CERIS Civil Engineering Research and Innovation for Sustainability

FIRECOMPOSITE – Fire Behaviour of Reinforced Concrete Structures Incorporating FRP Composites

Summary

Fibre reinforced polymer (FRP) materials used either as internal reinforcement of new concrete structures or for strengthening existing structures have been mainly used in bridges, in which fire resistance is not a primary design requirement. For buildings, widespread application is being delayed due to concerns regarding their performance at elevated temperature, since the strength, stiffness and bond properties of FRPs and adhesives are severely deteriorated at moderately high temperature (65-150 °C), namely when approaching the glass transition temperature (T_g). Furthermore, when exposed to 300-500 °C, their organic matrix decomposes, causing further deterioration. For these reasons, several international scientific organizations have unanimously recognized the fire behaviour of FRPs as one of the most critical research needs; moreover, present design guidelines generally do not recommend using FRP reinforcement in new concrete structures likely to be subjected to fire.

This research project focused on the behaviour at elevated temperature and under fire of (i) new concrete elements reinforced with FRP bars and (ii) existing concrete elements strengthened with advanced FRP systems (embedded through the section-ETS FRP bars, prestressed strips, strips with bent extremities or bonded with cement-based adhesives). The main motivation was to improve the understanding of their fire response, to optimize both FRP materials/geometries and fire protection systems, to develop fire design guidelines and ultimately to enable extending the structural use of FRPs in buildings. To this end, the experimental research programme was coupled with the development of supporting numerical modelling tools.

To carry out the proposed innovation, the research project comprised an extensive experimental programme, including materials development and characterization of the FRP and cementitious materials with small-scale tests, intermediate-scale bond tests on FRP-concrete specimens (Figure 1) and full-scale fire resistance tests on loaded FRP-RC and FRP-strengthened RC beams and slabs (Figure 2).

For the experimental study, in addition to standard mechanical tests of all materials at ambient temperature, tensile tests at elevated temperatures were performed on FRP bars and strengthening systems, including different formulations of cement-based adhesives. Dynamic mechanical analyses, thermo-gravimetric and differential scanning calorimetry tests were first performed on FRP, adhesives and fire protection materials, to analyse their thermophysical and thermomechanical behaviour. These experiments provided the glass transition and decomposition temperatures of the FRPs and adhesives, together with their thermo-physical properties (density, specific heat and thermal conductivity) as a function of temperature. These data were used as input for the numerical models developed (Figure 3).

Figure 1. GFRP-concrete bond tests setup.

In a second phase of the experimental programme, the FRP-concrete bond at elevated temperature was investigated in concrete specimens by means of (i) pull-out tests with FRP bars (Figure 1) and (ii) double lap shear tests with FRP strips. The tests were performed on a universal testing machine with an attached thermal chamber under steady state conditions, *i.e.*, the specimens were heated up to different temperatures (20 °C to 300 °C) and then loaded up to failure under constant temperature. In the pull-out tests, the influence of the bar surface finish (ribbed, sand coated with external wound fibres), diameter, geometry (straight *vs.* bent) and embedment length to concrete were assessed. In the double-lap tests, the influence of the type of adhesive (epoxy or cement-based) was be investigated. In these tests, the applied load, the slip at the FRP loaded and free ends, temperatures and strain distributions were measured. Based on the experiments, temperature-dependent local bond stress-slip laws were numerically calibrated and then implemented in finite element models to simulate the FRP-concrete interaction in the bond tests and in the fire resistance tests on FRP-RC and FRP-strengthened RC slabs.

Project Reference

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Leading Institution

IST-ID – Associação do Instituto Superior Técnico para a Investigação e Desenvolvimento (Portugal)

Partners

UMinho – University of Minho (Portugal), S&P – Clever Reinforcement iberica - Materiais de Construção Lda (Portugal), TRIA and HTecnic Construções, Lda (Portugal)

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Project Website

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In a third phase of the experimental programme, intermediate-scale fire resistance tests were conducted on loaded FRP-RC and FRP-strengthened RC beams and slabs (Figure 2). The tests were performed in a furnace according to the ISO 834 standard, allowing to determine temperature profiles, the evolution of deflections, the failure modes and fire resistance of the structural members. For the FRP-RC members, the different tests allowed to investigate the influence of the following constructive details: (i) type of bar surface finish, (ii) bar diameter, (iii) lap-splices (length and geometry), (iv) concrete strength and (v) cover thickness. For FRP-strengthened RC members, the tests allowed evaluating the effects of: (i) adhesive material (for both ETS and near surface mounted (NSM) techniques), (ii) FRP strip bending configuration, (iii) prestress level (for NSM) and (iv) different fire protection configurations (with thicker board insulation in the anchorage zones).

Tridimensional finite element models were developed to simulate the elevated temperature/ fire behaviour of FRP-RC and FRP-strengthened RC members, both unprotected and protected with different fire protection systems. The main developments comprised the implementation in an commercial software *(ABAQUS)* of the temperature-dependent material and interface properties, aiming to simulate: (i) the pull-out and double-lap tests and (ii) the fire behaviour of FRP-RC and FRP-strengthened RC members, retrieving their thermal responses, strain, stress and deflection evolution, and fire endurance estimates. Parametric studies were also conducted to (i) propose anchorage lengths for different types of FRP rebars as a function of temperature and to (ii) optimize the configuration of fire protection schemes.

At the end of this project, fire design recommendations were provided regarding the concrete cover, location and geometry of anchorage zones and lap splices of FRP-RC members. For FRP-strengthened RC members, the minimum fire protection thickness required to fulfil different performance levels related to fire resistance (30, 60, 90 or 120 min) were also proposed.

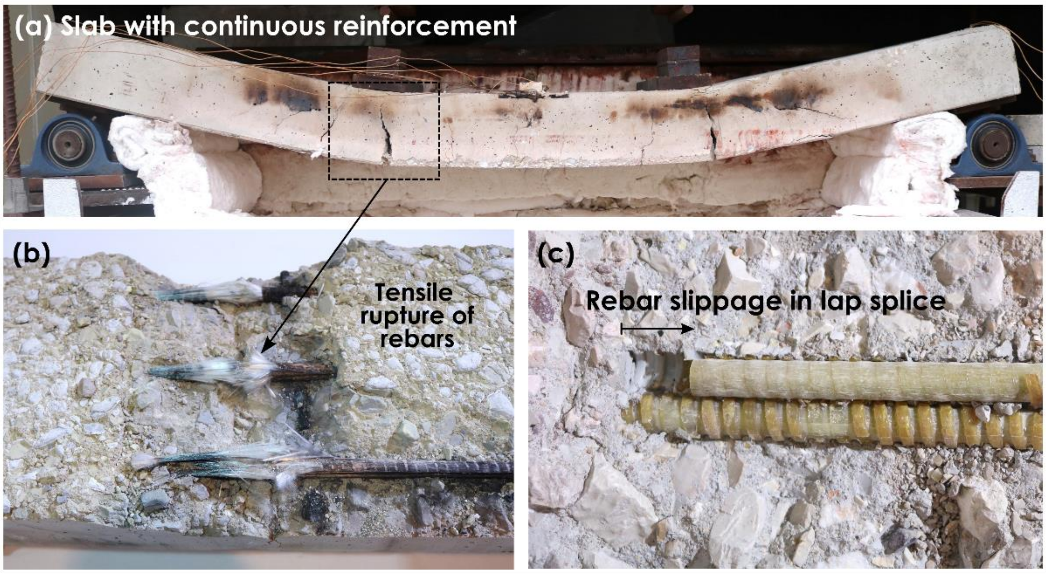

Figure 2. Post-fire observations of fire resistance tests on concrete slab strips reinforced with FRP bars.

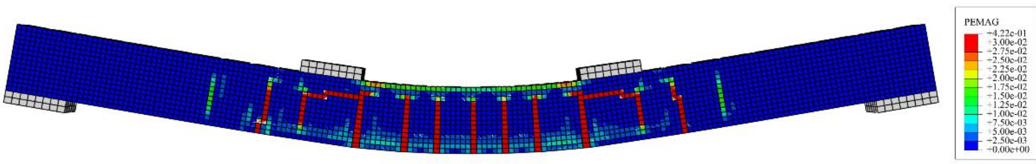

Figure 3. Numerical simulation of the failure of a concrete slab strip reinforced with FRP bars after fire exposure.