested polypropylene (PP), polyvinyl alcohol (PVA) and steel fibers (FA). All compositions were reinforced with the same amount of fibers (0.1% by volume) and subjected to a heating rate of 10ºC/min [14].

The authors observed a significant reduction in the pressure of the concrete mixture regardless the type of fibre used and its geometry. They also found that the longer fibers with smaller diameters attenuate the increase of pressure at the mixture pores when compared with the shorter fibers with larger diameters and regardless of the type of fibre. On the other hand, found that concrete mixtures reinforced with PP fibers had a better behavior under fire conditions than the PVA fibers, because PP fibers have better bonding properties with the concrete matrix [14].

The authors also found that the addition of steel and PP fibers reduce the cracking and spalling, respectively, since the last ones will sublimate for temperatures of around 170ºC, creating a net of micro-channels from which the water vapour can be released to outside and with this reduce the internal pressure at mixture pores. The experimental results showed that the addition of fibers with lower sublimation temperatures presented and improved the concrete performance when compared to fibers with higher melting temperatures [14].

This research appears in the context and view of the increasing need to manage rationally the natural resources [15-18]. The research aims to evaluate experimentally the compressive strength at room and high temperatures of a concrete made with tire recycled steel and textile fibers. This research aims also to study the influence of these fibres in the control of the spalling in concrete and the behaviour of concrete made with them in fire.

## 2. EXPERIMENTAL STUDY

### 2.1 Concrete composition and specimens

The following components were used: Portland cement CEM II/A-L 42.5R, superplasticizer Sikament-HE 200P (SP), coarse aggregates (CC) and sand (FS).

Table 1 presents some information about this cement in terms of chemical composition and mechanical properties.

Table 1: Some properties of Portland cement CEM II/A-L 42.5R

| **Chemical composition** | | | **Mechanical properties** | | |
|---|---|---|---|---|---|
| **Element** | $SO_3$ | Cl | **Compressive strength** | Age<br>2 days | Age<br>28 days |
| **%** | ≤ 4 | ≤ 0.10 | **MPa** | ≥20 | ≥42.5 and ≤62.5 |

The type and size of aggregates used in compositions are presented in Table 2.

Table 2: Type and size of aggregates

| **Aggregate type** | | **Aggregate size** |
|---|---|---|
| **Course** | crushed stone (CC) | 12.7mm |
| **Fine** | sand (FS) | < 4mm |

The five concrete compositions in study differed only in the type and amount of fibers in the mixtures. In the first composition, plain concrete (RC), there were no fibers. In the second and third composition were incorporated textile fibers (TF) (figure 1a) replacing the larger gravel limestone aggregates in the amount of 2 (TF1) and 4 (TF2) kg/m$^3$, respectively. In the fourth and fifth composition were used steel fibres (FA) (figure 1b) replacing the larger gravel limestone aggregates in the amount of 30 (FA1) and 70 (FA2) kg/m$^3$, respectively. The steel and textile fibers were recycled from tires.

It is decided to replace the larger aggregate for both types of fibers for different reasons: the textile fibers in order to allow the realizing of the water vapor in the concrete in case of fire and avoid the spalling and the steel fibers in order to resist the thermal stresses generated due to the heating.

Figure 1: Recycled fibers from tires. a) Textiles fibers. b) Steel fibers

The concrete compositions are presented in Table 3.

Table 3: Concrete compositions per m$^3$

| | CEM [kg/m$^3$] | FS [kg/m$^3$] | CC [kg/m$^3$] | W [l/m$^3$] | W/C | TF [kg/m$^3$] | SF [kg/m$^3$] |
|---|---|---|---|---|---|---|---|
| RC | 400 | 698 | 1097 | 173 | 0.43 | - | - |
| TF1 | 400 | 698 | 1095 | 173 | 0.43 | 2 | - |
| TF2 | 400 | 698 | 1093 | 173 | 0.43 | 4 | - |
| SF1 | 400 | 698 | 1067 | 173 | 0.43 | - | 30 |
| SF2 | 400 | 698 | 1027 | 173 | 0.43 | - | 70 |

In Table 4 are presented the compression strength and resistance class of the tested concretes according to EN 206-1 (2007) [19]. The specimens were cured in the ambient conditions of the laboratory (around 20ºC and 60% of relative humidity). The specimens were tested at least with three months of age.

Table 4: Compression strength and resistance class of tested concretes

| Concrete type | $f_{cm}$ (MPa) | Resistance class |
|---|---|---|
| RC | 46.44 | C35/45 |
| TF1 | 49.11 | C35/45 |
| TF2 | 46.62 | C35/45 |
| SF1 | 50.63 | C35/45 |
| SF2 | 45.14 | C30/37 |

The assessment of the compressive strength of concrete was carried out on cylindrical specimens of 75mm diameter and 225mm height, that corresponded to a height/diameter ratio of 3:1. The specimens were provided with five type K thermocouples in order to register the temperatures inside the concrete. The location of thermocouples in the specimens was based on the recommendations of RILEM TC 200 HTC [20] (Figure 2).

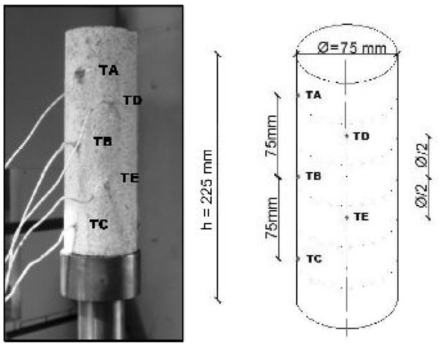

Figure 2: Specimens for the compressive and direct tensile strength tests and location of thermocouples

## 2.2 Test plan

The characteristics of the specimens are summarized in Table 5. Three tests as a minimum were developed for each combination of parameters.

Table 5: Test plan

| Test | Specimen dimensions (mm) | Loading level | Temperature (ºC) |
|---|---|---|---|
| compressive strength | cylinders, d=75:h=225 | $0.5f_{cd}$ | 20, 300, 500, 700 |

## 2.3 Test set-up and procedure

The experimental set-up for compression tests were composed by a universal tensile/compression machine of 600kN capacity (a), an electric tubular oven, attached on it, for heating the specimens (b). The oven had internal dimensions of d=125mm and h=300mm and maximum working temperature of 1200ºC, a data acquisition system (c) and an universal machine controller (d) (Figure 3).

Figure 3: Test-setup

The specimens were subjected, during the entire test, to a constant compressive loading equal to a percentage of the design value of the compression strength of the concrete at ambient temperature ($0.5f_{cd}$). This load tried to simulate the conditions when concrete is in a real compressed structural element.

The specimens were heated up at a rate of 3ºC/min up to the desired level of temperature. The temperature was considered achieved when the average temperatures on the three superficial thermocouples match the temperature of the oven. The maximum axial temperature differences between the three superficial temperature readings could not exceed 1ºC at 20ºC, 5ºC at 100ºC and 20ºC at 700ºC. The specimens were then kept at that temperature for an hour to stabilize. After this the compressive tests were carried out.

The test procedure was adopted according to RILEM TC 200 HTC recommendations [20]. The loading was increased in the compressive test at a loading rate of 0.25kN/s up to rupture of the specimen.

## 3. RESULTS

### 3.1 Temperature distribution

Figure 4 presents, as an example, the evolution of temperature in the cross-section of a concrete specimen with 30kg/m$^3$ of steel fibres (SF1) for the 500ºC test series. The analysis of the figure shows that temperature inside the oven was kept uniform during testing, since the temperature curves of the two zones of the oven were nearly coincident throughout the test. This resulted in a good thermal exposure that the specimen has been subjected in the oven and that remained in the different tests.

In Figure 4 it can be also seen a good temperature uniformity inside the specimen during the heating and temperature stabilization phase (60 minutes). However there is a slight delay in the concrete mass heating in the specimen up to about 120 min.

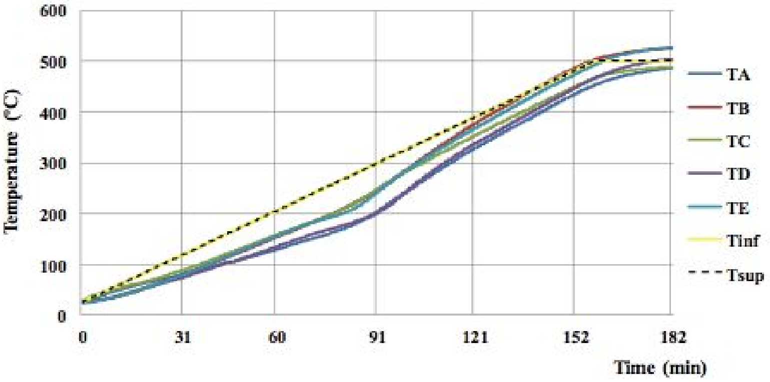

Figure 4: Temperature evolution in the cross-section of a SF1 specimen - 500ºC series

### 3.2 Compressive strength

The results obtained in the experimental tests for the compressive strength are summarized in Figures 5 and 6.

Figure 5 shows the variation with temperature of the compressive strength of the concretes with 2kg/m$^3$ (TF1) and 4kg/m$^3$ (TF2) of textile fibers, related to its value at room temperature. The values are compared to the ones of the plain concrete (RC). The results presented for 300ºC show an increase on the compressive strength of around 47% for the RC, 56% for the TF1, and

43% for the TF2. For 500ºC the RC value showed a similar strength to the one at ambient temperature and the others still showing a 20% strength higher than the one at ambient temperature. For 700ºC all the specimens have suffered rupture before reaching this temperature, making it impossible to be tested at compression.

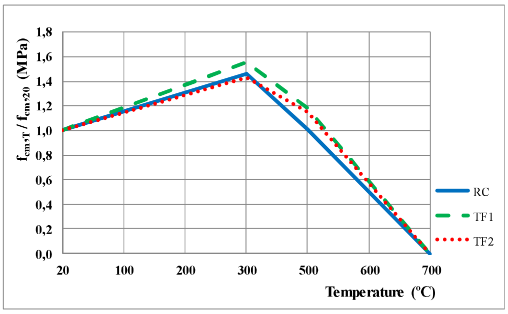

Figure 5: Compressive strength with temperature (RC, TF1 and TF2 concretes)

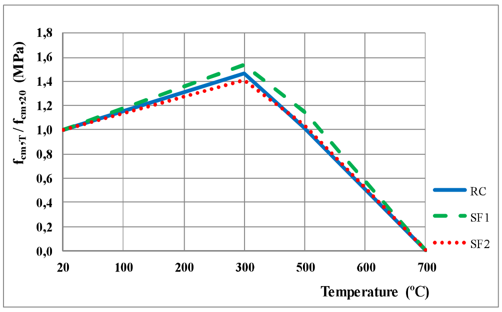

Figure 6: Compressive strength with temperature (RC, SF1 and SF2 concretes)

Concerning to Figure 6, it shows the variation with temperature of the compressive strength of the concrete with 30kg/m$^3$ (SF1) and 70kg/m$^3$ (SF2) of steel fibers, related to its value at room temperature. The values are also compared to the ones of the plain concrete (RC). The addition of steel fibers to the concrete also resulted in an increasing of the compressive strength for different temperature levels up to 500ºC.

At 300ºC there was an increase of the compressive strength of about 47% for the RC, 54% for the SF1 and 41% for the SF2 concrete. At 500ºC the compressive strength of the RC and SF2 concretes are similar to the one at ambient temperature and for the SF1 is 15% higher than the one at ambient temperature. Once more the strength was null at 700ºC. The results showed that an addition of 30kg/m$^3$ of steel fibers to the concrete presented a better result in terms of the compressive strength than an addition of 70kg/m$^3$.

Figure 7 presents, as an example, photos of the specimens after the compressive strength tests for the 500ºC test series. Higher amounts of fibers (steel or textile) lead the greater destruction on the specimens.

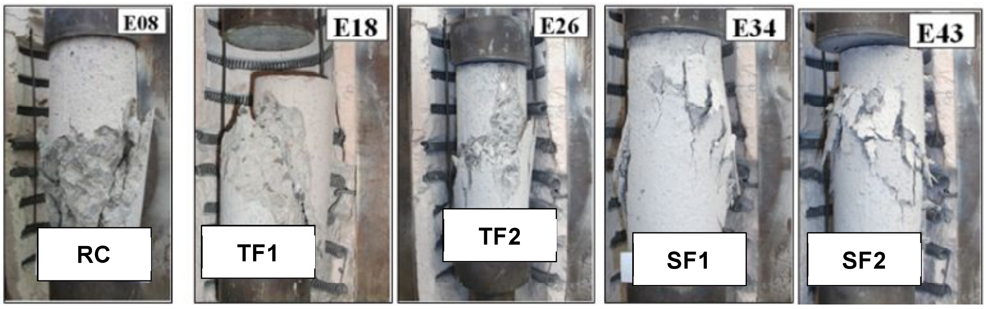

Figure 7: Specimens after the compressive strength tests - 500ºC series

## 4. CONCLUSIONS

The following conclusions may be drawn from the present study:

- For temperatures, between 300 and 500° C, the concrete with 30kg/m$^3$ (SF1) of steel fibers, gave better results in terms of compressive strength of concrete. The steel fibres, when not excessive, have a beneficial effect on the compressive strength of concrete. These fibers improve the behavior of the concrete because they resist to the thermal stresses generated during heating that degrades the concrete reducing the compressive strength;
- A quite similar result was observed for the concrete composition with 2kg/m$^3$ (TF1) of textile fibers;
- The textile and steel fibers from recycled tires showed to be a good solution in concrete composition to control cracking and spalling and can be a good substitute for the commercial steel and polypropylene fibers.

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