Repair and Renovation of Concrete Structures

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CONTENTS

EFFECT OF TEMPERATURE ON THE DURABILITY OF SYSTEM FOR STRENGTHENING OF CONCRETE STRUCTURES

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ABSTRACT. Nowadays, there is a need in solving problems about the reinforcement of concrete structures. The external reinforcement of concrete with composite materials is a technique that has acquired more and more potential. The bond between reinforcement and support is usually made with epoxy adhesives. However, it is in this part that the integrity of the system can be affected, namely by exposure to high temperatures, amongst various other reasons. In order to study the behaviour of the external reinforcement with the increase of air temperature, several beams were prepared and strengthened with CFRP laminates. After cyclical thermal exposition of 25 days, with maximum temperatures of 20°C, 40°C, 60°C and 80°C, the beams were subjected to bending tests. The results demonstrated that the improvement achieved with the reinforcement, disappears with the increase of the environment's temperature. The thermal resistance of this strengthened system is not very high, thus special needs to be taken into account when applied in warm locations.

Keywords: Durability, Temperature, Bond, Reinforcement, Epoxy resin.

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INTRODUCTION

During the period of their useful life, reinforced concrete structures must present good levels of security, durability and functionality. However several problems on project, construction and use, can put in risk some of these requirements.

The frequency of structures damages, imply the increase of the severity in the codes and in the number of reinforcement solutions. The civil engineering structure renewal has received considerable attention over the past few years throughout the world. The structures increasing decay is frequently combined with the need for upgrading.

In situ rehabilitation of reinforced concrete elements using bonded steel plates has been proven his performance [1]. The application is simple and fast with a minimum interference in the architecture. However, disadvantages inherent to the use of the steel stimulated research into advanced composite material made with fibres in a polymeric matrix (FRP).

Durability

Durability of a material is his ability to resist to service conditions [2]. The durability of the adhesion between building components is one of the most important features of the structure. It is generally believed that FRP have a high level of durability. But, this is not necessarily true; many systems exhibit reduced mechanical properties after exposure to certain environments, including temperature, humidity, and chemical exposure [3].

The systems that use FRP to externally reinforce concrete structures have polymers in two parts, the saturation resin and the adhesive. The glass transition temperature (T_g) is the temperature above which polymers change from relatively hard and elastic to viscous rubbery materials. Moreover, when the polymer is exposure to humidity, this temperature (T_g) decrease. By that reason, some recommendations suggested that FRP systems should not be used at temperature above their T_g and they recommended that selected materials should have a T_g at least 20°C above the maximum use temperature.

Adhesives

The purpose of the adhesive is to provide a shear load path between concrete surface and FRP. The principal structural adhesives formulated for use in systems for the external reinforcement of concrete are epoxies, which are the result of mixing epoxy resins with hardeners [4].

Epoxy adhesives can be formulated to provide a broad range of application characteristics and mechanical properties when cured. Depending on the application demands, the adhesive can contain toughners, flexiblers or fillers, all of which contribute to the physical properties [5]. Fillers, generally inert materials, originate epoxy mortars. The incorporation of fillers reduces cost, creep, shrinkage. Also, reduce the thermal expansion coefficient. This incorporation increases the viscosity of the fresh mixed system, which is useful in applications to vertical or inverted surfaces.

Surface preparation

Before the strengthening of a structure there are certain steps that must be undertaken. The behaviour of concrete elements strengthened is highly dependent on the proper preparation and profiling of the concrete surface [2]. The soundness of concrete substrate should be verified. If the deterioration of the concrete has reached a depth that no longer allows shallow surface repair, replacement of the concrete should be considered.

Bond failure can be expected if surface preparation is inadequate. However, surface preparation represents the most difficult part of the bonding process [5]. Subtract should be roughened. Laitance, contamination and serious imperfections need to be eliminated. FRP surfaces must be cleaned and at the time of epoxy application must be free of dust, dirt and oil.

TESTS

To verify the influence of temperature in the externally bonded CFRP reinforcement for reinforced concrete structures, a program of research was defined to give simple and comparative results.

Degradations

After the choice of the materials, a program of degradations, to submit several beams of reinforced concrete, was made. The glass transition temperature of the epoxy mortar was 62°C, so, a series of beams was submitted to a thermal exposition of 60°C. It would be equally important to exceed significantly that temperature and know the behaviour at lowers temperatures, such as laboratory room and other between that and glass transition temperature.

The thermal expositions are based in previous works and in a European standard [6]. Each sub-group (current concrete beams strengthened and un-strengthened and high-performance concrete beams strengthened and un-strengthened) of a series of tests was composed by three beams. The program of degradations is on table 1.

Reinforced concrete beams

To have more results, beams with two different kinds of concrete were produced: one of them was a current concrete (CurrC) and other one was a high-performance concrete (HPC). The beams were produced with the dimensions of $650\times150\times100$ mm^3.

The steel reinforcement was the same in HPC and in current concrete beams. The flexural reinforcement steel (f_{syd}=400 N/mm^2) had 6.0 mm of diameter and the shear reinforcement steel (f_{syd}=500 N/mm^2) had 3.0 mm of diameter.

The beams stayed in the moulds 24 hours. After, the specimens were removed and maintained 20 days inside water at 20°C. Before the bond, they stayed 7 days at the laboratory room at 20°C. The CFRP reinforcement was applied in beams when they have 28 days. At 28 days, the current concrete had middle compression strength of 30.0 N/mm^2 and the high-performance concrete presented 90.0 N/mm^2.

Table 1 Thermal degradations

THERMAL DEGRADATION				
Low temperature, °C	High temperature, °C	Degradation	Time by cycle, hours	Number of cycles
20	20, 40, 60, 80	T20, T40, T60, T80	6+6	50

Surface preparation for CFRP application

Passed 28 days, the CFRP can be bonded to the beams. To prepare the surface of the hardened concrete beam, it was used a diamond disc, an abrasive disc, air spurt and a soft brush. These resources are important to remove laitance, oils and dust. At the same time they confer roughness to the extremely smooth surface of the beams. The CFRP was cleaned immediately before the application of epoxy adhesive (Table 2), with the volatile product indicated by the supplier.

Table 2 Epoxy mortar properties

EPOXY MORTAR DATA	
Glass Transition Temperature, °C	62
Thermal Expansion Coefficient, °C^{-1}	$9x10^{-5}$

Bond

The adhesive used was an epoxy mortar. It was mixed immediately before the application. Resin and hardener were mixed with a reason of 3:1, respectively. They have different colours, so complete mixing can be judged when a uniform colour had been achieved [7]. This adhesive contains calcareous filler. It is important to spread the adhesive immediately after mixing, to dissipate the heat and extend its usable life.

Adhesive was applied either in concrete and CFRP surfaces [8]. This procedure reduces the risk of forming voids when pressing the CFRP plat against the concrete surface. Producer recommends a joint with a thickness between 0.5-2 mm. The reinforced beams were maintained in the laboratory room (20°C) during 7 days. After, they were submitted at the degradation process.

Three-point bending tests

After thermal cycles exposure of 25 days the beams were subjected to three-point bending tests. The load test was made with a controlled system guaranteeing a speed, in a middle of the beam, of 10 μm/s. The test was carried out with the beam at the maximum temperature of the thermal cycle

RESULTS

The evaluation was made in two perspectives, relative to the numerical results and to the visual analysis of the behaviour of the beams during the degradation and after the final test.

Figures 1 to 4 represent the middle curves of the tests after each one of the thermal expositions. The graph of Figure 5 presents the evolution of the maximum resistant moments for the different degradations.

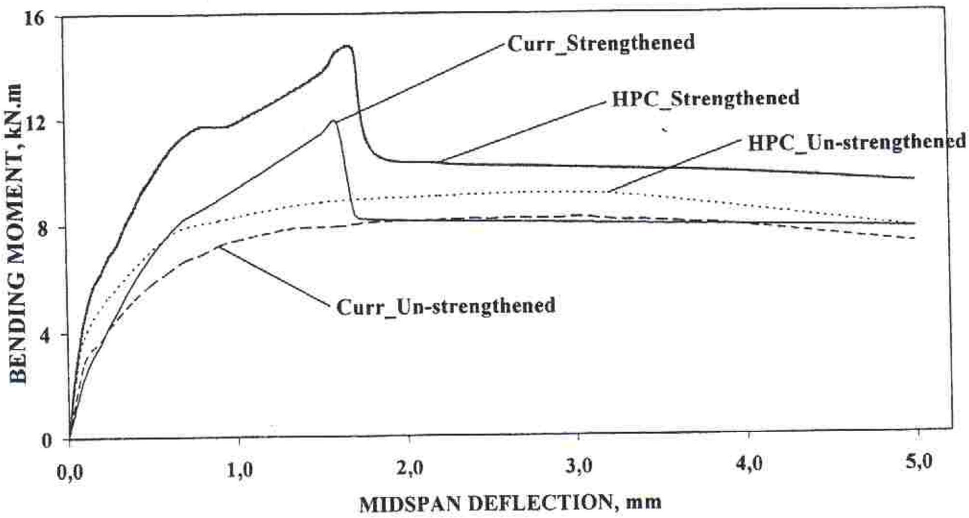

Figure 1 Variation of the bending moments with mid-span deflection, type of concrete and reinforcement (T20)

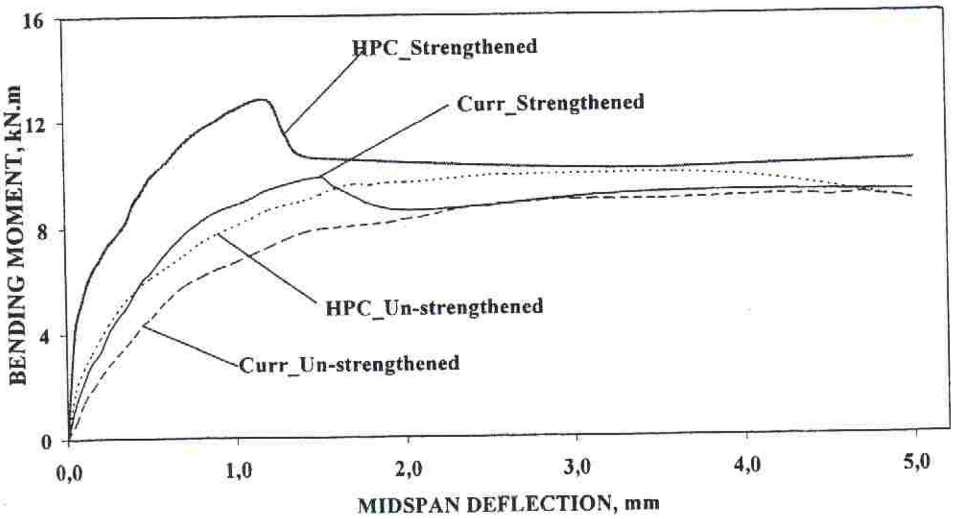

Figure 2 Variation of the bending moments with mid-span deflection, type of concrete and reinforcement (T40)

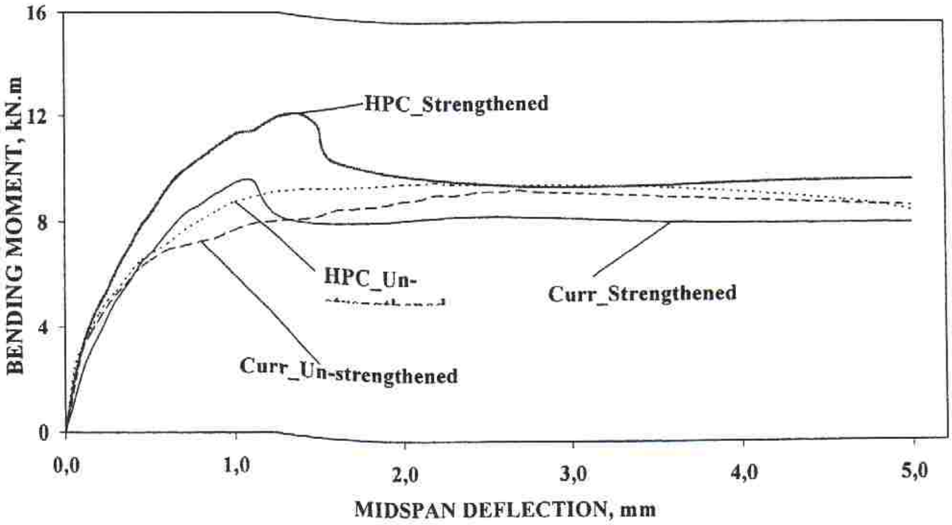

Figure 3 Variation of the bending moments with mid-span deflection, type of concrete and reinforcement (T60)

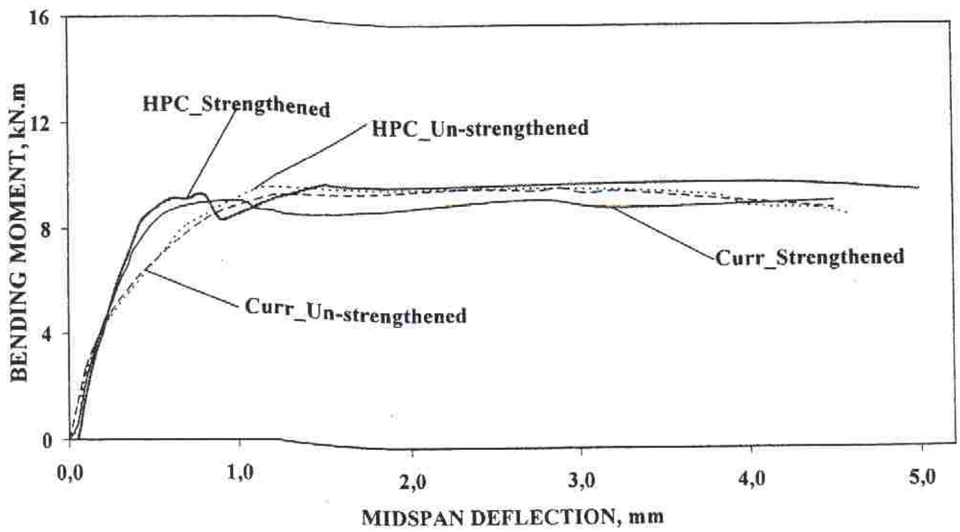

Figure 4 Variation of the bending moments with mid-span deflection, type of concrete and reinforcement (T80)

ANALYSES OF RESULTS

As waited, the increase of the thermal aggressiveness decreases the reinforcement efficiency. When glass transition temperature of the adhesive was exceeded (expositions T60 and T80), CFRP started debonding.

With the increase of temperature, the moment vs. deformation curves (Figures 1 to 4) of the strengthened beams become close to the curves of the beams without reinforcement. In the series without degradation (T20) and degradation T40, the beams without reinforcement had flexural failure (Figure 6) and the strengthened beams had delaminations caused by failure of the covering concrete (Figure 7). When the aggressiveness of the exposition was near the adhesive T_g, some debondings in the extremities of the CFRP reinforcement were verified. In these situations, debonding occurred at the concrete/adhesive interfaces (Figure 8). In the most rigorous exposition and with HPC beams, complete debonding of the reinforcement was verified. With the current concrete beams the visual results had not been so obvious.

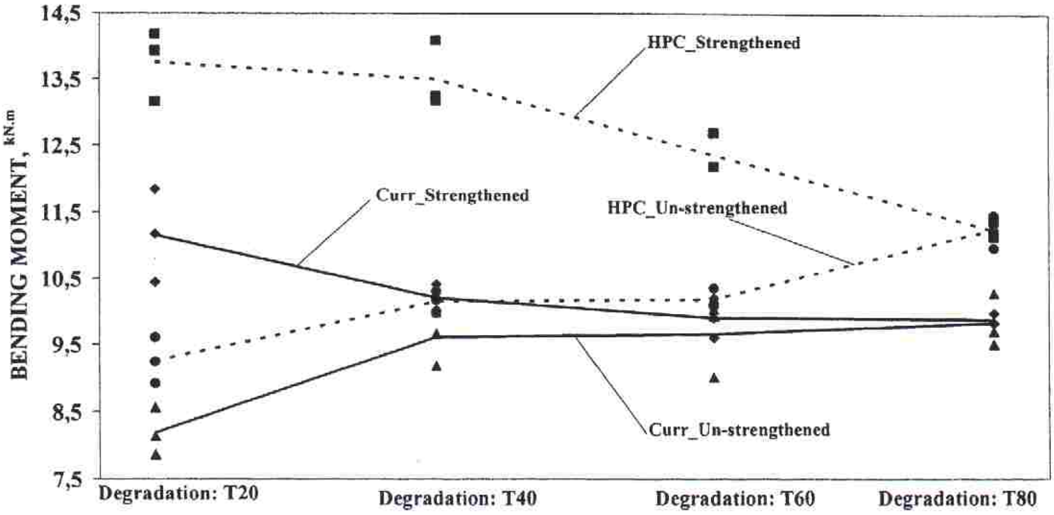

Figure 5 Evolution of maximum bending moments with temperature, type of concrete and reinforcement

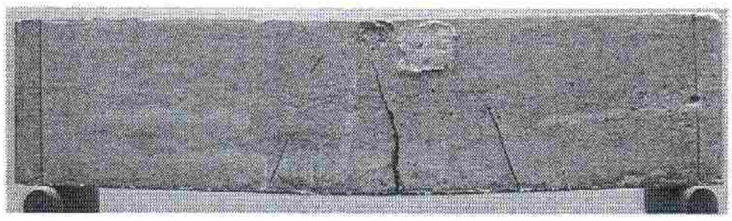

Figure 6 Flexural failure

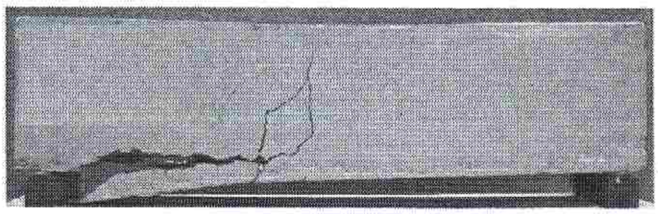

Figure 7 Delamination of the covering concrete

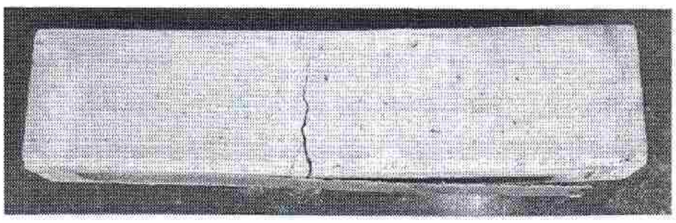

Figure 8 CFRP debonding

CONCLUSIONS

Bonding represents the natural method for jointing together dissimilar material such concrete and polymer composites. The durability of externally bonded reinforcement is very important. The load capacity of the reinforced beams decreases with the increase of temperature and the thermal resistance is not very high. In solar exposition of a concrete element, it is possible to have temperatures sufficiently high and capable to give problems. Therefore, use reinforced systems bonded with epoxies in warm locations needs to be done with special care.

The study involved temperature and load, but they could not be alone. At the same time, it is also possible, the action of humidity or chemically aggressive environment. It is recommended the selection of epoxies with a T_g of at least 20°C above the maximum use temperature or considerer the application of protection systems. It is also important a good quality control during the application.

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