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FIBER REINFORCED CONCRETE OF ENHANCED FIRE RESISTANCE

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Fire, high temperatures, high strength concrete, steel and polypropylene fibers.

ABSTRACT

In the present work, a Fiber Reinforced Concrete of Enhanced Fire Resistance (FRCEFR) was developed, combining the use of polypropylene (PP) and steel fibers. The influence of the temperature on the compression and flexural behavior of FRCEFR was analyzed. From the force-deflection curves obtained in the flexural tests, and applying an inverse analysis, the influence of the temperature on the fracture parameters of this material was assessed.

INTRODUCTION

High strength concrete elements are subjected to spalling when exposed to a fast temperature rise. The spalling intensity depends on a number of parameters such as: concrete composition, properties of the aggregates, water content, concrete porosity, temperature rise speed, and member's geometry. Spalling is usually described as the result of a combination of the stresses derived from the thermal expansion and the vapor pressure within the concrete, and the stresses due to phase changes of the concrete aggregates when the environmental temperature increases. Non metallic fibers, in particular PP fibers can efficiently reduce spalling hazards. Channels are formed into the concrete internal body when these fibers are melted (171 °C is currently referred) allowing the escape of the water vapor in the very early stages of a fire, which decreases significantly the risk of concrete spalling. The addition of steel fibers has contributed to decrease the brittle behavior of cement based materials, both at high temperature and at room temperature.

DEVELOPMENT OF FIBER REINFORCED CONCRETE OF ENHANCED FIRE RESISTANCE

The FRCEFR has a fibrous system that was designed to enhance the fire resistance of concretes of a characteristic compressive strength in the range of 60 MPa to 80 MPa, and to increase significantly the concrete post-cracking residual strength. To select the nonmetallic type of fiber, the following fibers were considered: Ultrafiber cellulose fiber; Asota AFC PP fiber; Duro-Fibril PP fiber; Polyester; Cotton. A constant dosage of 2 kg/m^3 of fibers was adopted. For comparison purposes, a concrete composition including Dramix® ZP 305 hooked ends steel fibers was also prepared. Fig. 1 shows that steel fibers provided the lowest performance in mass loss respect. In the nonmetallic fiber concrete the mass loss occurred at relatively lower temperatures. Explosive spalling occurred in Reference specimens at a room temperature of 425 ºC, while fibrous specimens maintained their integrity up to a temperature of 750 ºC.

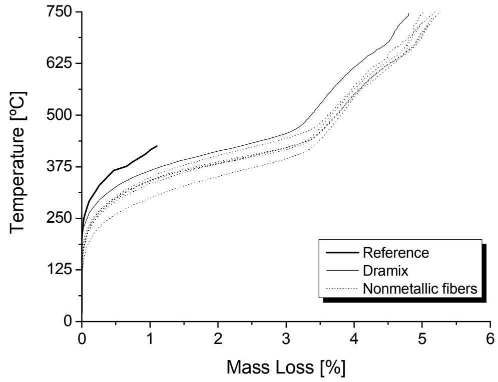

Figure 1: Mass loss (heating phase)

INFLUENCE OF HIGH TEMPERATURES ON THE MECHANICAL PROPERTIES OF THE DEVELOPED FRCEFR

The tests were executed at 28 days after FRCEFR having been exposed to the following levels of temperature: 250 ºC, 500 ºC, 750 ºC and 1000 ºC. One (PP1) and two (PP2) kg per concrete m^3 of PP Duro-Fibril fibers were used to manufacture the tested specimens. A content of 60 kg/m^3 of Dramix® ZP 305 hooked ends steel fibers was used in all compositions. The exposure to the 1000 ºC level of temperature led to the destruction of the concrete specimens, therefore the residual behavior of these specimens was not possible to obtain. The variation of the Young's modulus, compressive and flexural strength with the variation of the target test temperatures are shown in Fig. 2 and 3. The flexural tests were carried out according to the RILEM TC 162 TDF recommendations for the determination of the equivalent residual strength parameters, $f_{eq,2}$ and $f_{eq,3}$ that characterize the concrete flexural post-cracking behavior. From these tests the influence of the maximum temperature on peak load, F_P, was also evaluated. The obtained results, shown in Fig. 4 (PP2), reveal that up to 250 ºC the values of these parameters increased, but after this level of temperature they decreased significantly.

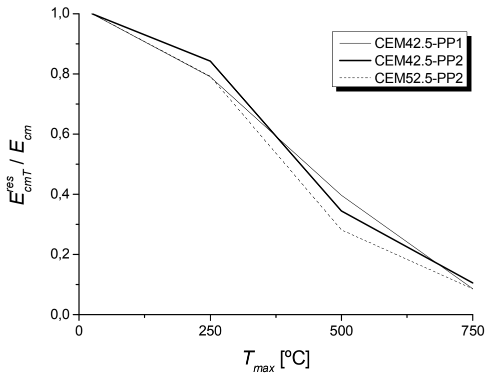

Figure 2: Influence of T_{max} on the Young's modulus

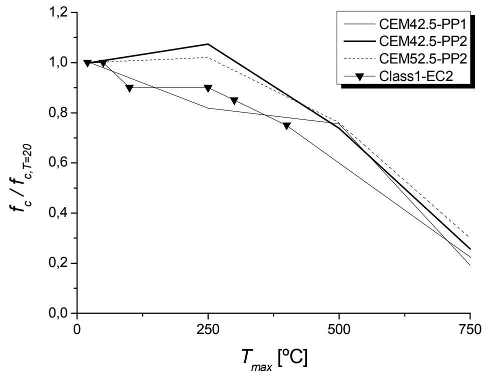

Figure 3: Influence of T_{max} on the compressive behavior

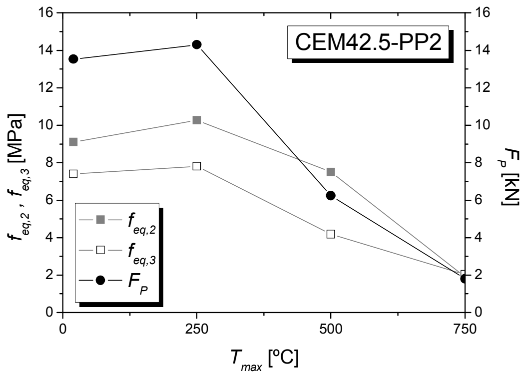

Figure 4: Influence of T_{max} on $f_{eq,2}$, $f_{eq,3}$ and F_L.

INVERSE ANALYSIS TO ASSESS THE INFLUENCE OF THE TEMPERATURE ON THE FRCEFR FRACTURE PARAMETERS

Based on the force-deflection curves obtained in the three point beam bending tests with FRCEFR specimens subjected to distinct levels of maximum temperature, an inverse analysis was carried out to evaluate the influence of the maximum temperature on the values that define the crack stress-strain diagram that simulates the post-cracking behavior of the tested FRCEFR. A trilinear stress-strain diagram was used to simulate the crack opening and propagation when using smeared crack models implemented into a FEM-based software. The trilinear post-cracking diagrams that have best fitted the experimental force-deflection curves (Fig. 5) are represented in Fig. 6.

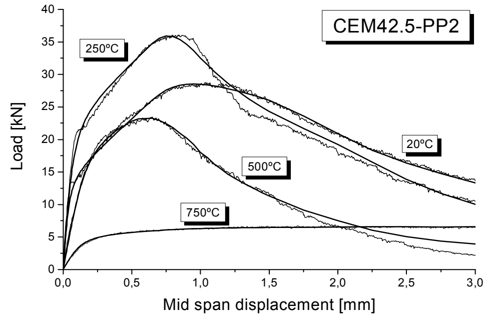

Figure 5: Inverse analysis

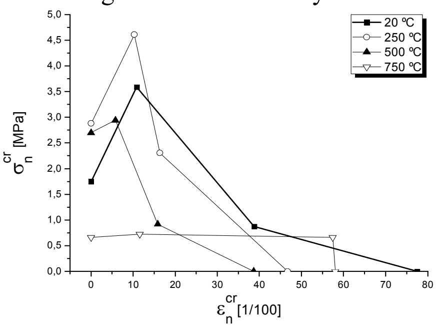

Figure 6: Influence of T_{max} on the constitutive law that simulates the crack initiation and propagation

CONCLUSIONS

From the obtained results it can be concluded that all used nonmetallic fibers can improve the concrete fire resistance, since explosive spalling was avoided. However, only PP fibers allowed a satisfactory and easy fibre distribution into concrete. Using 1 kg/m^3 of PP fibers, explosive spalling was avoided. Increasing the PP fiber dosage from 1 to 2 kg/m^3 the concrete residual behavior was not significantly improved.

LÚCIO LOURENÇO is currently pursuing his PhD at the ISISE, Dep. of Civil Engineering, UMinho. His main interests are the development of fiber reinforced concrete of enhanced fire resistance, material and structural characterization from experimental research, and numerical simulation by FEM analysis.

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