Crack Formation in Cement-Based Composites

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Abstract. The cracking properties in cement-based composites widely influences mechanical behavior of construction structures. The challenge of present investigation is to evaluate the crack propagation near the crack tip. During experiments the tension strength and crack mouth opening displacement of several types of concrete compositions was determined. For each composition the Compact Tension (CT) specimens were prepared with dimensions 150x150x12mm. Specimens were subjected to a tensile load. Deformations and crack mouth opening displacement were measured with extensometers. Cracks initiation and propagation were analyzed using a digital image analysis technique. The formation and propagation of the tensile cracks was traced on the surface of the specimens using a high resolution digital camera with 60 mm focal length. Images were captured during testing with a time interval of one second. The obtained experimental curve shows the stages of crack development.

1. Introduction

The development of new types of concrete focuses on High Performance Fiber-Reinforced Cement Composites (HPFRC). Fiber-Reinforced Concrete (FRC) is a composite material in which certain characteristics are developed for a particular application and environment. These characteristics are not only strength, but improved durability, increased resistance to various external agents, high rate of hardening, better aspect, etc. This concrete is characterized by an enhanced postcracking tensile residual strength, also defined as toughness in the following, due to the fiber reinforcement mechanisms provided by fibers bridging the crack surfaces. Fibers in concrete provide improved mechanical and physical properties of the material [1, 2].

The durability and deformation characteristics of a material are just as important as its strength properties. Therefore, designers and engineers need to know those properties of concrete and must be able to take them into account in the structure analysis [2, 3].

This paper reports on an experimental investigation of the cracking resistance of several types of HPFRC using the Compact Tension test.

2. Experimental program

The experimental work included the preparation of two HPFRC compositions with polyvinyl alcohol (PVA) fibers constituting 2% of the total amount of cement with and without nanosilica. The HPFRC mixtures consisted of cement, water, quartz sand (grain size 0.3 - 1 mm), silica fume, nanosilica, microsilika, plasticizer Sikament and two types of PVA fibers. PVA fiber properties are listed in Table 1. For the purposes of this paper the batches containing microsilika were designated MS PVA and the ones containing microsilika and nanosilika – NS PVA [4].
The testing procedure developed for the present work consisted of applying a tensile load to a single-edge notched specimen. The selected specimen shape resembles the one used for the evaluation of crack propagation behavior in metals (ASTM-E647 2005) [5], the so-called Compact Tension (CT) specimen. With the purpose of maximizing the stress intensity at the tip of the notch, the notch thickness was reduced to 0.5 mm using a small diamond cutting disc. The depth of the specimen was also reduced, promoting the plain stress state. Summarizing, the dimensions adopted for the specimens were 150 mm by 150 mm (perpendicular and parallel to the notch) and 12 mm (thickness). The available path for progress of the initiated crack parallel to the notch was 30 mm. The distance between the loading axis and the tip of the notch was also 50 mm (see Figure 1).

The testing sequence consisted of subjecting the specimens to a tensile load at a constant displacement rate, transmitted by two rods with a diameter of 20 mm (see Figure 2). The use of the two rods allowed the transmission of the displacement while keeping free the rotation of the specimen with respect to the rods. The adopted displacement rate was 1 μm/s [6].

The formation and propagation of the tensile crack was traced on the surface of the specimens using a high resolution digital camera positioned 70 mm away from the specimen. The lens with a 60 mm focal length allowed the observation of a 36 mm by 24 mm area on the surface of the specimen (see Figure 2). Shooting settings – lens aperture F11, shutter speed 1/30, ISO 200. Images with a 24 megapixel resolution were captured during testing at an interval of one second. These images were subsequently used for conditions for the strain field interpolation were met with the need of applying a speckle pattern on the surface of the specimen.

To experimentally measure the deformation during the CT tests the ARAMIS software was used.

In the present case, fluorescent lights were used and positioned in such a way that the intensity of the light reflected by the specimen surface was even. The images of the surface of the specimens were
analyzed prior to testing and sufficient image correlation was obtained. Each facet was composed of 15x15 pixels. Each pixel covered a real area of 6x6 μm2. The total area of 36x36 mm2 was modeled by a facet mesh overlay composed of approximately 400x260 facets [6].

Before testing, to measure crack mouth opening displacement (CMOD), the extensometer with precision +/-2.5 mm was centrally and symmetrically positioned at the edge of the test plate’s notch.

3. Results and Discussion
The “cocktail” of two types of PVA fibers exhibited different behavior in HPFRCC. The main role of short dispersed fibers was to control the opening and propagation of small cracks, whereas long fibers control the large cracks and serve as a bridge between the two sides of the crack [1]. Figure 3 shows the behavior of short and long fibers and the experimental load – crack mouth opening displacement (CMOD) curves are presented.

Several stages of HPFRCC behavior can be identified. The first stage 0A (from zero to about 60-80% of peak load) corresponds to the ascending linear elastic portion of the curve where the section is not cracked. The second stage AB (from about 60-80% of peak load to peak load) corresponds to the portion of the curve where cracking starts and during which crack formation stabilizes and the specimen reaches its peak load. A peak point – B where the maximum resistance is attained. The third stage BC (from peak load to about 60% of peak load) correspond to the portions of the curve where strain softening starts and where the load–strain curve response is almost linear elastic and crack widths increase and the fourth stage (from C to the end) is a non-linear portion where either or both materials are in their non-linear range and crack widths continue to increase (according to Naaman [7]).

![Figure 3. Load – CMOD curves measured during testing](image)

The experimental results (see Figure 3) are quite similar and they indicate that nanosilica does not have significant influence on the tensile load and CMOD properties of HPFRC. The average tensile load for NS PVA specimens was 570 N and CMOD was 0.57 mm respectively. The average tensile load for MS PVA specimens was 613 N and CMOD was 0.59 mm.

The Figure 4 shows the crack visibility to the human eye and by the system "Aramis". By human eye crack is visible when specimen is already collapsed but system “Aramis” allows the observation of how the cracks initiate and propagate in specimen. The crack becomes clearly visible, although their openings are very small. Detailed information about those experiments look for [4].
4. Conclusion
Two High Performance Fiber-Reinforced Cement Composite (HPFRCC) mixes with polyvinyl alcohol (PVA) fibers containing 2% of the total amount of cement by weight with and without nanosilica were prepared for a laboratory examination. The tensile load and the cracks mouth opening displacement (CMOD) were determined.

The experimental study indicates that nanosilica does not have significant influence on the HPFRCC tensile strength and on the CMOD properties.

Wider use of this material permit the construction of sustainable next generation structures with thin walls and large spans that cannot be built using the traditional concrete.

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