

CORK CONCRETE MECHANICAL BEHAVIOR UNDER HIGH TEMPERATURES

Maria de Lurdes Belgas da Costa
CICC, Department of Civil Engineering
Technical Institute of Tomar, Quinta do Contador, 2300-313 Tomar, Portugal
e-mail: lbelgas@ipt.pt

Fernando G. Branco
Department of Civil Engineering
University of Coimbra, Rua Luís Reis Santos, 3030-788 Coimbra, Portugal
e-mail: fjbranco@dec.uc.pt

ABSTRACT

Nowadays, fire remains a risk with potentially severe consequences for most buildings and structures. In fact, beyond the physical damage to the structure, which may require their subsequent repair or demolition, the fire also implies risks for the safety of occupants. Concrete exposure to high temperatures causes a progressive physical and chemical degradation that changes its microstructure and properties. Experimental studies have already been carried out on different types of concrete, under temperature increase. Lightweight, standard and high strength concrete, reinforced with various types of fibers has already been studied. The various types of concrete have shown significant differences in their behavior. However, the behavior of concrete containing cork was not yet studied. In the present study, cork concrete specimens were subjected to high temperatures (ranging from 90°C to 600°C). The specimens were produced replacing the amount of sand from a reference composition with several percentages (20, 25, 30 and 40%) of a mixture of granulated cork expanded. The results were analyzed and compared with those obtained for identical concrete samples that were not subjected to heating. The results revealed that the presence of cork has a beneficial effect on the residual strength of concrete subjected to high temperatures. Despite the reduction of concrete strength with increasing

temperature, concrete batches with higher cork amounts reported lower percentage strength reduction.

Key words: Concrete, Cork, High Temperature, Compressive Strength.

Introduction

Concrete exposure to high temperatures leads to its chemical and physical progressive decay, due to changes in its microstructure. This decay has been researched since the beginning of XXth century 50's. Among these first studies, one may find those by Abrams [1], Malhotra [2] and Schneider [3]. The mechanical properties decay under temperature raise may occur due to physical and chemical changes in the cement paste or aggregates, but also due to differential thermal expansion of different constituents [4,5]. External factors, such as the heat increase rate, maximum temperature and the time-length of the heating stage, the applied load, the size and age of the concrete element, and eventual sealing of the external surface that may prevent the loss of internal moisture.

The influence of temperature on the compressive strength of concrete has been studied by various authors [6, 7, 8, 9]. Compressive strength at high temperatures depends mainly on the initial constitution of the concrete (aggregate type, water/cement ratio, type of binding agent, additives, etc.). Two types of laboratory test may be carried out to quantify this parameter: tests performed at high temperature, and tests carried out after cooling, that allow determining concrete residual strength.

The present communication aims at quantifying the compressive strength of cork concrete. Laboratory tests were carried out on specimens were subjected to high temperatures (ranging from 90°C to 600°C). The specimens were produced by replacing the amount of sand from a reference composition with several percentages (20, 25, 30 and 40%) of a mixture of granulated cork expanded. The results were analyzed and compared with those obtained for identical concrete samples that were not subjected to heating.

Laboratory tests

The objective of this research was to quantify the influence of cork granulates, used as aggregates, on the compressive strength of concrete, under high temperature. Small-sized expanded cork granulates (ECG) were used to partially replace sand in a concrete mixture, and to check if its presence would improve the concrete performance at high temperature.

Four series of concrete containing different amounts of ECG (20%, 25%, 30% e 40% percentage of sand replacement by volume) were subjected to heating up to pre-established temperature levels (90°C, 100°C/115°C, 200°C, 300°C, 400°C, 500°C e 600°C). The specimens were then allowed to cool naturally to room temperature, and

then the residual compressive strength was determined. The results were compared with those from reference specimens containing no cork granulate.

Prismatic concrete blocks 150x150x600mm³ were produced for all concrete series tested. These blocks were heated up to the prescribed temperature in a campanula furnace. This type of furnace allowed applying the desired temperature on the superior surface of the prismatic blocks. The heating process occurs in a uniform and unidirectional way, from the surface towards the interior of the specimens. The dimensions of the specimens were specified to guarantee that the degradation during the heating process was compatible with testing. The specimens were heated at 5°C/min rate. This heating rate is frequently used in this type of tests, since it does not lead to significant temperature gradient. High temperature gradients may lead to excessive damage of the specimens due to differential dilatation between the surface (hotter) and the center of the specimen (colder).

The definition of the maximum temperature for each series took into account the temperature values usually taken as reference in similar experimental work, and also to cover the range of temperatures that can be achieved in real fire conditions. The maximum temperature level in this series of tests is 600°C, taking into account that above this temperature concrete experiences significant changes in its physical characteristics, namely on compressive strength. Above 600°C, concrete spalling is also more frequent. After reaching the desired temperature, the specimens were allowed to cool naturally inside the furnace until room temperature (20°C). After cooling, five cylinder specimens were drilled out from the prismatic blocks. These specimens were cut and rectified, and test specimens 100mm long, with height/diameter ratio of 1. The cylinders were then subjected to axial compressive loads, to determine their residual strength. The results obtained were compared with those obtained from similar specimens that were not subjected to pre-heating.

Concrete mixtures

Six different types of concrete were studied. As a reference (BR), a conventional and widespread type of concrete, made from limestone coarse aggregates, was produced. Another type of concrete (BAER), containing components and component proportions similar to BR, was studied. However, BAER contained and air entrainment chemical (SIKA AER), in such a proportion that it would produce and amount of air bubbles inside the concrete of approximately 4% volume.

The performance of these two concrete formulations was compared with the results obtained from four concrete series containing different amounts of expanded cork granulates (GCE): BE20, BE25, BE30 and BE40. In BE_{xx} series, part of the small size aggregate (river sand) was replaced by the same volume of expanded cork granulates (xx% in volume) with a similar particle size distribution. For this purpose, two types of expanded cork granulate were previously mixed: 74.2% of granulate with particle size 0.5/1 and 25.8% of granulate 1/2. Table 1 presents the components of the studied concrete types.

TABLE 1. Components of the concrete series.

Component	BR	BAER	BE 20	BE25	BE30	BE40
River sand (kg/m^3)	457.0	457.0	365.6	342.8	319.9	274.3
Coarse aggregate (kg/m^3)	1372	1372	1372	1372	1372	1372
Cement (kg/m^3)	380	380	380	380	380	380
Water (l/m^3)	190	190	190	190	190	190
Air entrainment chemical (l/m^3)	-	0.36	-	-	-	-
GCE (0.5/1) (kg/m^3)	-	-	7.37	9.21	11.05	14.74
GCE (1/2) (kg/m^3)	-	-	2.13	2.66	3.20	4.26

Preparation of specimens and heating process

From each concrete batch, three prismatic specimens $150 \times 150 \times 600 \text{ mm}^3$ were produced. The concrete was cast in metallic moulds and vibrated. They were removed from the mould 24h after casting, and kept in a climatic chamber, in controlled temperature ($\pm 20^\circ\text{C}$) and humidity ($\pm 95\%$) conditions. At the moment of the test, all specimens were more than 2 months old. One of the blocks from each series was not subjected to heating, and these specimens were tested at room temperature. The remaining prismatic blocks were heated to the selected test temperature levels. Before the heating process, two type K thermocouple probes were installed in all prismatic blocks: Probe 1 was located at half-thickness of the block (75mm depth) and Probe 2 was located at 25mm depth. These probes allowed monitoring the temperature evolution inside the concrete along the heating and cooling phases. The blocks were put over a concrete layer (see FIG 1a) and then covered with a steel mesh (FIG 1b), to prevent damage on the furnace due to eventual spalling. Mineral fiber thermal insulant was used on the periphery of the testing area. The campanula furnace was then placed over the blocks. The blocks were subjected to temperature increase on their upper surface.

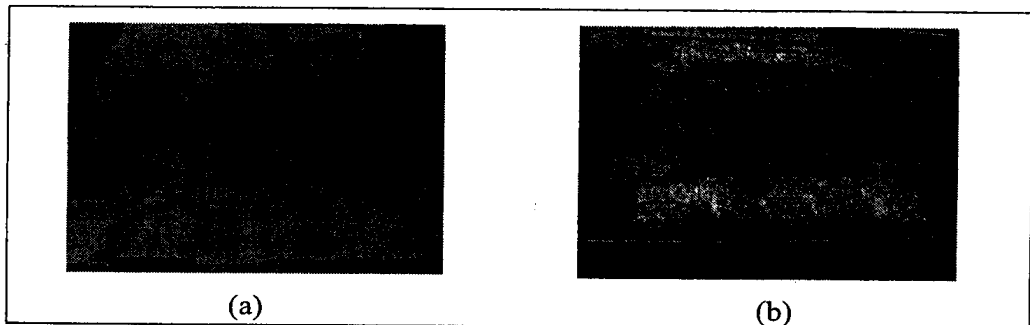


FIG 1. a) Prismatic concrete blocks and thermal probes inside the furnace;
b) Metallic mesh and mineral fiber.

An electric campanula type furnace was used in the tests (FIG 2). This furnace had external dimensions of 900×900×450 mm³. This furnace reached a maximum 1200°C. The equipment was open on the lower part, where the concrete blocks upper surface was located. Three sets of electric resistances, with a total power of 19kW, assured the required energy.

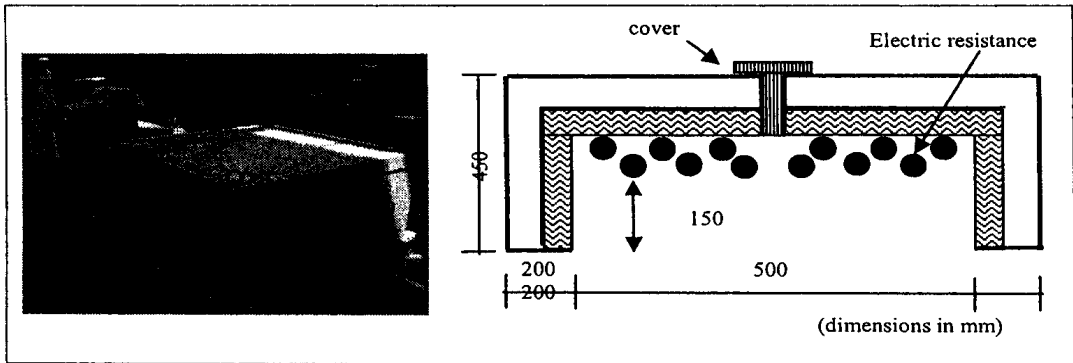


FIG 2. Electric campanula furnace used in the tests.

The temperature evolution within the furnace was controlled by two Eurotherm series 2400 controllers. The temperature level was monitored via two type K thermocouples located inside the furnace. All test specimens were subjected to the same process of heating/cooling. FIG 3 illustrates an example of the temperature evolution for the different series tested. In a first stage, the blocks were heated up for a time period $\Delta t_1 = t_1 - t_0$, at constant heating rate of 5°C/min, until the furnace thermal probe registers the desired test temperature ($T_{\text{máx}}$) for the test. The temperature inside the furnace was then kept constant for a time period $\Delta t_2 = t_2 - t_1$, to allow the temperature inside the concrete block reaching the required level. The length of Δt_2 , required for temperature equilibrium inside concrete, depends of the value of $T_{\text{máx}}$ and the type of concrete. When $T_{\text{máx}}$ is higher, the required Δt_2 decreases.

After reaching the desired temperature level inside the blocks, the furnace is turned off. Due to their different compositions, the several concrete types tested exhibited different heating and stabilization time for the same pre-defined $T_{\text{máx}}$.

The concrete blocks were kept inside the furnace, for a time length $\Delta t_3 = t_3 - t_2$, and allowed to cool down naturally, until they reach approximately 20°C.

Preparation of specimens for compressive tests

After cooling, the concrete blocks were removed from the furnace and the test cylinders were drilled, cut, rectified, and subjected to mechanical compression tests. From each block, five 100mm diameter cylinder specimens were extracted. The drilling was carried out according to standard NP EN 12504-1 [10], applicable in-situ extraction of samples in concrete structures. The cylinders were cut and rectified

and test samples 100 ± 2 mm diameter (d) and height (h) that is $h/d \cong 1$ ratio were obtained. Before the compressive testing, the specimens were subjected to capping using a sulfur mixture (FIG 4a), following the procedures from standard NP EN12390-3 [11] Annex A.

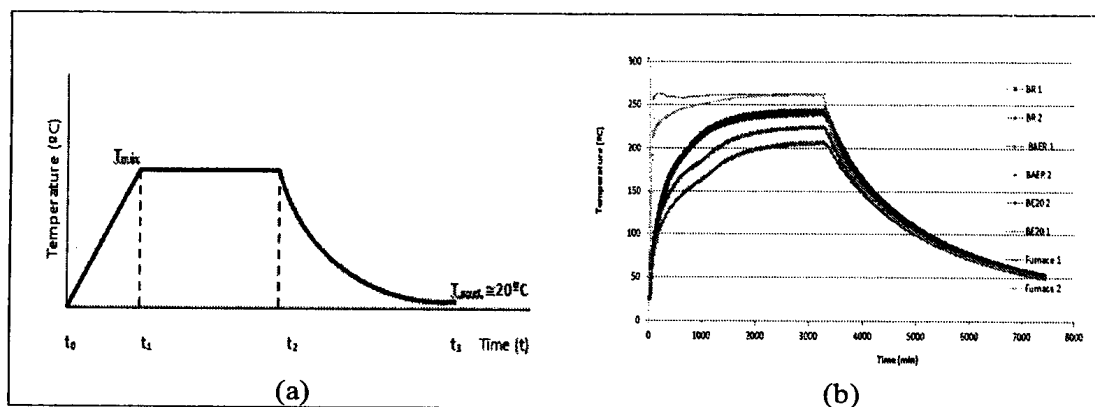


FIG 3. Temperature evolution: a) scheme; b) Example.

Compressive strength testing

The laboratory tests carried out to quantify the residual compressive strength of the concrete were carried out at the Department of Civil Engineering of the University of Coimbra, in a universal testing machine Servosis MUF-404/100, equipped with a 1000kN load cell. The test procedures are described in NP EN 12390-3 [11] standard. FIG 4b shows the concrete specimens after being subjected to the compressive testing.

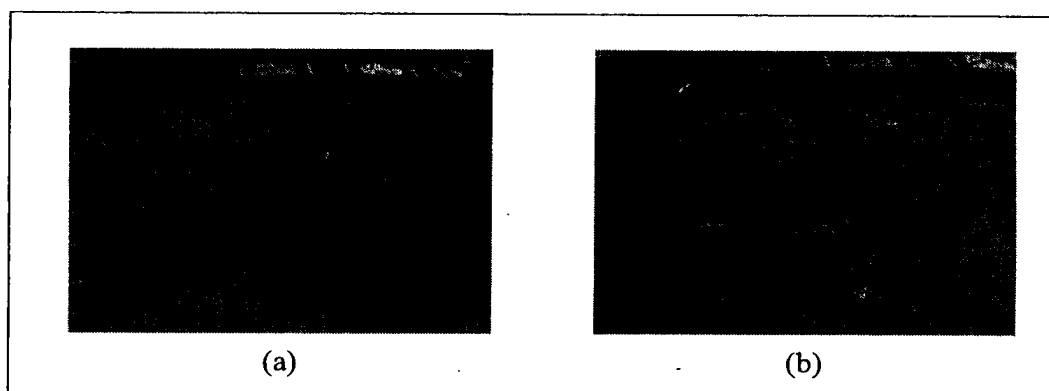


FIG 4. Concrete cylinder test specimens: a) cut and capped, ready for the compressive test; b) after compressive test.

Test Results

Table 2 presents the average strength and standard deviation (between brackets) for the residual strength of the several series of concrete tested.

TABLE 2. Residual compressive strength of concrete after heating: average value and standard deviation (MPa).

Series	20°C	90°C	100°C	115°C	200°C	300°C	400°C	500°C	600°C
BR	31,40 (0,64)	31,25 (0,60)	31,00 (0,50)	30,85 (0,50)	15,38 (1,33)	15,00 (1,32)	11,42 (0,56)	11,73 (1,54)	(*) -
BAER	28,98 (1,10)	24,73 (1,56)	23,79 (1,29)	20,90 (1,46)	12,85 (0,67)	10,64 (0,78)	10,33 (1,14)	6,63 (0,27)	6,90 (0,49)
BE20	30,60 (1,38)	29,35 (0,93)	28,58 (1,80)	28,55 (0,51)	14,60 (0,56)	14,82 (0,69)	11,67 (0,96)	12,53 (0,81)	8,90 (1,03)
BE25	33,14 (0,69)	32,07 (0,97)	32,00 (0,96)	- -	30,40 (1,45)	27,73 (1,71)	27,21 (1,12)	23,95 (1,67)	17,74 (0,79)
BE30	32,40 (1,05)	31,77 (0,38)	31,26 (0,31)	- -	29,49 (0,67)	29,47 (0,66)	24,49 (0,79)	22,35 (1,59)	19,04 (0,97)
BE40	27,96 (0,75)	23,95 (1,09)	22,9 (0,83)	- -	21,98 (1,03)	21,38 (1,03)	19,82 (0,98)	17,70 (1,12)	17,54 (1,07)

Residual strength variation with maximum temperature

FIG 5a shows the average residual compressive strength for the studied concrete series as a function of the maximum temperature. As expected, all series exhibited a residual strength reduction as maximum temperature increased. This reduction is more noticeable on the references series (BR), on concrete containing air-entraining agent (BAER), and the series with smaller amount of cork (BE20).

FIG 5b illustrates the variation of the residual strength of each series, obtained for each maximum heating temperature ($f_{c,T}$) as a percentage of the initial compressive strength ($f_{c,20^\circ\text{C}}$) of that series when tested at room temperature ($f_{c,T}/f_{c,20^\circ\text{C}}$).

Up to 115°C, the influence of temperature on the residual strength of concrete series BR, BE20, BE25 e BE30 was not very noticeable. On the other hand, concrete series BE40 and BAER presented, at this temperature level, a strength decay of 20%. Several authors [1, 2, 3, 20] refer that concrete strength loss up to 200°C is not significant. Above 200°C, moisture inside concrete was removed, and the strength concrete decreases as maximum temperature rises.

Except for series BE20, cork concrete presented smaller percentages of strength loss with temperature. At 500°C, series BE25, BE30 e BE40 registered 60% to 70% of their initial strength, while for other series the strength was about 40% for series BR and BE20, and 20% for series BAER. Concrete series containing higher amount of cork showed more gradual strength decay with temperature increase.

At 600°C, series BE40 showed no strength reduction when compared with 500°C, while series BE25 and BE30 still showed a small decay. At this temperature, it was not possible to determine residual strength for series BR, since the concrete blocks suffered spalling on the heating phase.

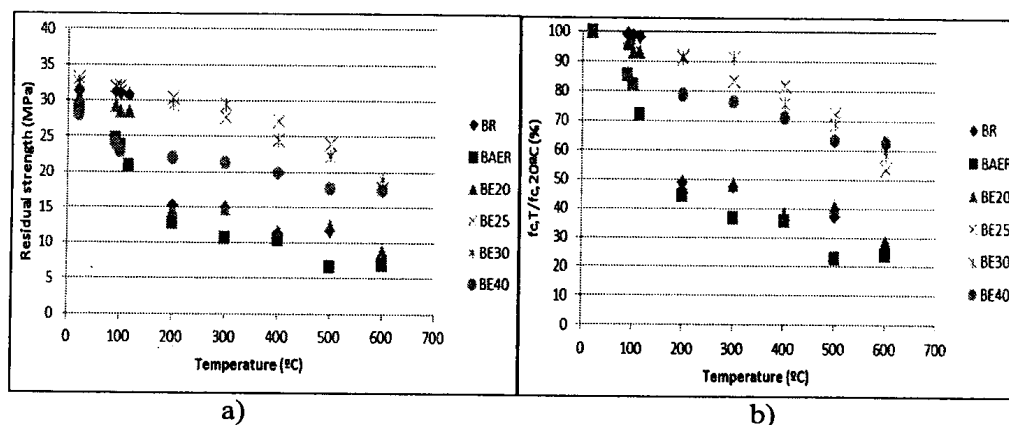


FIG 5. Variation of average residual compressive strength of concrete with temperature: a) nominal value; b) as a percentage of the strength observed at room temperature.

The values obtained for series BR are similar to those observed in other published research works on concrete produced with coarse limestone aggregates. The results obtained showed that the introduction of air-entraining agent for this kind of concrete did not improve its performance at high temperatures. Series BAER presented the higher percentage of strength loss for all test temperatures analysed.

According to Schneider [3], the type of aggregate is one of the parameters with more influence on the residual strength of concrete. The results obtained indicate that the presence of cork has a positive influence on concrete mechanical performance when subjected to high temperature. As the concrete amount increased, the cork concrete exhibited smaller strength decay, in percentage of the initial strength.

Conclusion

The results obtained from the laboratory tests carried out indicate that the presence of cork improves the performance of concrete when subjected to high temperature. Despite the lower initial strength, cork concrete compressive strength decays at a lower rate as temperature rise. Testes carried out for concrete series where river sand

aggregate was partially replaced by expanded cork granulates with the same particle size showed that, as the amount of replacement increased (BE25, BE30 e BE40), lower percentages of strength reduction were observed. At 600°C, cork concrete still kept 60% of their initial strength.

References

- [1] Abrams, M.S. Compressive Strength of Concrete at Temperatures to 1600°F, American Concrete Institute, SP 25, Temperature and Concrete, (1968), pp.33-58.
- [2] Malhotra, H.L. The effect of temperature on the compressive strength of concrete. Magazine of Concrete Research, Vol. 8/ 22 (1956), pp. 85-94.
- [3] Schneider U. Behaviour of Concrete at High Temperatures, Deutscher Ausschuss für Stahlbeton, Heft 337, Beuth Verlag, Berlin, 1982.
- [4] Khoury, G. A. Effect of fire on concrete and concrete structures. Progress in Structural Engineering Materials, Vol. 2 (2000), pp. 429-447.
- [5] Arioiz, O. Effects of elevated temperatures on properties of concrete. Fire Safety Journal, Vol. 42/ 8 (2007), pp. 516-522.
- [6] Phan, L.T., Carino, N.J. Review of the principal properties of HSC at elevated temperatures. Journal of Materials in Civil Eng., Vol. 10/1 (1998), pp.58-64.
- [7] Husem, M. The effects of high temperature on compressive and flexural strengths of ordinary and high performance concrete. Fire Safety Journal, Vol. 41/2 (2006), pp. 155-163.
- [8] Chan, S.Y.N., Lou, X.,Sun, W. Effect of high temperature and cooling regimes on the compressive strength and pore properties of high performance concrete. Construction and Building Materials, Vol. 14/ 5 (2000), pp. 261-266.
- [9] Reis, M. L. B., et al. High-Temperature Compressive Strength of Steel Fiber High-Strength Concrete. Journal of Materials in Civil Engineering, ASCE, Vol. 13/ 3 (2001), pp. 230-234.
- [10] NP EN 12504-1, Ensaios do betão nas estruturas. Parte 1: Carotes: Extração, exame e ensaio à compressão. IPQ, Portugal, 2009.
- [11] NP EN 12390-3, Ensaios do betão endurecido. Parte 3: Resistência à compressão dos provetes. IPQ, Portugal, 2009.