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ULTRA-HIGH PERFORMANCE CONCRETE-INFLUENCE OF THE STEEL FIBER REINFORCEMENT

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Abstract : *The paper presents the influence of the steel fibers reinforcement types on the physical-mechanical properties of the ultra high performance concrete (UHPC). This new fiber reinforced cementitious composite is analyzed towards composition no- reinforced concrete and fiber reinforced concrete using : first, hooked end long fibers with a diameter of 0.4mm and 25 mm in length and second, a mix of long fibers and short straight fibers 0.16mm in diameter, 6mm in length. The physical-mechanical properties that were investigated comprised elastic modulus of elasticity, compression strength and stress-strain curves.*
Keywords : *UHPC, fibers, compression, modulus, stress-strain*

1. INTRODUCTION

Ultra-high performance concrete (UHPC) is a cemetitious composite with compression strength that exceeds 150 MPa, tensile strength over 7 MPa and low porosity [1,2]. The durability and mechanical characteristics are due to the improved homogeneity of the composition by replacing the coarse aggregates with very fine sands and quartz powder [3]. The composition is also characterized by the use of silica fume, large quantities of cement, small water / binder (w/b) ratios and the use of superplaticizers. The UHPC matrix exhibits brittle behavior and micro-cracking tendency due to high autogenous shrinkage and for that reason, steel or organic fibers are added in the concrete composition. [4] [3].

2. EXPERIMENTAL PROGRAMME

2.1. Materials, mixing and curing procedure

The concrete used in this study was designed within an vast experimental research regarding ultra-high performance concrete conducted by prof.dr. C Magureanu (Technical University of Cluj-Napoca, Romania). The concrete composition and fresh concrete properties can be found in [6]. The designed concrete used mostly locally available materials in order to reduce the costs and to see if suitable for producing ultra-high performance concretes. The composition comprised quartz sands (Somes Valley, Cluj County, Romania) with an maximum particle size of 1.2mm, large quantities of Portland cement type CEM I 52.5 R (producer Lafarge Romania) and silica fume (imported). The large quantities of binder required last generation superplasticizers (producer BASF Romania) to ensure suitable flowability and a small water/binder ratio. The concrete matrix was fiber reinforced using two types of steel fiber: long hooked end fiber with length/diameter=25/0.4mm (Figure 1), short straight fiber with l/d=6/0.175mm (Figure 2).

Figure 1: Long hooked and fibers

Figure 2: Short straight fibers

From the reinforcement point of view three types of concrete were used for the determination of hard concrete properties: (a) non-reinforced concrete (UHPC); (b) 2.55 Vol.% long fiber reinforced concrete (UHPFRC-L); (c) 2.55 Vol.% hybrid reinforced concrete (50% short fibers+50% long fibers) (UHPFRC-H). The concrete was produced using a 85 l mixer. After mixing the concrete was cast and the specimens were covered with a thin oil film to prevent evaporation. The specimen were demolded after 24 hours and subsequently were subject to steam curing regime (80% RH, 90C) for 6 days.

2.2. Testing methodology

Properties of the hardened concrete were tested at the age of 6 days, immediately after the steam curing finalization. The mechanical properties were tested using a computer controlled testing machine type Advantest 9 with a capacity of 3000 kN. The computer control permitted an accurate measurement of both load and displacements. The concrete was tested for elastic modulus of elasticity, compressive strength and strain-stress curves in compression.

The elastic modulus was tested using 100x100x300mm prismatic specimens as secant modulus. The tested specimens were loaded at stress levels of 0.4 fc (compressive strength). The compressive strength (fc) was previously tested on same type specimens (100x100x300mm prism). The loading-unloading cycles were performed with a speed of 2 MPa/s. This relatively large speed is necessary having in mind the ultra-high strengths of this concretes, which can exceed 150 MPa. A general view of a specimen setup for elastic modulus determination is displayed in Figure 3.

Figure 3: Elastic modulus setup

The compressive strength and stress-strain curves in compression were tested using 50x50x50mm cubes. The cube dimension are smaller than those used for normal strength concrete, but are justify having in mind the small particle size (0…1.2 mm) of the ultra high concretes components. The 50mm base length is much larger than the minimum required which is generally 4 times the maximum particle size. The compression test were performed at a load rate of 2 MPa/s.

3. RESULTS AND DISCUSSIONS

The modulus of elasticity in compression (Ec) results are plotted in Table 1 for non reinforced concrete (UHPC), long fibers reinforced concrete (UHFRC-L) and hybrid reinforced concrete (UHPFRC-H). The results are the average of 5 tests for each type of concrete. The results showed that the influence of fibers on the modulus of elasticity is small. The fiber addition increased the elastic modulus by 4.6% for the long fibers and by 2% for hybrid fibers when compared with non-reinforced concrete. The small difference between non-reinforced concrete and reinforced concrete in terms of elastic modulus could be due to the stress level used in this tests (0.4 fc). The fibers contribution, as can be seen in compression tests, is more prominent at higher levels of load.

Table 1: Modulus of elasticity in compression

Composition	E [MPa]
UHPC	41 255
UHFRC-L	43 162
UHPFRC-H	42 077

The compressive strength results are plotted in Figure 4. The results represent the average of minimum 10 specimens for each concrete composition. The results show that compressive strength increases by approximately 13% for both types of reinforced concretes (UHPFRC-L, UHPFRC-H), when compared with non-reinforced concrete (UHPC). There seems to be no difference in terms of compressive strength between hybrid reinforcement and long fibers reinforcement.

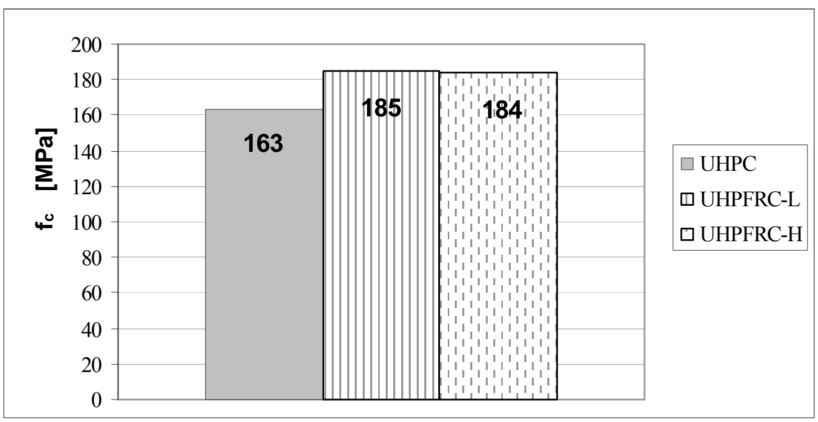

Figure 4: Compressive strength of 50x50x50mm cubes (age 6 days)

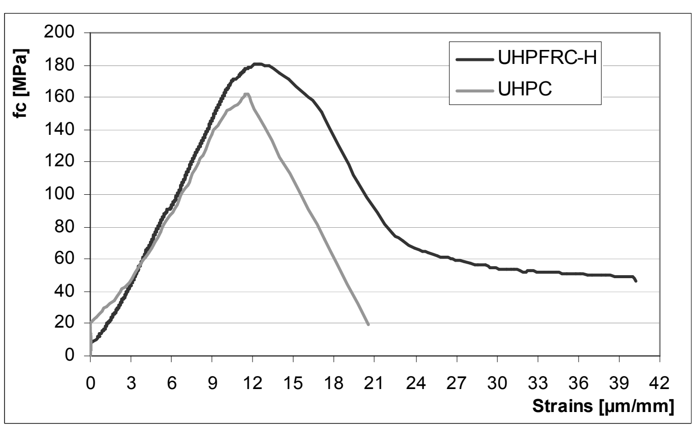

Figure 5: Compressive strength of 50x50x50mm cubes (age 6 days)

The concrete reinforced with long fibers (UHPFRC-L) exhibited a similar behavior to that of hybrid reinforced concrete (UHPFRC-H), therefore the stress-strain curves in compression are displayed only for UHPFRC-H and UHPC (Figure 5). The non-reinforced concrete (UHPC) and the fiber reinforced concrete (UHPFRC-H) behaved in linear-elastic manner almost until the maximum stress was reached. Afterwards, the fiber reinforced concrete displayed an ductile behavior with large deformation in contrast with non-reinforced concrete which exhibited a brittle behavior with an sudden failure. A general aspect of the two types of failure is displayed in Figure 6 for the fiber reinforced concrete and in Figure 7 for non-reinforced concrete.

Figure 6: UHPFRC-H failure

Figure 7: UHPC failure

3. CONCLUSIONS

Ultra-high performance concrete displayed a modulus of elasticity between 41 and 43 GPa for both non-reinforced and for fiber reinforced concrete. There seems to be no influence of the type of reinforcement, hybrid fibers or long fibers, on elastic modulus.
The compressive strength of both fibers reinforced concretes increased with 13% compared to non-reinforced concrete
The influence of fibers is more obvious in the post-peak behavior: non reinforced concrete displayed a brittle behavior in contrast with fiber-reinforced concrete which displayed a ductile behavior.

4. ACKNOWLEDGEMENTS

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