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COMPRESSIVE STRENGTH AT HIGH TEMPERATURE OF RECYCLED TIRE AGGREGATE CONCRETES

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ABSTRACT

This paper presents the results of an experimental research on the normal and high- temperature compressive strength of concretes with steel or textile fibres or rubber aggregates from recycled tires. The studied compositions included a reference (RC), two textile fibers (TF), two steel fibres (SF) and a rubber aggregates (RA) concrete. The specimens were tested in compression for different levels of temperature (20, 300, 500 and 700ºC). During the heating the specimens were subjected to a constant loading level of $0.5f_{cd}$. The results of this experimental program showed that steel and textile fibres are a good solution in the compressive behaviour of the concrete regarding to cracking control. The results for the rubber aggregate concrete revealed a loss on compressive strength with the increase of the rate of these aggregates in concrete.

NOTATION

$\boldsymbol{d}$ – diameter ; $\boldsymbol{h}$ – height
$\boldsymbol{\rho}$ – specific weight
f_{cd} – design value of the compression strength of the concrete at normal temperature
$f_{c,T}$ – compression strength of concrete at temperature T
$f_{cm,T}$ – mean value of the compression strength of concrete at temperature T
$f_{cm,20}$ – mean value of the compression strength of concrete at normal temperature
σ_x – standard deviation
σ – stress ; ε – strain

1 INTRODUCTION

In civil construction industry the use of recycled materials, mainly in concrete manufacture is increasingly and seems a viable reality. In this sense, there are different studies of concrete with the insertion of recycled materials from tires.
Schneider (1982) highlighted the type of aggregates, loading level and cooling process, as the main parameters responsible for concrete cracking and loss of strength [1].

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Bazant and Kaplan (1996) referenced that due to the fact that the coefficients of thermal expansion of the aggregates and cement paste are not equal leads to thermo-differential stress with micro-cracking and spalling in the concrete matrix [2].

Khoury (2000) developed important studies in this area studying the mechanical properties of the concrete at high temperatures. The author found that the mixing proportions of aggregates with cement and water has a major impact on the mechanical properties of the concrete at high temperatures because this influencing the chemical and physical reactions on concrete with losing of cohesion and degradation [3].

Lau and Anson (2006) studied the effect of the addition of 1% of steel fibers on the behaviour of the concrete at high temperatures. In this study the authors found that higher was the temperature, lower the permeability and higher the risk of spalling of the concrete were. The steel fibers improves the behaviour of the concrete at high temperatures and consequently the compressive strength [4].

Çavdar (2012) 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. 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 [5].

Bangi and Horiguchi (2012) 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.

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.

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 reducing the internal pressure at concrete matrix 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 [6].

In this context and in the light of increasing the need to manage natural resources rationally [7] appears this research which aimed to evaluate experimentally the compressive strength at normal and high temperatures of concretes made with recycled tire aggregates (rubber, textile and steel fibers). This research in this way contribute to the sustainability as an alternative solution to the tire deposit after its life time.

2 EXPERIMENTAL RESEARCH

2.1 Materials and methods

Concrete compositions

The materials used in this compositions were Portland cement (C) type II/AL 42.5R (chemistry composition: SO3 ≤ 4% e Cl ≤ 0.10%; compressive strength: 2 days - 20MPa and 28 days - 42.5MPa), natural sand (FA) and crushed aggregates (CA) (6.3 - 16mm). The choice of this cement was based on its enhanced workability, high strength and behaviour at high temperatures.
In the concretes were also used different types of tyre recycled aggregates obtaining different concrete compositions: rubber aggregates (RA), nominal size between 6.3 - 12mm, steel (SF) and textile (TF) fibers. Different amounts of rubber aggregates or steel or textile fibers were added in the concretes. In total were studied seven concrete compositions: a reference one without fibers (RC), two textile fibers ones with 2 (TF1) or 4 (TF2) kg/m^{3}of these fibers, two steel fibres ones with 30 (SF1) or 70 (SF2) kg/m^3 of these fibers and two rubber aggregate ones with 15% (RA1) and 30% (RA2) of these aggregates, respectively. The addition of recycled aggregates / fibers was carried out by replacing gravel limestone aggregates in the mixture.
Table 1 shows the specific weight of the materials used in the concrete compositions while Table 2 presents their compositions.

Table 1. Specific weight of the aggregates, cement and water

	ρ [kg/m^3]
Water (W)	1000
Cement (C)	3100
Natural sand (FA)	2600
Crushed aggregate (CC)	2700
Coarse recycled fraction (RA)	1100

Table 2. Concrete compositions

Concrete mixture	RC	TF1	TF2	SF1	SF2	RA1	RA2
Water (dm^3/m^3)	122.5	122.5	122.5	122.5	122.5	122.5	122.5
Cement (kg/m^3)	400	400	400	400	400	400	400
Natural sand (kg/m^3)	567	567	567	567	567	567	567
Crushed aggregate (kg/m^3)	959	957	955	929	889	560	161
Coarse recycled fraction (kg/m^3)	-	-	-	-	-	165	330
Textile fibers (kg/m^3)	-	2	4	-	-	-	-
Steel fibers (kg/m^3)	-	-	-	30	70	-	-
Water/Cement	0.31	0.31	0.31	0.31	0.31	0.31	0.31
Compressive strength (MPa)	63.68	49.11	46.62	50.63	45.14	24.63	10.60
at days:	28	28	28	28	28	28	28
Strength class	C50/60	C35/45	C35/45	C35/45	C30/37	C16/20	C8/10

The compressive strength and resistance class of the concretes were evaluated according to EN 206-1 (2007) [8]. The results achieved are reported in Table 2. As expected the rubber aggregate (RA) concretes had significantly lower compressive strength than the reference concretes (RC). The decreasing in the strength and stiffness of the concrete is strictly connected to the rubber compressive strength and rubber particles in the concrete matrix that causes voids making the concrete vulnerable.

Specimens and Test procedure

The compressive strength tests were 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 [9] (Fig. 2).

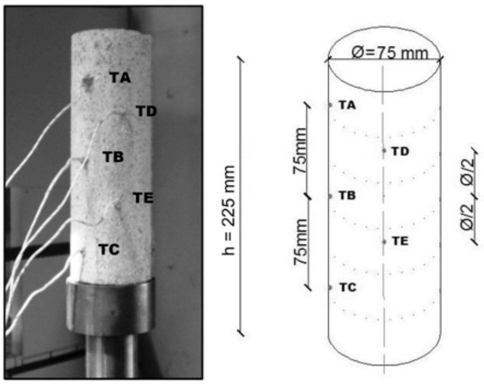

Fig. 1. Specimens and location of thermocouples

The specimens were cured, during 28 days, in a vapour saturated ambient (relative humidity > 98%) and temperature of 20ºC. After this they were removed and left in the lab ambient temperature (between 18 and 20ºC) and humidity (between 40 and 50%) waiting for testing. The specimens were tested at least with three months of age.

The characteristics of the specimens and the test plan are summarized in Table 3. Three tests as a minimum were developed for each combination of parameters.

The experimental set-up for the compression strength tests were composed by a universal tensile/compression machine of 600kN where was accomplished an electric tubular oven for heating the specimens and a data acquisition system for data recording (Fig. 2).

Table3. Test plan

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

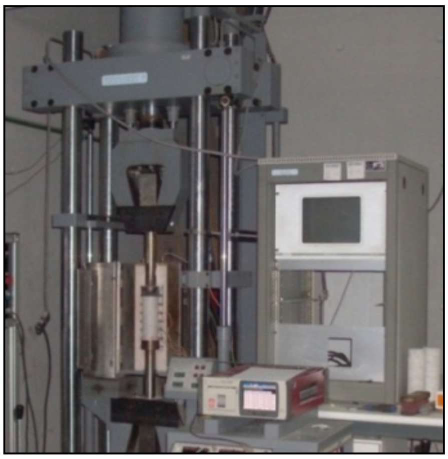

Fig. 2. Test-setup

The specimens during the heating process were subjected to a constant compressive load level equal to 0.5 of the design value of the compression strength of the concrete at normal temperature ($0.5f_{cd}$). This load tried to simulate the conditions of the concrete when 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 thermocouples 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. This test procedure was adopted according to RILEM TC 200 HTC recommendations [9].
After this the compressive tests were carried out. The compressive load was increased at a rate of 0.25kN/s up to the rupture of the specimen.

3 RESEARCH RESULTS

3.1 Compressive strength

The results of the compressive strength of tested concretes are summarized in Figures 3, 4 and 5.

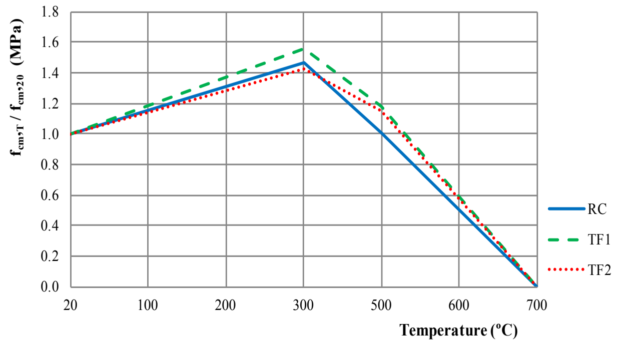

Fig. 3. Compressive strength of the reference (RC) and textile fibers (TF1 and TF2) concretes with temperature

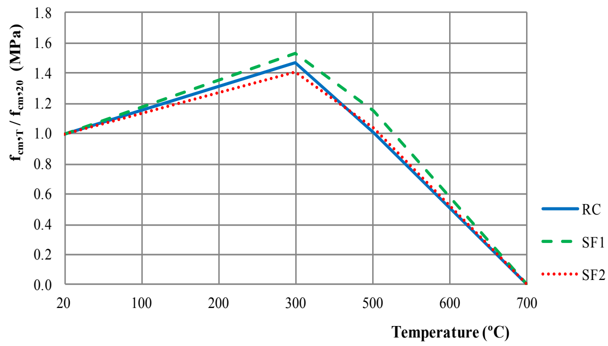

Fig. 4. Compressive strength of the reference (RC) and steel fibers (SF1 and SF2) concretes with temperature

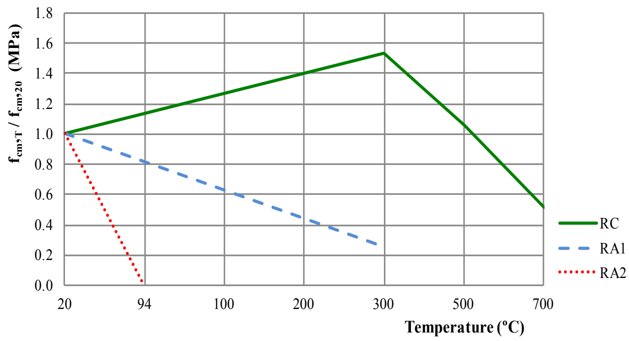

Fig 5. Compressive strength of the reference (RC) and rubber aggregate (RA1 and RA2) concretes with temperature

Figure 3 shows the results for the concretes with 2kg/m^3 (TF1) and 4kg/m^3 (TF2) of textile fibers compared with the ones of the plain concrete (RC) all related to their values at normal temperature. The results show at 300ºC an increasing on the compressive strength of around 47% for the RC, 56% for the TF1 and 43% for the TF2 concrete. At 500ºC the RC presented a strength similar to and the others 20% higher than the one at normal temperature. For 700ºC all specimens have suffered rupture before reaching this temperature making impossible the test for this temperature level.

Figure 4 shows the results for the concretes with 30kg/m^3 (SF1) and 70kg/m^3 (SF2) of steel fibers related to its value at normal temperature. The values are also compared with 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 the different levels of temperature up to the 500ºC. At 300ºC there was an increase on the compressive strength of about 47% for the RC, 54% for the SF1 and 41% for the SF2 concretes. At 500ºC the compressive strength of the RC and SF2 concretes are similar and the SF1 is 15% higher than the one at normal 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 than the 70kg/m^3.

Figure 5 shows the results for the rubber aggregate concretes with 15% (RA1) and 30% (RA2) of these aggregates. The analysis of the Figure shows that for temperatures 300ºC it was only possible to carry out tests on the reference and 15% rubber aggregate concretes since the specimens for the 30% rubber aggregate concrete suffered rupture before reaching this level of temperature. At this temperature it was verified that the compressive strength of the reference concrete increased about 50% regarding to the one at normal temperature. This was not verified for the 15% rubber aggregate concrete that presented a reducing of about 24% on the compressive strength when comparing to the one at normal temperature.

Figures 6 and 7 present a comparison of the stress-strain curves in the compressive tests, for the three specimens tested on the 500ºC series, between the SF1, SF2 and the RC and between the TF1, TF2 and the RC concretes, respectively. Figure 8 presents the same type of curves but for the RA1 and RA2 concretes and again comparing with the RC, but in this case for the 300ºC series.

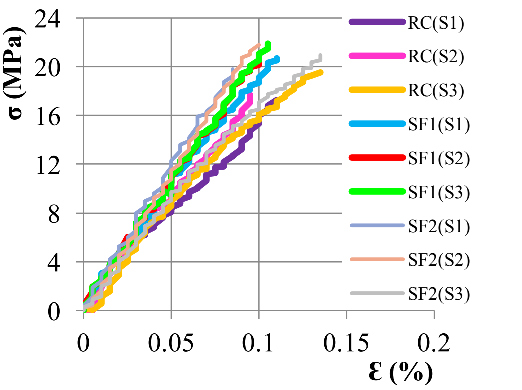

Fig. 6. Stress-strain curves – 500ºC - RC, SF1 and SF2

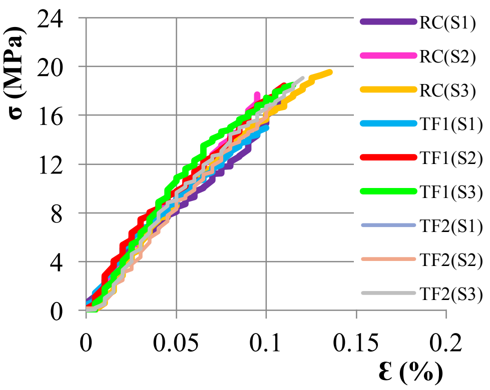

Fig. 7. Stress-strain curves – 500ºC - RC, TF1 and TF2

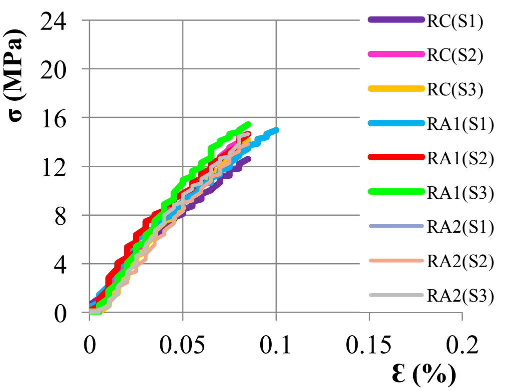

Fig. 8. Stress-strain curves – 300ºC - RC, RA1 and RA2

The observation of Figures 6-8 show faster increasing on the tensile in fiber (SF and TF) than in rubber aggregate concretes (RA), being the tensile higher, for the same level of strain, in the steel fiber concretes.

4 CONCLUSIONS

The following conclusions may be drawn from the present study:

- The concrete compositions with textile or steel fibers presented, for temperatures lower than 500 ºC, compressive strengths higher than the ones at normal temperature.
- For temperatures, between 300 and 500 °C, the smaller addition of steel fibres in concrete gave better results. The steel fibres, when not excessive, have a beneficial effect on the concrete preventing its degradation with the temperature. A quite similar result was observed for the concrete compositions with textile fibres.
- The concretes with steel fibers presented a gentle rupture when comparing to the plain concrete attesting the effectiveness of these fibers in concrete ductility and cracking control.
- The textile and steel fibres recycled from tires showed to be a good solution in concrete composition to control cracking and spalling and can be a good solution for replacing the commercial polypropylene and steel fibers, respectively.
- The concretes with 30% of rubber aggregates presented a higher degradation in the compression strength with the temperature than the ones with 30% of rubber aggregates.
- The results showed that the insertion of rubber aggregates in concrete did not give good results at high temperatures but the use of rubber fibres is maybe a good solution.

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