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CFRP FIRE BEHAVIOUR – PASSIVE PROTECTION SYSTEM

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Introduction

The technique of reinforcing concrete structures by means of bonding composite fibre reinforced polymers (FRP) has been applied in the construction industry. There are several examples of application of these materials in bridges and buildings, both in new construction and rehabilitation and/or strengthening of damaged structures. Repair with externally bonded FRP reinforcement is attractive to owners, engineers and constructors because of the ease and speed of installation, the structural efficiency of the repair, the corrosion resistance of the materials, and the minimal effect that these materials have on structural aesthetics, and versatility [1].

Although many tests have been conducted to investigate strengthening reinforced concrete members with FRP composites materials, there are still many aspects of their use that remain to be investigated. Composites present some disadvantages such as low through-thickness mechanical properties, poor impact damage tolerance, and anisotropic properties. Among these subjects, there are legitimate concerns about the behaviour of FRP materials when exposed to fire action [2-4]. When composites are exposed to high temperatures (typically above 300-400 ºC) the organic matrix decomposes with the release of heat, smoke, soot and toxic volatiles. Organic fibres used to reinforce composites, such as carbon, glass and aramid, also decompose and contribute to the generation of heat, smoke and fumes. The heat, smoke and gases released by a burning composite and the degradation in structural integrity can make fire-fighting extremely hazardous and increase the likelihood of serious injury and death. The susceptibility of composites to fire has been the key issue in restraining their use in many infrastructure and public transportation applications.

The fire hazard of composites is often defined by their fire reaction and fire resistant properties. Fire reaction is used to describe the flammability and combustion properties of a material that affect the early stages of fire, generally from ignition to flashover. Fire reaction also describes the smoke toxicity of a combustible material. Important fire reaction properties that affect fire growth are the heat release rate, time-to-ignition, flame spread rate and oxygen index [2].

Therefore, different strategies of fire protection measures may be necessary in order to improve the fire performance of FRP materials. Among those, passive measures are intended to prevent the ignition of fires and decrease the impact of fires through mechanisms that require no human intervention or automate response.

In addition to the above applications of passive fire protections for FRP composites on the material level, implementation of fire protective material on surface of FRP structural members are also common approaches, especially for structural engineers, as these approaches are well accepted or practiced in fire protection. Such surface fire protective materials include fire resistance gypsum plasterboards (PBs), CS boards, cementitious mortar and intumescent coating [5].

An experimental programme was performed in order to evaluate the behaviour of composite materials when exposed to fire, in particular composite materials based on carbon fibres (CFRP). Therefore a campaign of tests on concrete specimens with 100×100×40 [mm] was developed. The dimensions and the test method were established according to the EN ISO 13927 [6] standards. The CFRP sheet is glued on the surface of the specimens using epoxy resin and exposed to thermal action.

The surface of the reinforcement system is exposed to the action of different radiant heat fluxes (HF) equal to 35 [kW/m^2] and 75 [kW/m^2], from a cone calorimeter and changes in temperature are measured by thermocouples placed between the surface of concrete and CFRP.

The influence of passive protection systems on the burning behaviour of CFRP is analysed using different fire protection material, such as gypsum plasterboard (PB) and intumescent paint (IP). The temperature evolution of the contact surface of the different materials is determined for the two heat fluxes referred above, allowing to analyse the influence of these protective materials in the structural reinforcement capabilities of the CFRP when subjected to high temperatures.

Experimental program

Several tests were conducted in order to study the behaviour of CFRP submitted to fire, with and without protection. Concrete testing samples, with the dimensions 100×100×40 [mm], were produced. After drying the specimens the surface was treated and the CFRP was glued with epoxy resin, Fig. 1.

For the analysis of the CFRP' temperature evolution when exposure to the radiant heat flux, a thermocouple was introduced into the concrete specimen in contact with the lower face of CFRP bonded to concrete surface, Fig. 2.

Fig. 1 – Preparation of test specimens

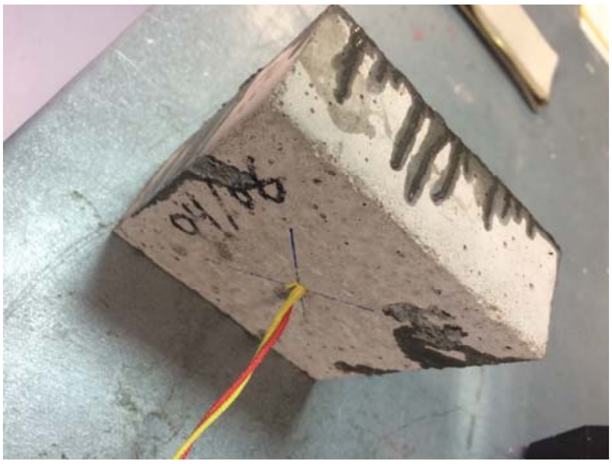

Fig. 2 – Thermocouples applied into specimen

The protection systems used in this work are only related to fire safety passive systems. These materials must have a low weight to represent a non-significant load increase on the element, low thermal conductivity and high specific heat [7, 8]. The main goal of this type of protection is to prevent the ignition of the material by reducing the heat, smoke and toxic gases released by the FRP. Typically, passive protection systems are based on the isolation of the structural elements, avoiding the spread of fire and posterior collapse of the structure. Though this experimental campaign it was intended to study the effectiveness of two different materials of fire protection: gypsum plasterboard (PB), Fig. 3, and intumescent paint (IP), Fig. 4.

The gypsum plasterboard applied, which was manufactured by Gyptec Iberian Company, is formed by two paper sheets with high quality gypsum inside, and reinforced with glass fibre to improve the reaction to fire. These plates are suitable for areas requiring high fire resistance [9].

The intumescent coating with white matt finish used for fire protection was supplied by International (Product Interchar 1160). This Interchar paint is a water based coating which allows fire protection times mainly from 30 to 60 [min], having a specific mass of approximately 1400 [kg/m^3]. This paint is mostly used for fire protection of steel structures, [10], and may be applied by conventional spray, airless spray, brush or roller. The specimens were protected with three different nominal dry film thicknesses: 0.5 [mm], 1.0 [mm] and 2.0 [mm], Fig. 4.

Fig. 3 – Application of the Gypsum plasterboard

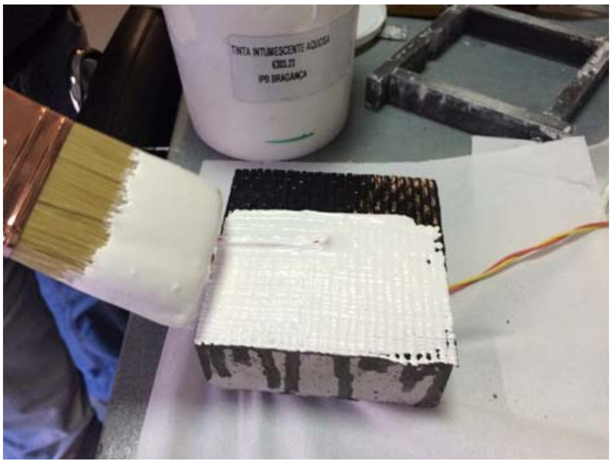

Fig. 4 – Application of the intumescent paint

Experimental tests

The cone calorimeter is a device that measures the fire reaction properties of a material when subjected to a given radiant heat flux. This device has a high precision load cell allowing the mass registration of the sample over time of thermal exposure [11]. For the tests done in this work and for both heat fluxes used, the mass loss calorimeter was calibrated for a distance between the lower base of the cone and the upper surface of the sample of 25 [mm].

From Fig. 5 one can observe unprotected samples where ignition on epoxy resin applied to the CFRP occurred. The elapsed time to ignition is about 4 [min] for the heat flux of 35 [kW/m2], and about 1 [min] for heat flux of 75 [kW/m2]. The final appearance of the test samples were similar for both heat fluxes, Fig. 6.

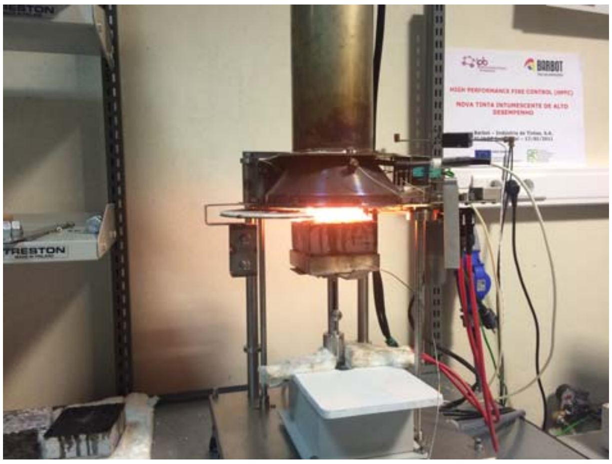

Fig. 5 – Ignition of epoxy resin from an unprotected specimen

Fig. 6 – Final aspect of unprotected sample

The concrete specimens with CFRP protected with the gypsum plasterboard were also subjected to two considered heat fluxes. In these tests, the temperatures were registered using two type K thermocouples, one being inserted in the bottom face of CFRP (T1) and the other on the lower face of the gypsum board (T2). No ignition was observed during the tests. The specimen state after the test end are shown on Fig. 7 and Fig. 8, for both heat fluxes. No deterioration was observed on specimens under the heat flux of 35 [kW/m^2], but for specimens under the heat flux of 75 [kW/m^2] the thermal decomposition of the epoxy resin was verified.

Fig. 7 – Specimen protected with plasterboard submitted to HF = 35 [kW/m^2]

Fig. 8 – Specimen protected with plasterboard submitted to HF = 75 [kW/m^2]

The concrete specimens with CFRP protected with intumescent coating were also monitored using two type K thermocouples, one being inserted in the bottom face of CFRP (T1) and the other between CFRP and intumescent coating (T2), Fig 4 and Fig. 9. For both heat fluxes ignition from the gases produced by the intumescent coating thermal decomposition was registered, Fig. 10. Fig.11 and Fig. 12 show the final aspects of specimens for both heat fluxes.

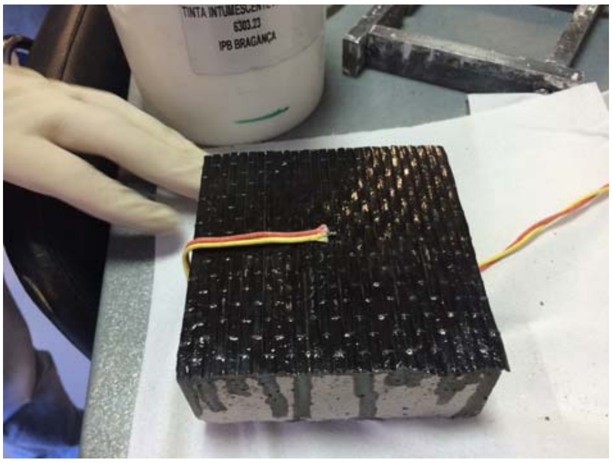

Fig. 9 – Thermocouples applied on specimens protect with intumescent coating

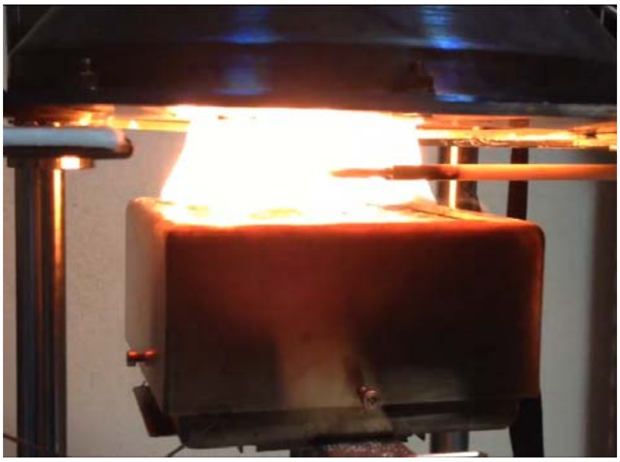

Fig. 10 – Ignition of intumescent coating

Fig. 11 – Final aspect of specimen protected with intumescent coating submitted to HF = 35 [kW/m^2]

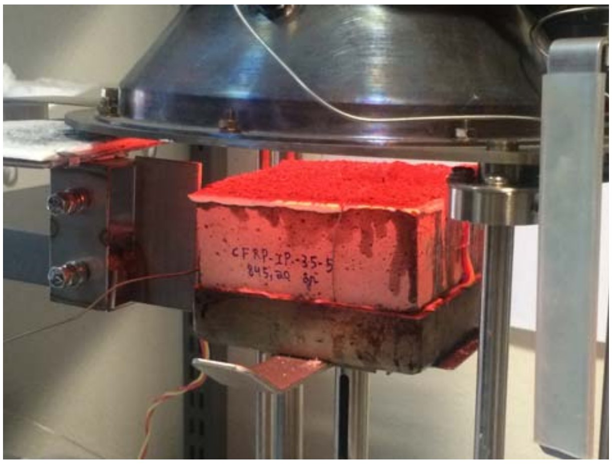

Fig.12 – Final aspect of specimen protected with intumescent coating submitted to HF = 75 [kW/m^2]

Experimental results

A comparison between the measured temperatures at CFRP of both the unprotected and protected specimens, subjected to the heat fluxes of 35 [kW/m^2] and 75 [kW/m^2] is presented in Fig. 13 and Fig. 14, respectively. The specimens were protected with gypsum board (CFRP-PB) and intumescent paint (CFRP-IP) with thickness of: 0.5 [mm] (CFRP-IP-0.5), 1.0 [mm] (CFRP-IP-1), and 2 [mm] (CFRP-IP-2). The results shows are from the thermocouple placed in the bottom surface of CFRP (T1).

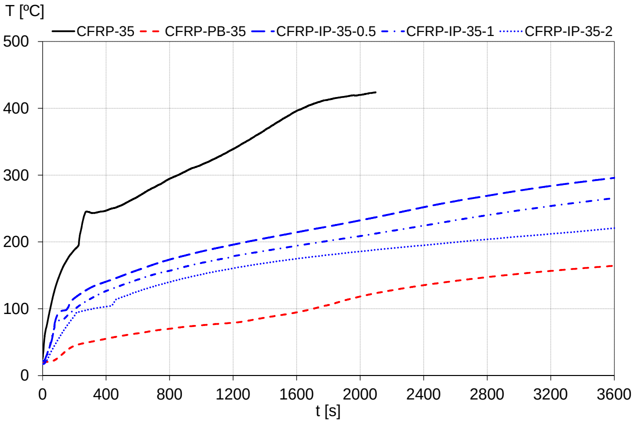

Fig. 13 – Temperatures at the centre of the CFRP for HF = 35 [kW/m^2]

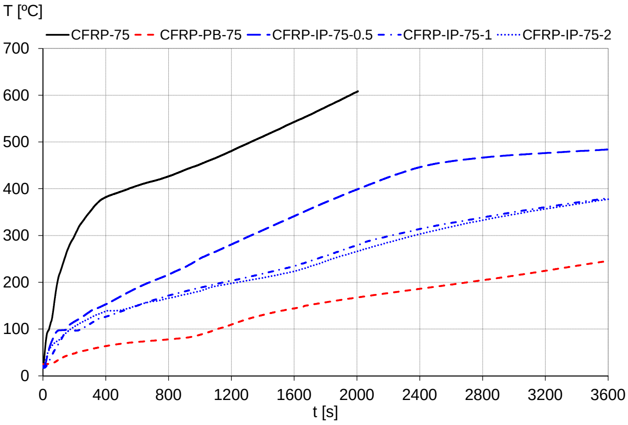

Fig. 14 – Temperatures at the centre of the CFRP for HF = 75 [kW/m^2]

The analysis of the results presented in Fig. 13 and Fig. 14, clearly shows that the protection systems produce a temperature decrease in CFRP bottom surface. For the case when the heat flux is 35 [kW/m2], the unprotected test specimens reached values of the order of 420 [ºC] decreasing to 300 [ºC], 250 [ºC] and 220 [ºC] in protected specimens with intumescent paint with 0.5 [mm] 1.0 [mm] and 2.0 [mm] thick, respectively, and 160 [ºC] in the samples protected with gypsum board. For the heat flux equal to 75 [kW/m2], the values obtained for the temperature are higher than in previous tests, resulting in values of about 600 [ºC] in the samples without protection and for the same thermal exposure time. When the specimens are protected with intumescent paint with nominal dry film thickness of 0.5 [mm] and 1.0 [mm] the values obtained for temperatures were of 480 [ºC] and 380 [ºC], respectively. For samples with 2 [mm] of intumescent coating, similar results were obtained as for the specimen with 1 [mm] thick intumescent paint. For samples protected with gypsum board, the recorded temperature reached 245 [ºC]. The most effective protection system proved to be the plasterboard for both heat fluxes considered.

During the tests the heat release rate and the specimens' mass loss were measured. These fire reaction properties of the unprotected specimens with time are plotted in Fig. 15 and Fig. 16.

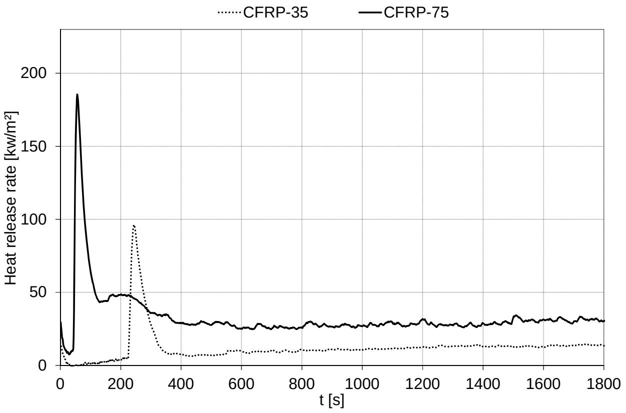

Fig. 15 – Heat release rate for unprotected specimen

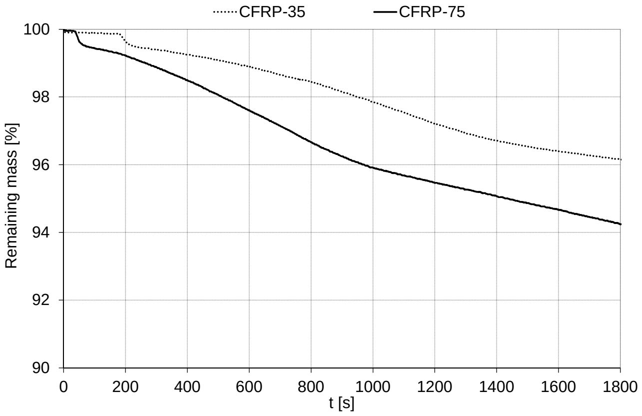

Fig. 16 – Remaining mass for unprotected specimen

With regard to the heat release rate (HRR) time variation, Fig. 15, and for both heat fluxes, there was an initial period during which the unprotected specimens did not release any heat, because the temperatures of the material was still below the pyrolysis temperatures of the polymeric matrix. After this initial period, whose duration decreased with the heat flux, the HRR suffered a rapid increase due to the combustion of volatiles and rapidly reached its peak value. Then, the HRR decreased gradually with increase time due to the decrease of resin content of the specimen. After a certain period of time, when all resin was decomposed, the heat release rate became negligible. It is shown that the peak HRR of the CFRP increased with the heat flux, with 185 kW/m2 for HF = 75 kW/m2 and 94 kW/m2 for HF = 35 kW/m2. The remaining mass (RM) curves of the unprotected specimens, Fig. 16, follow the tendency of the HRR curves, showing an initial plateau without mass loss followed by a mass loss step at the instant when the epoxy resin start to decompose and ignite. After this the mass loss slows down but the specimens continues to loose mass. The remaining mass was of 4% and 6%, of the total concrete and CFRP mass, for HF = 35 kW/m2 and HF = 75 kW/m2, respectively.

Conclusions

The behaviour of CFRP subjected to fire was evaluated using cone calorimeter tests. The tests were performed on specimens without any fire protection system (reference) and protected with two passive fire protection materials: laminate plaster board and intumescent paint with three different thicknesses. The tests were carried out for two heat fluxes of 35 [kW/m2] and 75 [kW/m2]. Temperatures in the lower face of the CFRP were measured using a type K thermocouple.

The fire reaction properties of the unprotected CFRP were not considerably different from those of CFRP fibre reinforced polymers reported in the literature.

From the tests carried out it was found that the temperature measurements showed that both fire protection materials gave a significant reduction in temperature in CFRP. However, there is a better performance with laminated gypsum board protection than in the samples protected with intumescent paint, considering the coating thicknesses tested.

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