EFFECT OF TEMPERATURE ON THE RUPTURE OF SYSTEMS FOR THE REINFORCEMENT OF CONCRETE

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Abstract. The adhesives used in systems for the external reinforcement of concrete are epoxies. Like all the polymers, they have low thermal resistance. This paper presents the results of an experimental work made with specimens of hydraulic mortar reinforced on the exterior with steel or CFRP plates. The specimens were exposed seven days, to temperatures between 20 and 250 ºC. To determine the adhesion, we used flexure tests. The results of the tests show a decrease of the adhesion strength with temperature. The failures change to adhesive failures above 150 ºC and 200 ºC, for the reinforcement with steel plates and for the reinforcement with CFRP plates, respectively. Even maintaining the mortar failures, the efficiency of the reinforcements decreases significantly above 50 ºC. This temperature can be considerer as the thermal resistance of the two tested reinforcements.

1. INTRODUCTION

The external reinforcement of concrete was traditionally made by bonding steel plates. Since 1960 this technique is used. Firstly, the steel plates were bonded to the tension face of reinforced concrete beams [1, 2]. Other applications were developed along the years. Recently, new systems based in bonding composite materials like carbon fiber reinforced polymer (CFRP) plates were used [3]. These composites are in some aspects better than steel. They have low mass, no ability to corrode and extreme flexibility in application to surfaces of any shape or nature [4, 5].

Epoxies are the oldest and most widely used polymers in repair. They have a lot of advantages when compared with other polymers [6]. One of the advantages is the high adhesion to various materials like mortar [7], concrete [8, 9], masonry units, glass, metals [7] and wood [9]. However, they have some bad properties like thermal behaviour [10].

Epoxies are thermosetting polymers. Once they are polymerised or cured, they cannot be reused by melting and reprocessing. Compared with other construction materials, epoxies have higher coefficients of thermal expansion [9]. This difference causes stresses at the interface when the temperature increases or decreases. The thermal resistance of epoxies is very low. The decrease of adhesion strength when epoxies are near high temperatures is well known. The problems appear for temperatures above the “Glass Transition Temperature” T_g [11].

In our study, one epoxy was used to bond steel or CFRP plates to hardened mortar. Seven days after bonding the specimens were exposed at temperatures between 20 and 250 ºC. After seven days of exposure, the specimens were tested in flexure. The results of these tests show the influence of high temperatures on the behaviour of external reinforcement systems.

2. TESTS

The mortar specimens were prismatic with 4x4x16 cm^3 and were prepared in accordance with an european standard [12]. We used normal Portland cement – CEM I 42,5 [13]. This means that it has a minimum compression strength of 42,5 MPa at 28 days. A normalised mortar was used. This mortar was made with the CEN normalised sand. The proportions of the mixture cement:sand:water were 1:3:0.5 by mass. The mixing and the compactation were made like specified by the mentioned standard [12].

The specimens stayed in the moulds 24 hours. After, the specimens were removed from the moulds and maintained 20 days inside water at 20 ºC. Before the bond of the external reinforcements, the specimens stayed 7 days at the laboratory room at 20 ºC.

The epoxy adhesive used for the bonds has the properties mentioned in Table 1. It is furnished in two parts, one is the resin and other is the hardener. The proportions of the epoxy adhesive are extremely important. The mixture was made with a spatula till we obtained a homogeneous colour.

Table 1 - Properties of the epoxy adhesive

Glass transition temperature (ºC)	63
Compressive strength (MPa)	90
Flexural strength (MPa)	45
Proportions of the epoxy adhesive parts	resin – 44 hardener -6

As mentioned above, two kinds of bonds were made: hardened mortar/steel plate and hardened mortar/CFRP plate (Fig. 1). The steel plates had the dimensions of 40x40x1 mm^3. The CRRP plates had the dimensions of 40x40x1.4 mm^3. The two kinds of plates have an elastic modulus of 200 GPa.

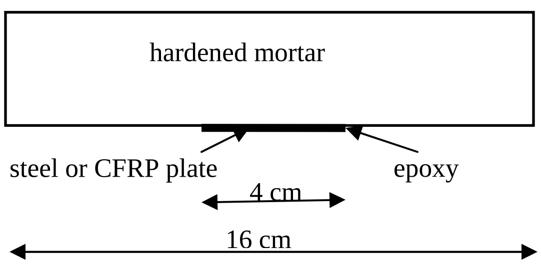

Fig. 1 - Specimen with external reinforcement.

In order to obtain good bonds is necessary to take special care with the preparation of the surfaces [9, 14]. The surface of mortar was passed with a steel brush to eliminate cement laitance and open the voids in contact with the exterior. After that, a jet of compressed air was applied (Fig. 2). The steel and the CFRP surfaces were cleaned with a cloth drenched in alcohol in order to eliminate any grease, dirt or oxide. The alcohol is the only product necessary to obtain a good surface preparation.

After the preparation of the surfaces, the epoxy was applied to the specimens and to the plates with the care necessary to obtain a good soaking (Fig. 3 and 4). The surfaces were maintained in horizontal position during the application of the adhesive. After the time indicated by the manufacturer, the plates were bonded to the mortar specimens (Fig. 5). To obtain a good penetration of the epoxy in the voids, we put above a weight of about 1 kg.

Fig. 2 – Specimen after surface preparation.

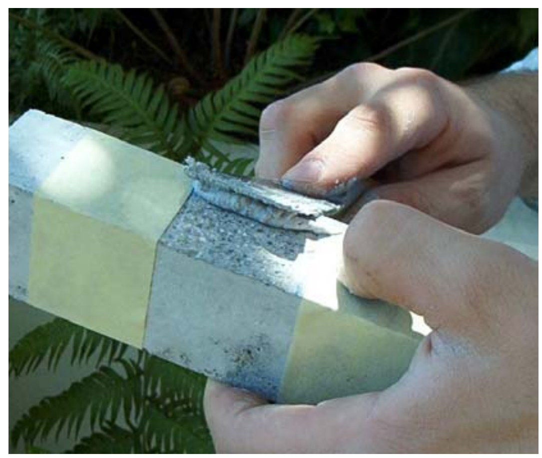

Fig. 3 – Application of epoxy on a specimen.

The reinforced specimens were maintained in the laboratory room during seven days. After, they were maintained at one fixed temperature during seven days. The temperatures used were 20, 50, 100, 150, 200 and 250 ºC. The adhesion strength was determined with three-point flexure tests (Fig. 6), at room temperature.

3. RESULTS

After the flexure tests, the failure load and the failure mode were recorded. The reinforced specimens presented mortar failure (Fig. 7 and 8) or adhesive failure (Fig. 9 and 10). The results of the tests are presented in Fig. 11. The adhesion strength indicated at each temperature is the mean of the flexural strength of five specimens.

Fig. 4 – Application of epoxy on a CFRP plate.

Fig. 5 – Bonding a CFRP plate to a mortar specimen.

The specimens with steel reinforcement presented mortar failures, except the 200 ºC specimens. Only the 250 ºC CFRP specimens presented adhesive failures. The flexural strength of the mortar without reinforcement was 7,59 MPa at 28 days.

With the results presented in figure 11, the variation of adhesion strength, f_a, can be related with temperature, T, by the following expressions:

$$f_a = -5x10^{-5}T^2 - 0{,}0015T + 10{,}405 \quad (1)$$

$$f_a = -2x10^{-5}T^2 - 0{,}005T + 8{,}644 \quad (2)$$

Expression (1) and (2) are valid only for T in ºC and for f_a in MPa. Expression (1) was determined with the results of the specimens reinforced with CFRP plates and expression (2) with the results of the specimens reinforced with steel plates. The R^2 is 0,98 for the CFRP specimens and 0,86 for the steel specimens.

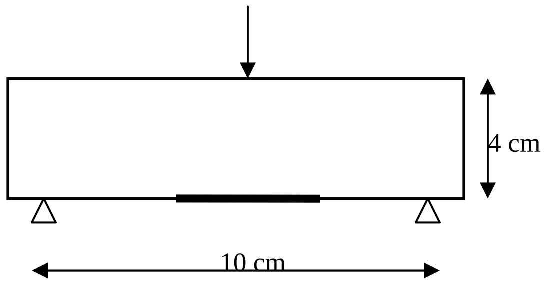

Fig. 6 - Three-point flexural tests.

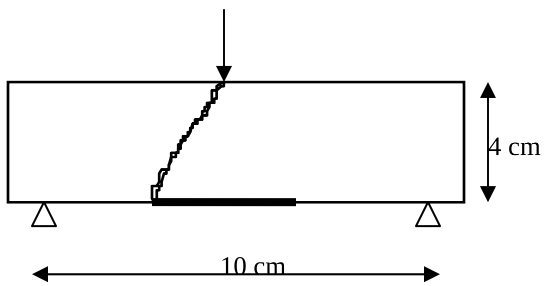

Fig. 7 - Mortar failure.

Adhesion strength decreases always with temperature. The decrease is more important after 50 ºC. This can occurred because the glass transition temperature of the epoxy is 63 ºC.

Even with mortar failures, the efficiency of the reinforcement decreases with the temperature. The efficiency of the reinforcement, in percentage, can be expressed by:

$$Ef = \frac{f_a(T) - f_f(20)}{f_f(20)} x100 \quad (3)$$

where:

$f_a(T)$ – adhesion strength of the reinforced specimens at a temperature T (ºC);
$f_f(20)$ – flexural strength of the mortar at 20 ºC.

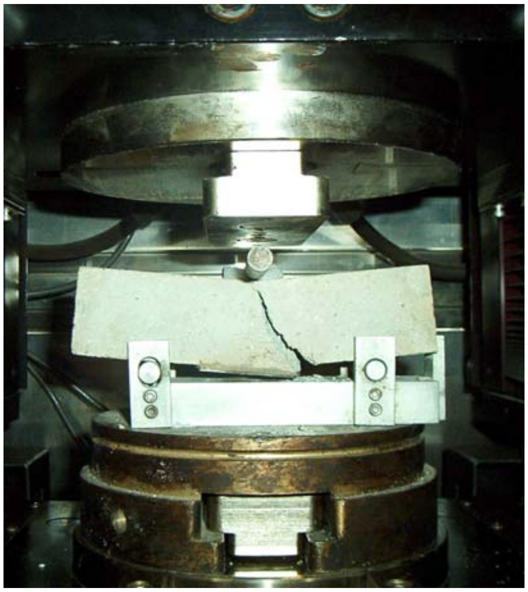

Fig. 8 – Mortar failure of a specimen.

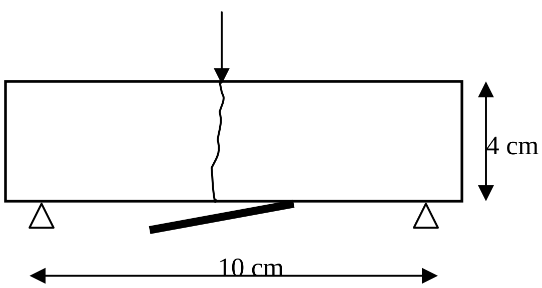

Fig. 9 - Adhesive failure.

Figure 12 presents the variation of the efficiency of the reinforcement with temperature. The efficiency of the steel plates is lower than the efficiency of CFRP plates. This occurred because the thicknesses of the plates were different. The thickness of the CFRP plates was 1,4 mm. The steel plates only had a thickness of 1 mm.

The reinforcement with CFRP plates has a better behaviour with high temperatures. For the reinforcement with steel plates the 0 % of efficiency occurred at 100 ºC (Fig. 12). The same efficiency occurred at 250 ºC for the reinforcement with CFRP plates. However, for this reinforcement, the efficiency is only 7,1 % at 200 ºC and the lost of efficiency above 50ºC is considerable.

Fig. 10 – Adhesive failure of a specimen.

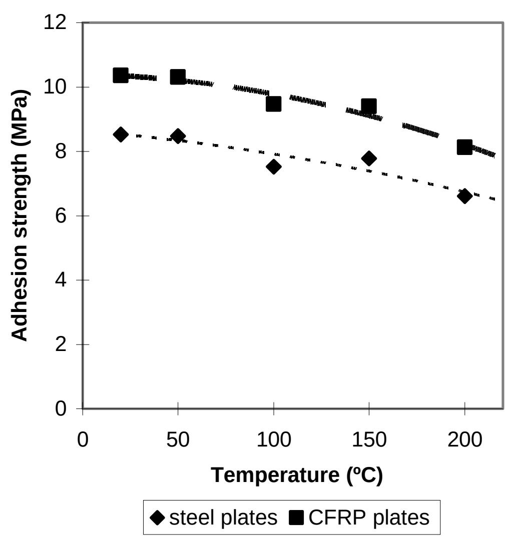

Fig. 11 - Variation of adhesion strength with temperature.

The different behaviours can be explained by different thicknesses and by the different materials of the plates. The CFRP plates have two properties that can explain the better behaviour under high temperatures. Firstly, they isolate from temperature more than the steel plates. Secondly, CFRP and epoxy have similar thermal coefficients of dilatation. This avoids the concentration of stresses at the joints.

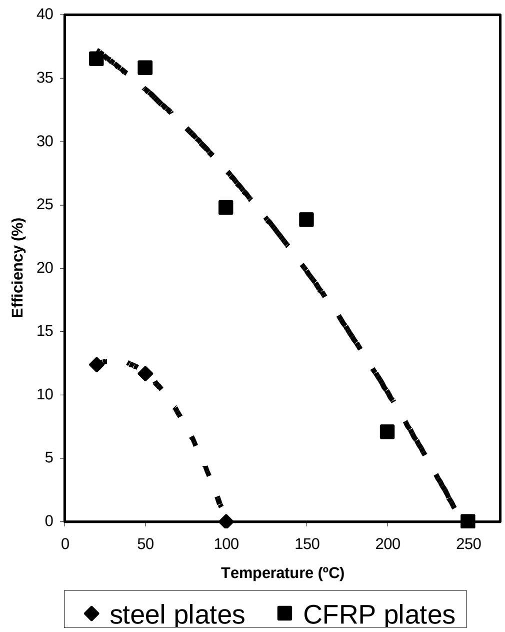

Fig. 12 – Variation of the efficiency of the reinforcement with temperature.

4. CONCLUSIONS

The load capacity of the reinforced specimens decreases with the increase of temperature The thermal resistance of the tested external reinforcements can be considered 50 ºC. For temperatures above this value the efficiency of the reinforcements decreases significantly, even if failures continue to be mortar failures.

The adhesive failures only occurred for temperatures above 150 and 200 ºC, for the reinforcement with steel plates and for the reinforcement with CFRP plates, respectively.

The thermal resistance determined is not very high. Therefore, the use of reinforced systems bonded with epoxies is not recommended, without a protection system. The behaviour will be critical near furnaces, boilers or chimneys and during a fire.

5. REFERENCES

[1] Emmons, P. H. and Vaysburd A. M., “Concrete Repair at the Threshold of the 21st Century: Focus on Strengthening of Existing Structures,” in High-Performance Fiber-Reinforced Concrete in Infrastructural Repair and Retrofit, SP-185, (Ed. Krstulovic-Opara, N. and Bayasi, Z.) p.p. 121-140, American Concrete Institute, Farmington Hills, Michigan, USA (2000).

[2] Perkins, P. H., “Repair, Protection and Waterproofing of Concrete Structures”, E & FN Spon, London, UK (1997).

[3] Ignoul, S., Brosens, K. and Van Gemert, D., “Strengthening of Concrete Structures with Externally Bonded Reinforcement: Practical Applications in Belgium,” in Proceedings of International Seminar Repair, Rejuvenation and Enhancement of Concrete, (Ed. Dhir, R. K., Jones, M. R. and Zheng, L.) pp. 371-379, University of Dundee, Scotland (2002).

[4] FIB, International Federation for Structural Concrete, “Management, Maintenance and Strengthening of Concrete Structures”, FIP Commision 10, Lausanne, Switzerland (2002).

[5] ACI, American Concrete Institute, “State-of-the-Art Report on Fiber Reinforced Plastic (FRP) Reinforcement for Concrete Structures”, ACI Committee 440, Farmington Hills, Michigan, USA (1996).

[6] ACI, American Concrete Institute, “Guide for the Selection of Polymer Adhesives with Concrete”, ACI Committee 503, Farmington Hills, Michigan, USA (1992).

[7] Aguiar, J. B. and Pimenta, T. J., “Influence of High Temperatures on the Adhesion of Epoxy to Hardened Mortar, Fresh Mortar or Steel Plate”, in Proceedings of International Conference Infrastructure Regeneration and Rehabilitation, (Ed. Swamy, R. N.) p.p. 995-1004, Sheffield Academic Press, Sheffield, UK (1999).

[8] Aguiar, J. B., “Essais d’Adhérence des Époxydes au Béton Hydraulique,” Materials and Structures, 26, 90-97 (1993).

[9] ACI, American Concrete Institute, Use of Epoxy Compounds with Concrete, ACI Committee 503, Farmington Hills, Michigan, USA (1993).

[10] Kinloch, A. J., Durability of Structural Adhesives, Applied Science Publishers, London, UK (1983).

[11] Desiderio, P., “Durability of Externally Bonded FRP Systems for the Strengthening of Existing Structures,” in Proceedings of 9th International Conference on Durability of Materials and Components, Brisbane, Australia (2002).

[12] CEN, European Committee for Standardisation, EN 196-1, Methods of Testing Cement - Determination of Strength, Brussels, Belgium (1994).

[13] CEN, European Committee for Standardisation, EN 197-1, Cement - Composition, Specifications and Conformity Criteria for Commom Cements, Brussels, Belgium (2000).

[14] Hutchinson, A. R. and Quinn, J., “Materials”, in Strengthening of Reinforced Concrete Structures, (Ed. Hollaway, L. C. and Leeming, M. B.) p.p. 46-82, Woodhead Publishing Limited, Cambridge, England (1999).