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Influence of concrete admixture on the bond strength of reinforced concrete submitted to high temperature

Estudo do comportamento da aderência aço-concreto sob o efeito de altas temperaturas

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Abstract

High temperatures can affect the macro and micro structural properties of reinforced concrete. This work aimed to analyze the bond strength behavior after high temperature exposure of two classes of concrete, the conventional 30 MPa and the high compressive strength 65 MPa concrete. The pull-out test proposed by RILEM CEB / FIP RC6 (1983) was used for the evaluation of the compressive strength and modulus of elasticity. The influence of temperature on the physical-mechanical properties of concrete samples under a simulated fire situation was also studied for the evaluation of the resistant capacity in a post-fire situation. In addition to the analysis at 28 days, samples of the 30 MPa (group I) and 65 MPa (group II) classes were also investigated at 90 days exposed to room (23 °C), 400 °C and 800 °C temperatures. The bond strength curve was similar to that of compressive strength, where, at 400 °C, there was no statistical difference regarding room temperature and, at 800 °C, there was significant loss of strength in all cases. At 90 days age there was a loss of bond strength of 51 and 40 % for groups I and II, respectively. At 800°C the reductions were above 50 % in compressive strength and above 80 % in the modulus of elasticity, for both groups. These results show the structural impairment under high temperature. Comparing the test 28 and 90 days ages, there was no significant influence of age on the bond and compressive strength of the concretes.

Keywords: steel-concrete bond, reinforced concrete, Pullout test, high temperature.

Resumo

O concreto armado é um material compósito formado pela interação entre o concreto e o aço e deve suas boas características à aderência entre eles, onde o concreto absorve os esforços de compressão e o aço os de tração, majoritariamente. Este trabalho tem por objetivo analisar o comportamento da tensão de aderência de duas classes de concreto após a exposição a diferentes níveis de temperatura. Utilizou-se o ensaio de arrancamento direto (Pull out test) proposto pela RILEM CEB/FIP RC6:1983 e também avaliou-se o comportamento da resistência à compressão e do módulo de elasticidade. Foram ensaiados, aos 28 e aos 90 dias de idade, corpos de prova em concreto de classes 30 MPa e 65 MPa, expostos às temperaturas ambiente (23°C), 400ºC e 800ºC. A curva do comportamento da aderência foi semelhante à de compressão, em que, aos 400°C, estatisticamente, não houve variação significativa em relação à temperatura ambiente e, aos 800°C, perda expressiva de resistência em todos os casos, chegando a 57,09% de redução na resistência à compressão e 40,05% na resistência de aderência.

Palavras-chave: aderência aço-concreto, concreto armado, *Pull Out Test*, altas temperaturas.

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1. Introduction

The combined use of steel and concrete for structural purposes increases the tensile strength, therefore increasing the load capacity. The bond between steel and concrete is extremely important in crack control. The Brazilian standard ABNT [1] refers to reinforced concrete elements as 'those in which their structural behavior is related to the bond between concrete and reinforcement, and do not have initial reinforcement elongation before the bond.'

Tavares et al [2] express that the bond is the factor that enables the reinforcement anchorage in concrete and helps to prevent the slide of these reinforcements in the segments between the cracks, reducing their effects. Araújo [3] states that because concrete shows low tensile strength, the component cracks in the tensile zone of the structural element, therefore, the tensile stresses are absorbed by the reinforcement, preventing the immediate collapse of the structures.

A structural element with a larger number of cracks but with smaller individual opening allows better protection of the reinforcement and the greater the bond, the greater the probability of obtaining this result. [4]

Some researchers, including Araújo [3], state that the bond stress varies throughout the component, however, for design purposes; it is considered an average value. Castro [4] asserts that knowledge on bond behavior is essential for the correct sizing of anchorages and joints, calculation of displacements considering the contribution of the tensioned concrete, control of cracks and, therefore, minimum reinforcement.

According to Araújo [3] and Negrão and Pimentel [5], several factors influence the behavior of steel-concrete bond, such as: the type of bar rib configuration, the diameter of the bar and the state of its surface, the disposition at the time of casting the concrete, the water-cement ratio, the mechanical strength of the concrete, density, the age of rupture, among others.

In lower strength concretes, compressive strength is an important factor, since the pullout of the steel bar will be due to the crushing of the concrete part in front of the rib. The compressive strength can withstand the concentrated diagonal stresses generated on the steel ribs. Caetano [6] states that with the increase of concrete strength, the bond is favored; however, confinement techniques should be employed to control their tendency to break in a fragile way, as in premature splitting.

Splittings, common in high strength concrete, occur when the circumferential tensile stresses reach or exceed the concrete tensile strength. Bond on the steel-concrete interface can occur by three mechanisms: surface adhesion, friction and a dominant portion of mechanical adhesion. However, as mentioned by Oliveira and Jacintho [7], this division is solely didactic, and it is not possible to determine each component separately, due to the complexity of the phenomena involved.

When a fire strikes a building, the building can suffer considerable structural damage. Moreover, in the case of concrete, both cement and aggregates are made of elements that to a lesser or greater degree change or decompose on exposure to heat. In these situations, the reinforced concrete structure is reduced in capacity, however, for safety reasons, it must have a minimum resistance so that the site can be evacuated and the flames extinguished [8].

Under high temperatures, there are fewer researches on the behavior of the bond between steel and concrete. Therefore, few studies report the mechanical properties of concrete under fire. The bond behavior at high temperatures has been analyzed with pullout tests.

As concrete exposed to high temperature deteriorates, the friction grip mechanism is weakened and consequently the peel strength of the steel bar decreases. Since tensile strength and compressive strength are very important parameters in the analysis of bond behavior and since friction is influenced by tensile strength, with decreasing strength, that mechanism is reduced. The mechanical grip is due to the protrusions that ribbed reinforcements have. Adhesive forces are associated with concentrated compressive forces that appear perpendicular to the rib faces when the bar is pulled and tends to slide.

Ergün et al [9] comment that it is very difficult to quantify the relationship between the increase and decrease of temperature in the bond stress, as it depends on several parameters. The authors report that the studies about the bond between steel and concrete at high temperatures by Morely and Royles [10], Haddad and Shannis [11], Haddad et al. [12] and Bingol and Gul [13] report that there was a considerable loss of bond strength when the temperature increased. The results of these studies showed that the bond strength was changed between 30 and 70 % according to the parameters examined, such as concrete and steel properties, diameter and heating and cooling regime, etc., when subjected to 500 ºC for 90 days.

According to Silva [14] and Lima [15], at high temperature, the concrete undergoes chemical and physical changes in which dehydration of the cement paste and volumetric variations in the aggregates occur, causing cracking. Leonhardt and Mönnig [16] state that bond stresses can prevent spalling, preventing the loss of the covering. Fletcher et al [17] point out that some of these changes are reversible after cooling, but others are not and can significantly weaken the concrete structure after a fire. If the temperature reaches 400 °C the calcium hydroxide in the cement will begin to dehydrate, generating more water vapor and also bringing a significant reduction in material strength. Quartz-based aggregates increase in volume at about 575 °C due to a transformation of the material and at 800 °C they are decomposed.

Studying the effects of temperature on different concrete groups, Poloju et al [18] showed that the loss on strength is greater with temperature increase in the groups with higher compressive strength. In the tests at 400 ºC, the class 20 MPa concrete had 12 % loss, the class 40 MPa 26.9% loss and the class 60 MPa concrete a 30.6 % loss in compressive strength. Above 600 ºC this difference was less significant. In situations where variations in temperature occur, such as fires, steel heats faster than concrete due to its higher thermal conductivity, so it undergoes greater expansion.

Caetano [6] in his research observed that exposure to high temperatures considerably affects the bond strength, the effect being influential from 350 ºC and increasing after 400 ºC. For high strength concretes, Caetano [6] shows that from 740 to 470 ºC the temperature threshold causes the reduction in bond stress of 50 %, when the compressive strength was increased from 15 to 80 MPa. The bond of the 80 MPa concrete at 470 ºC is still almost 3 times higher than that of 15 MPa concrete at 740 ºC. When the temperature exceeded 835 ºC, the bond stress of all specimens tended to be the same.

Ergün et al [9] studying the compressive strength at 100 ºC found an average increase of 1 %. At 200 ºC an average reduction of 6 %. At temperatures between 400 and 600 ºC a reduction of 29 to 40 % and at 800 ºC a large loss of 73 % on average was observed. Regarding the bond stress, Ergün et al [9] found reductions of 21, 27, 60 and 76 % at 200, 400, 600 and 800 ºC, respectively, at 90 days.

El-Fitiany and Youssef [19] analyzed concrete sections exposed to fire and commented that, as new codes move toward the design for fire-based situations, new tools are needed to assess the performance of heated sections under fire. According Khouri [20], in the design of fire-resistant materials the heat transfer in an element must be kept within acceptable limits through the overall section and the reinforcement must be covered with concrete in order to keep the steel temperature below critical values for the required period to reach fire resistance. Caetano [6] states that the conditions of a structure after an accident must be checked to determine the need and possibility of recovery of the structure, as well as its total or partial demolition. One of the requirements for a structural element to be safe is the existence of a minimum bond among the constituent elements.

The ABNT Brazilian standard [21] classifies concretes in resistance groups I, ordinary concretes, and II, high performance concretes (HPC), that is, showing better performance than the ordinary concretes belonging to group I, whose limit is the concrete with 50 MPa strength. According Castro [4], the HPC concretes, besides greater resistance than ordinary concretes, show durability and workability.

In this context, further studies on the bond of steel and concrete after exposure to high temperature are needed. The present work was based on the studies of Caetano [6] and Scotton [8]. The first one studied bond in C65 class concretes and the second one in C30 class concretes, with the same admixtures and materials similar to those used in this research; both studies performed the tests at 28 days at room temperature in comparison with high temperature.

Therefore, the present work aims to determine the effect of temperature (23, 400 and 800 ºC) on the bond strength of C30 and C65 class concretes with the ribbed steel reinforcement after exposure. In addition to 28 days of age, tests were performed at 90 days to verify if the structural elements have reduced their adhesion resistance due to the time required for stabilization of the internal reactions of concrete in a way that could compromise the structure. The pullout test method was used to determine the compressive strength and bond stress of both classes of concrete under rising temperature (23, 400 and 800 ºC) over time (28 and 90 days of age). The characteristic bond stress was compared to the effective bond stress.

2. Materials and methods

The tests were performed at the Building Materials Laboratory, Structural Laboratory and Mechanical Testing Laboratory, located at i·parque (Scientific and Technological Park of the Universidade do Extremo Sul de Santa Catarina) at Criciúma (SC).

The concretes showed average compressive strength at 28 days of 30 MPa for group I and 65 MPa for group II according to ABNT [21]. The admixtures were defined based on the works of Caetano [6] and Scotton [8] using similar materials (Table 1). CP IV cement (Cimentos Votorantim) was used for the manufacture of concrete samples. The fine aggregate had a fineness modulus of 2.37, maximum characteristic size of 2.4 mm and an apparent specific mass of 2.36 g/cm³. The coarse aggregate, of granitic origin, showed fineness modulus of 6.65, maximum characteristic size of 19 mm and apparent specific mass of 3.00 g/cm³. Both aggregates were in accordance with the ABNT [22] requirements. Tap water and superplasticizer (Grace Tec-flow 7000, 1.075 - 1.115 g/cm³ density) were used. Ribbed steel (Gerdau CA-50) with a diameter of 12.5 mm and characteristic yield strength of 500 MPa was used as reinforcement.

The concrete samples were prepared with the aid of a 400-liter concrete mixer, therefore each concrete needed to be divided into three parts due to the large volume required. Each group was shaped in one day. The ABNT cone trunk abatement test [23] was performed, resulting in 11 and 22.8 cm abatement for concretes of the groups I and II, respectively. The molding of the specimens for the axial compression tests and the determination of the static modulus of elasticity followed the requirements of ABNT [24] standard, using cylindrical metal molds with 10 cm diameter. For the pullout test, 20 cm-shaped cubic wood molds were made, as recommended by CEB [25] (Figure 1). The steel bars were cleaned and prepared so that the lamination marks did not remain in the adherent part and the protection for the non-adherent part was made with PVC pipes. The thickening process in the cylindrical specimens was made with a manual 2-layer socket with 12 strokes each. For the cubic specimens, mechanical compaction with a needle-type vibrator was used.

At the end of concreting, the specimens were covered with plastic sheeting to prevent evaporation of the water present in the mixture and, after 24 hours, they were demolded and relocated. The curing was performed by daily rinsing the specimens for 15 days. After that, they were stored in a place without sun and wind. This procedure was performed for all cylindrical and cubic samples, with the same curing factors (setting).

Table 1
Concrete admixtures

Concrete	Cement: Sand: Gravel Ratio	a/w relationship	Additive	Group
C30	1 : 2.5 : 3.5 (110.8: 277.1: 387.9) kg	0.51 60.4 kg	0%	Group I
C65	1 : 1.34 : 2.16 (176.4 : 236.3 : 380.9) kg	0.32 56.4 kg	0.5 % cement 0.882 kg	Group II

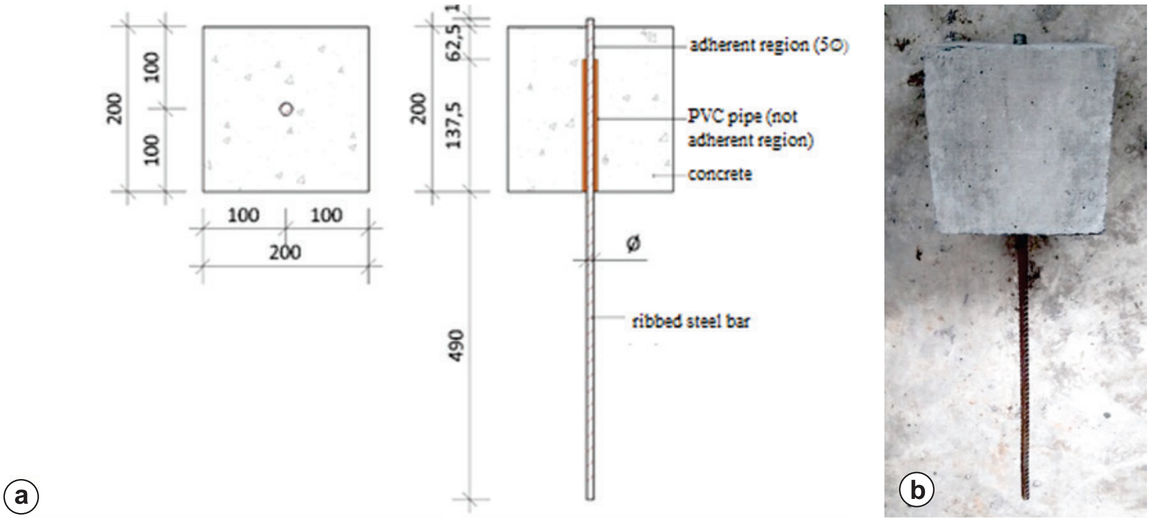


Figure 1
Test specimen for the *pullout test* (a) layout: dimensions in mm (b) photo

The experimental program is shown in Figure 2. Three samples were molded for each setting condition to determine the axial compression and elastic modulus and five samples were molded for each pullout test, resulting in 60 cylindrical and 45 cubic samples. Samples of each concrete class (group) were exposed to rising temperature: 23 (room temperature, reference for the work), 400 and 800 °C. The 28 days of age was used as a standard, considered the reference for resistance design. 90 days of age was used because the stabilization of the concrete internal reactions takes place at this time, according Metha and Monteiro [26]. After this time, the chemical reactions that occur in the concrete tend to stabilize, consequently reducing the interference that could be caused by the effects of chemical reactions.

The samples for the pullout test have part of the reinforcement exposed that required special protection in order to avoid direct exposure to high temperatures, because in concrete structures the reinforcement is always encased. During the exposure of group II at 28 days glass wool was used for protection. However, the glass wool was not adequate at high temperature because it was transformed into glass at temperatures above 400 °C. Nevertheless, these samples were submitted to the resistance tests because probably there was no influence of heating on the exposed parts of the bars, since all heating process was monitored by K-type thermocouples, showing similar curves in all exposures. Therefore, the change in protective materials did not interfered in the results. In addition, the results of this work were similar to others, as Scotton [8]. For all other exposures, rock wool was used which showed better insulation.

The heat treatment was carried out in an electric oven (Novus N1200, Brazil). The heating rate was 3 ºC/min according to RILEM [27] and each maximum temperature was held for 30 minutes.

The procedures of ABNT standard [28] were used for the compressive strength tests. The test was performed in a 200 kN

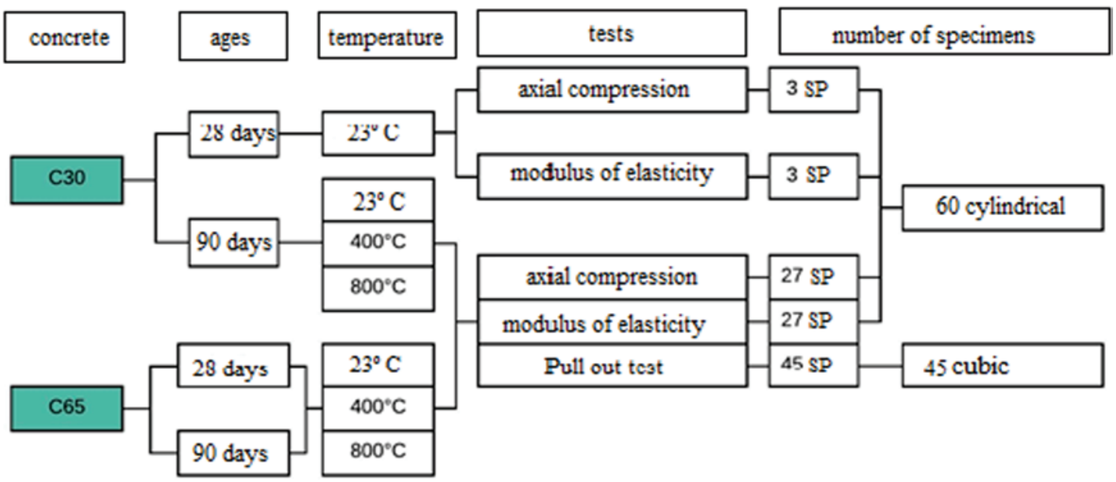


Figure 2
Organizational chart with the experimental matrix

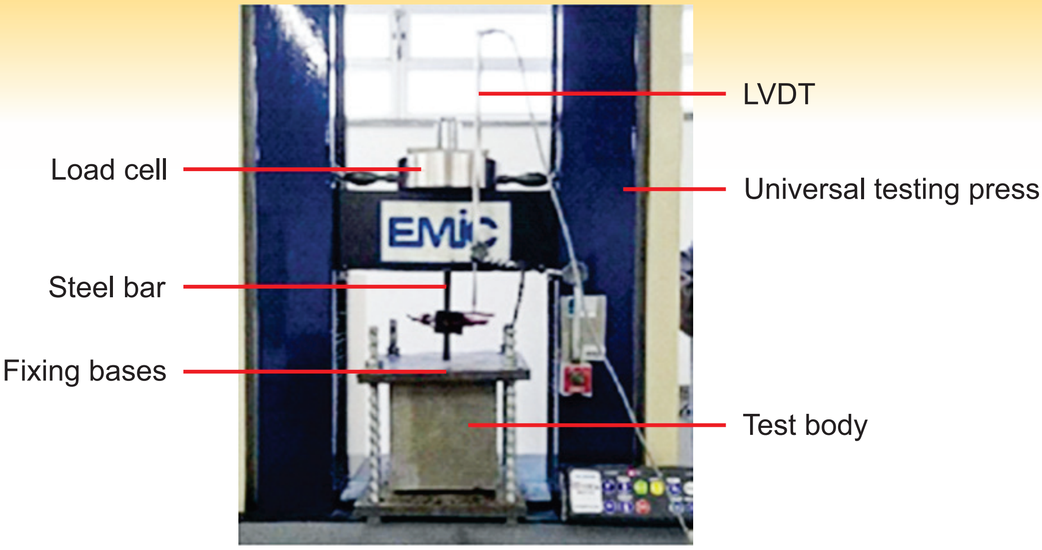


Figure 3
Pullout test

hydraulic press (EMIC PC200I, Brazil) using the TESC (Test Script) software. The samples were placed in the press and capped with neoprene. The determination of the static elastic modulus by the compression test was performed on a 200kN servo hydraulic press (EMIC PC200CS) according the ABNT standard [29]. In this test, strain gauges were used following the methodology A: fixed stress. The pullout test followed was performed according the CEB recommendations [25] in a 30 ton universal testing machine (EMIC DL30000, Brazil). The steel bar was pulled out along the longest end by a tensile force, the other remaining without tension. The specimens were placed in the support with the longest bar length facing upwards (Figure 3). A linear variable differential transformer (LVDT) device measured the relative displacement between steel and concrete and the load was determined by a 250 kN load cell connected to a computer by the Catman Easy software. The tensile load, which was loaded in the same direction as the reinforcement, but in the opposite direction, was increased until the rupture of the sample. The loading speed was 10 mm/min, not in accordance with CEB [25] that states 78.125 N/s. In this study it was not possible to control the speed by the applied load, only by displacement, due to equipment limitations. Therefore, curves of load versus sliding of the steel bar were obtained.

The bond stress (τ_b) is calculated according to Equation 01, dividing the tensile load by the bond area. There are different ways of calculating the grip. Leonhardt and Mönnig [16] have used Equation 01, however, assigning the tensile load at the displacement of 0.01 mm. In this work the calculation was based on the works of Scotton [8] and Silva [30] that used the ultimate stress at break. According to Silva [30], the bonding stress is considered evenly distributed, not corresponding to the actual condition.

$$\tau_b = \frac{P}{\pi \emptyset l_o} \qquad (1)$$

Where: τ_b: ultimate bonding stress; P: ultimate tensile load; Ø: diameter of steel bar; l_o: length of bonding.

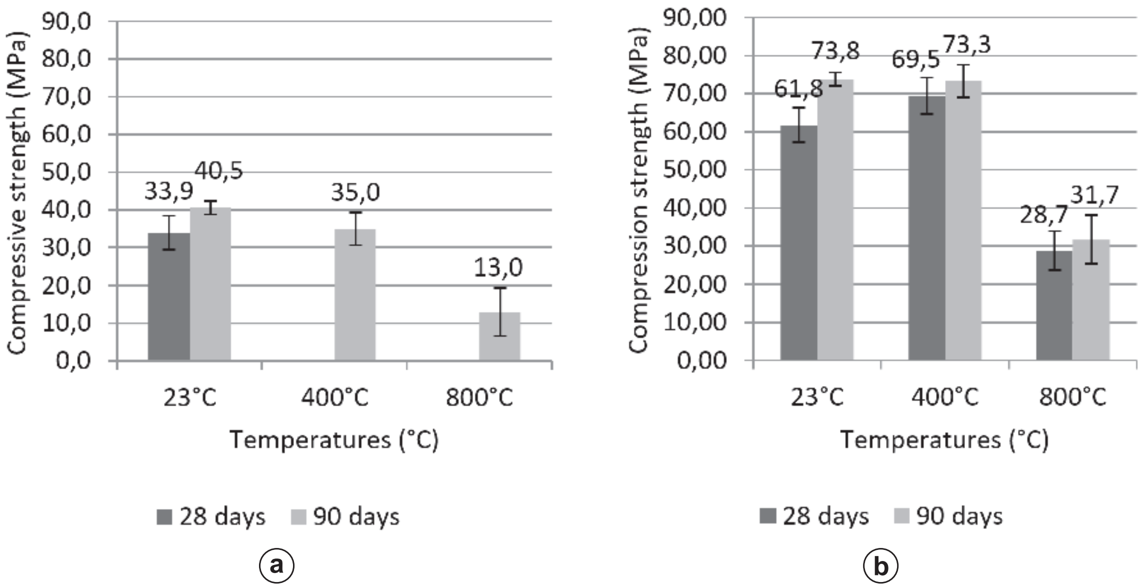


Figure 4
Compressive strength: (a) group I; (b) group II

Table 2a
Tukey's test for compressive strength

Group and age	Temperature (°C)	Average strength (MPa)	p-value		
			23 °C	400 °C	800 °C
Group I (90 days)	23 °C	40.54	—	0.3308	0.000797
	400 °C	34.96	2.208	—	0.002271
	800 °C	12.97	10.87	8.662	—
Group II (28 days)	23 °C	61.77	—	0.2048	0.0005682
	400 °C	69.47	2.762	—	0.0003195
	800 °C	28.73	11.85	14.61	—
Group II (90 days)	23 °C	73.8	—	0.9901	0.0002633
	400 °C	73.28	0.1907	—	0.000267
	800 °C	31.67	16.08	15.89	—

3. Results and discussions

The results were statistically analyzed using the ANOVA (Variance Analysis) technique to verify if there was a significant difference between the studied variables, using the Statistica 7 software, available at UNESC. When this difference was relevant, the Tukey test was used to assess which groups were different from each other. Both tests were performed considering 95% reliability.

3.1 Compressive strength of concrete samples

The axial compressive strength for concretes of groups I and II after exposure to high temperature at 28 and 90 days of age is shown in Figure 4.

According to the ANOVA analysis, for the compressive strength at 90 days for both groups of concrete exposed at room temperature, 400 and 800 ºC, the coefficient of determination was 0.878, that is, 87.8% of the total variation is explained by the change in compressive strength. At 5 % significance ($\alpha = 0.05$) there are differences in the compressive strength at 90 days for both groups and for different temperatures. By Tukey's method, Table 2(a), not all exposure temperatures had an influence on compressive strength. Comparing the compressive strength at 23 and at 400 °C the results are statistically equivalent. However, there are differences when comparing the strength at 800 °C with 23 and 400 °C.

At 90 days, in both groups, the compressive strengths decreased when the specimens were submitted to high temperatures, the largest reductions for group I, 13.6 and 68 %, respectively, for 400 and 800 °C. Ergün et al [9] achieved reductions of 19 and 73 % at the same temperatures.

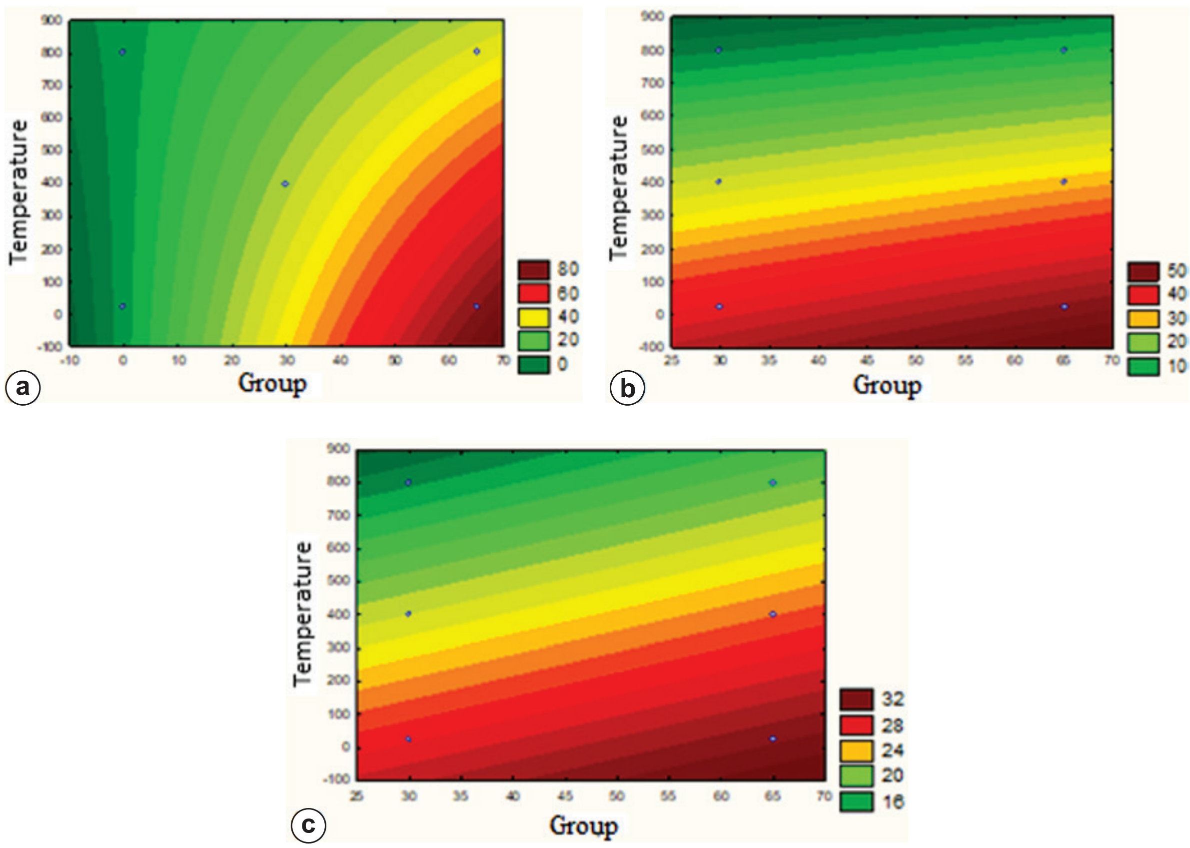


Figure 5
Response surface for groups I and II at 90 days for 23, 400 e 800 °C: (a) compressive strength; (b) modulus of elasticity; (c) bond strength

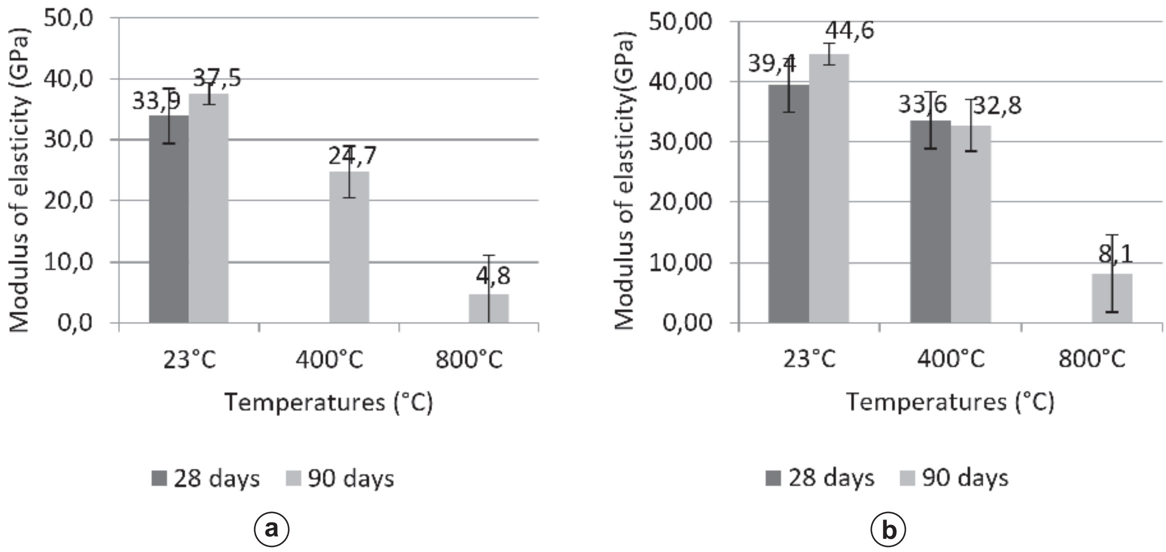


Figure 6
Modulus of elasticity: (a) group I; (b) group II

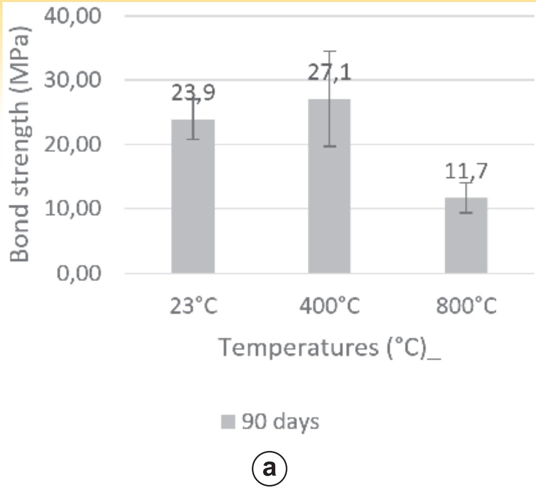
At the age of 28 days for group II there was a 12.5 % increase in strength at 400 ºC and a reduction of 53.6 % at 800 °C. Scotton [8] found no change in strength at 400 ºC in comparison to room temperature. At 600 ºC, the highest temperature studied by Scotton [8], there was a of reduction 29 %.
The response surface for the compressive strength at 90 days is shown in Figure 5(a) considering the groups and temperature. There is little variation in group II (Class 65) when exposed to temperatures of 23 and 400 ºC. The highest compressive strengths are obtained for group II at room temperature, with estimated values of 74 MPa.

3.2 Static modulus of elasticity to compression

The average and standard deviation of the modulus of elasticity for concretes of groups I and II is shown in Figure 6 in function of temperature and age. At 28 days, it was not possible to perform the test for group II at 800 °C because the specimens suffered cracks and splinters, that is, spalling. For both groups, the modulus increases with increasing age because the cement reactions are stabilized and the effect of temperature is higher than age in the compressive strength. The modulus of elasticity decreased when the specimens were submitted to 400 and 800 °C. At 90 days the reductions in strength were, respectively, 26.5 and 81.8 % for group I and 34.1 and 87.2 % for group II. Morales et al [31] achieved a reduction in elastic modulus of approximately 46 % at 300 ºC and 73 % at 450 ºC.
For the ANOVA, for both groups, at 90 days, at room temperature, 400 and 800 ºC, the coefficient of determination was 0.977, i.e., 97.7 % of the total variation is explained by the variation of the modulus of elasticity. The variation in temperature significantly affected the modulus of elasticity, Table 2(b) and Figure 5(b). The factor 'groups' and the interaction between 'groups' versus 'temperature' were not statistically significant for this property. The largest modulus of elasticity takes place for group II at room temperature, 45 GPa estimated, Figure 5(b).

Table 2b
Tukey's test for the *pullout test*

Group and age	Temperature (°C)	Average strength (MPa)	p—value		
			23 °C	**400 °C**	**800 °C**
Group I (90 days)	23 °C	23.926	—	0.4005	0.0007719
	400 °C	27.098	1.898	—	0.0002555
	800 °C	11.67	7.325	9.222	—
Group II (28 days)	23 °C	30.01	—	0.5334	0.0002217
	400 °C	31.55	1.553	—	0.0001937
	800 °C	20.1	9.98	11.53	—
Group II (90 days)	23 °C	29.11	—	0.9239	0.006774
	400 °C	27.95	0.538	—	0.01324
	800 °C	17.45	5.371	4.833	—



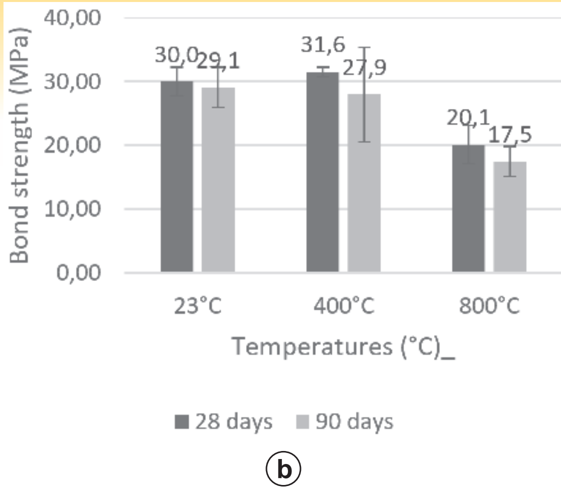


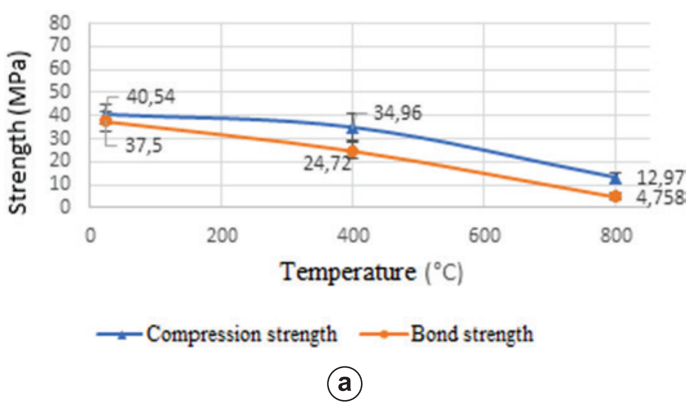
Figure 7
Bond strength: (a) group I; (b) group II

3.3 Steel-concrete bond stress

The results of bond stress by the pullout test for groups I and II after exposure to temperatures is shown in Figure 7. In the Analysis of Variance of the bond stress at 90 days of age for both groups at room temperature, 400 and 800 ºC, the coefficient of determination was 0.71, that is, 71 % of the total variation is explained by the variation of bond stress. There was no significant difference at 95 % confidence for temperature.
By the Tukey test, the strengths were statistically similar at 400 ºC, but significant differences occurred at 800 ºC for both groups, Table 2(b). For group I, at 400 °C, there was a resistance increase of 13.4 % and at 800 °C a reduction of 51.1 %. At 400 ºC, for group II at 28 days, there was an increase in bond resistance of 5.33 %. At 800 ºC, reductions of 33 and 39.9 % were observed at the ages of 28 and 90 days, respectively. In Scotton's work [8], a 2 % increase was observed at 400 ºC and at 600 ºC there was a 29 % reduction in the first concreting at 28 days. In 80 MPa compressive strength concretes, Caetano [6] obtained at 470 ºC a 50 % reduction in bond strength. Ergün et al [9] found reductions of 21, 27, 60 and 76 % at 200, 400, 600 and 800 ºC, respectively, at 90 days. There are significant differences at 800 °C for bond stress, Figure 5(c), response surface. The highest bond stress at 90 days are obtained once again for the combination of group II at room temperature, with estimated values of 30 GPa.
By the Tukey test, for 28 days (Table 2(b)), not all temperatures had an influence on compressive strength. Comparing the bond stresses at 23 and 400 °C, they are statistically similar. Comparing the results at 800 with 23 and 400 °C, there are significant differences, similar at 90 days.
The fact that significant changes start after 400 °C may be due to the dehydration process of the C-S-H gel that starts at 100 °C and ends near 400 °C. Lima [15] states that during this process water release occurs and, in some cases, formation of anhydrous silicates and calcium oxide (CaO). During cooling, partial rehydration of these components may occur. For samples heated above 600 °C and then cooled, the CaO rehydrates, causing expansion that may contribute to the appearance of cracks in the concrete, making it fragile.

3.4 Comparative analysis between compressive strength and bond stress

Comparing the curves of compressive strength and bond stress for group I, Figure 8(a), they show a similar behavior. Group II, Figure 8(b), shows similar behavior between the different ages, but with significant statistical difference for compressive strength between ages.



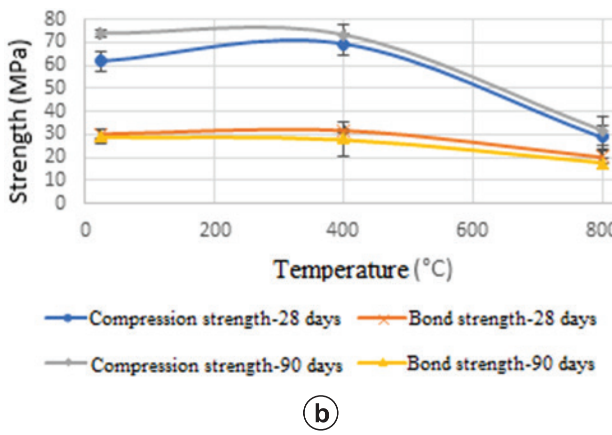


Figure 8
Comparative analysis between compressive strength and bond strength: (a) group I at 90 days; (b) group II at 28 and at 90 days

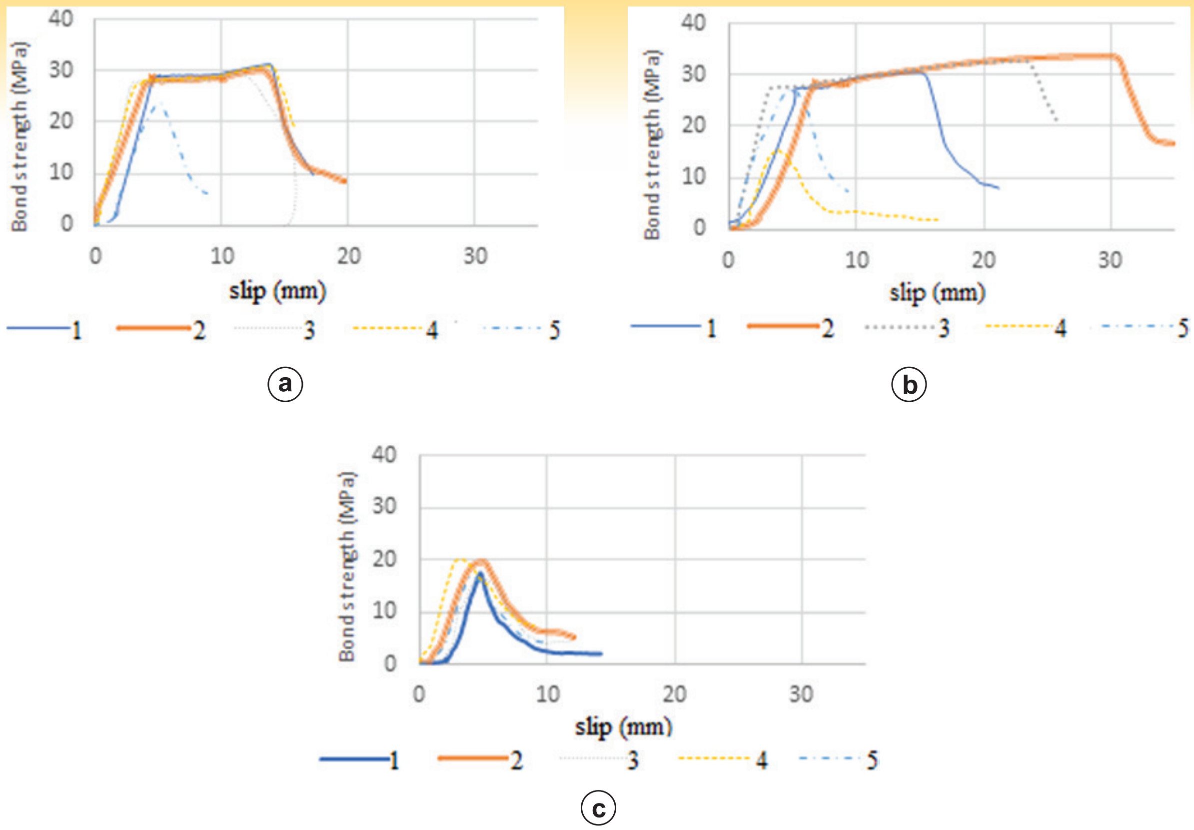


Figure 9
Bond strength-slip curve, group II at 90 days: (a) 23 °C, (b) 400 °C, (c) 800 °C

3.5 Bond stress-slip correlation

The curve of bond stress versus slippage for the concrete of group II at 90 days, after exposure at 23, 400 and 800 ºC is shown in Figure 9. At 23 °C, only the specimen SP5 was cracked, for the others, there was sliding and flow of the steel bar. At 400 °C, SP4 and SP5 samples were cracked and sliding occurred in the others; at 800 °C all specimens were cracked.

3.6 Bond stress characteristic versus effective strength

The ABNT Brazilian standard [1] establishes an equation to determine the design stress. As in this work the bending test was not performed, ABNT [1] admits the correlation between the average tensile strength and the characteristic compressive strength (fck). Therefore, for group I with fck = 30 MPa, the design bond stress is 3.26 MPa. For group II with fck = 65 MPa the design stress is 5 MPa. In all groups, even after exposure to high temperature, the bond continues to meet the required value for project design, emphasizing that the Brazilian standard is in favor of safety.

4. Conclusions

The results of this work show that the performance of both compressive strength and bond stress, for concretes of both groups, changes when subjected to different (and rising) temperature.
The bonding and compressive strength curves were similar at room temperature. At 400 °C there was no significant variation for them and at 800 °C there was significant loss of strength in all cases. Therefore, there is a close relationship between bond stress and compressive strength. As Caetano [6] quotes, exposure to high temperatures considerably affects bond strength after 400 °C. At the age of 90 days, for the 30 MPa and 65 MPa concretes, the reduction in bond strength at 800 ºC was 51.1 and 39.9 %, respectively, which shows the significant loss of bond, compromising the structure.
This work and others, as Scotton's [8], show that up to 400 °C a small increase in strength can occur. In this study, there was a 12.5 % increase in compressive strength and 5.33 % in bond strength for group II at 28 days. High temperatures significantly reduced the modulus of elasticity, with reductions higher than 80 % at 800 °C.
The age had no significant influence on the bond stress of concrete in both groups. For a better analysis of the bond stress versus slip curve, good reinforcement confinement is important so that splitting failure does not occur before the bar slips.

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