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Crack Development Research in Extra Fine Aggregate Cement 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.**

Keywords: **cement-based matrix, fibre reinforced concretes, high performance concretes, PVA fibres.**

I INTRODUCTION

The development of new types of concrete focuses on Extra Fine Aggregate Cement Composites (with the largest aggregate dimension ≤ 5 mm) (EFACC). It 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 EFACC using the Compact Tension test.

II MATERIALS AND METHODS

The experimental work included the preparation of two EFACC compositions with polyvinyl alcohol (PVA) fibers constituting 2% of the total amount of cement with and without nanosilica. The EFACC 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 microsilica were designated MS PVA, and the ones containing microsilika and nanosilica - NS PVA [4].

TABLE 1
PROPERTIES OF PVA FIBRES

Fibre type	Ø [μm]	L [mm]	f_t [GPa]	E [GPa]
MC 40/8	40	8	1.6	42
MC 200/12	200	12	1.0	30

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, see Figure 1.

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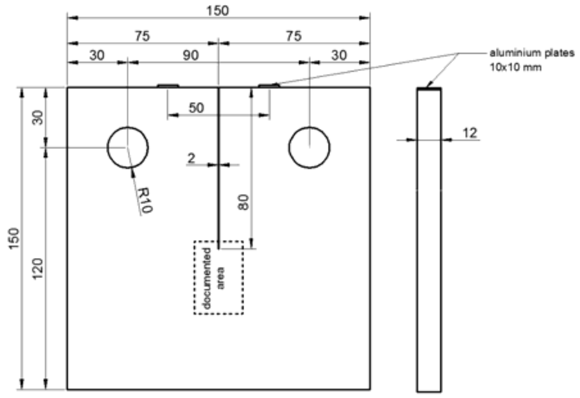

Fig. 1. Geometry of the Compact Tension (CT) specimen

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 2).

Fig. 2. Preparation of Compact Tension specimens

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 3). 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 1μm/s [6].

Fig. 3. Determination of tensile strength and uniaxial tensile crack development research

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 3). 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 continuous interpolation of the strain fields at the inspected surface of the specimen. Optimal 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 μm^2. The total area of 36x36 mm^2 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.

III RESULTS AND DISCUSSION

Experimental durability tests clearly prove and confirm the hypothesis that by applying fiber “cocktail” higher material behavior and destruction effectiveness is reached than when using only one type of fibers, as every length (type) of fibers has their own function: the short fibers strengthen cement matrix and perform clamping of long fibers, but long fibers connect large cracks, making a fiber bridge between edges of cracks [1] and does not allow brittle, instant failure of cement composite, which is extremely important in exploitation of load-bearing structures. Figure 4 and 5 show relationship of tension load and crack mouth opening displacement of several types of EFACC.

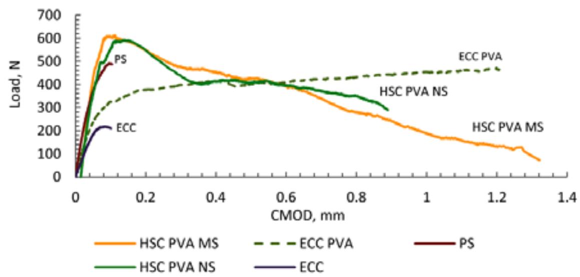

Fig. 5. Tensile strength and crack mouth opening displacement (CMOD) of different kind of cement composites

Several stages of EFACC behavior can be identified, (see Figure 4).

The Figure 6 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]

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]).

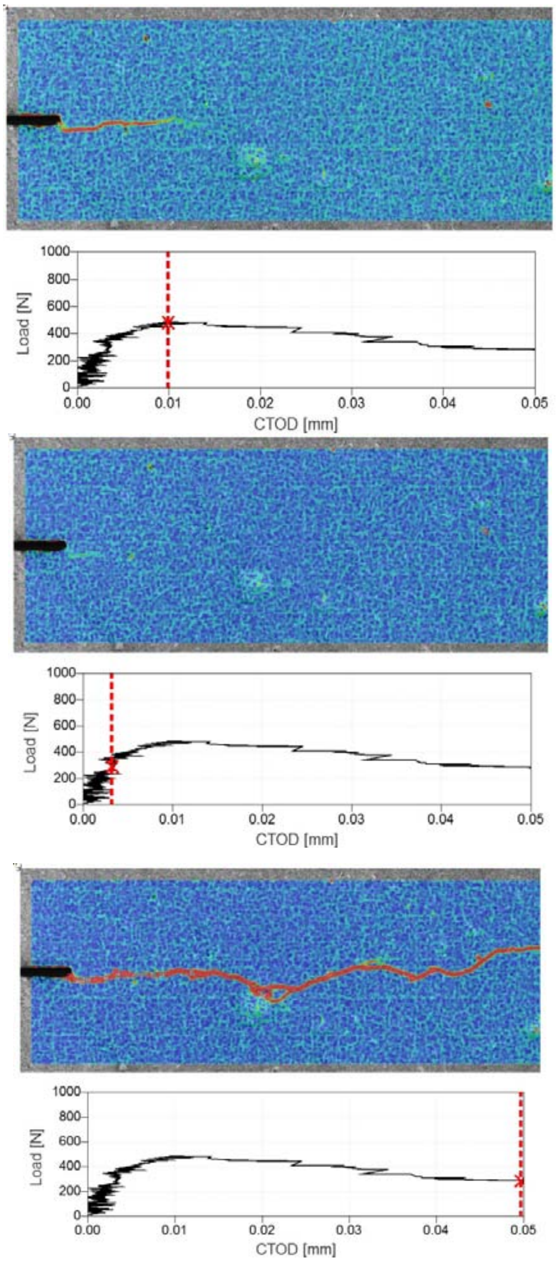

Fig. 4. Crack development of cement composite with nano silica mineral filler and the "cocktail" of two types of PVA fibers by using digital image-based monitoring system "Aramis"

IV CONCLUSIONS

Two Extra Fine Aggregate Cement Composites (EFACC) 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 EFACC 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.

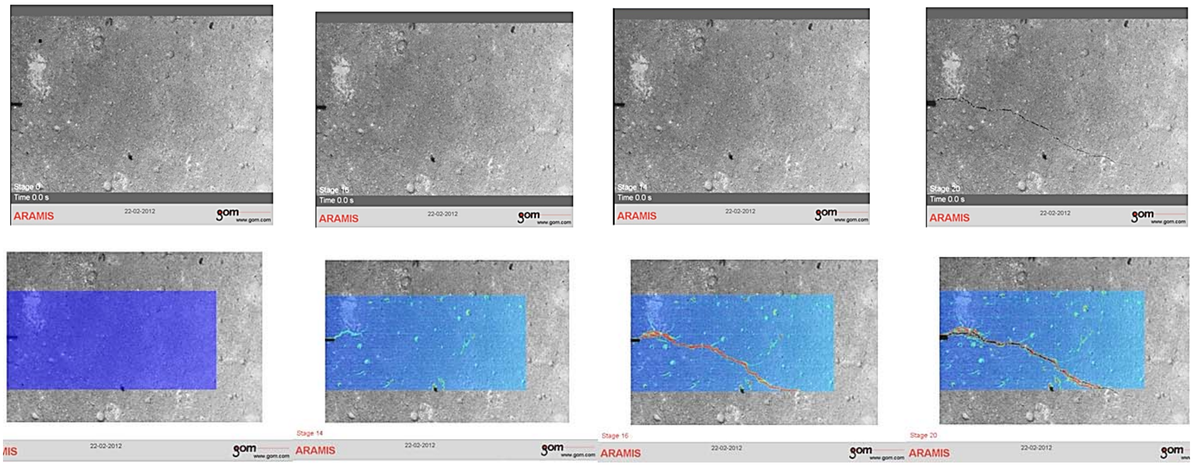

Fig. 6. Crack visibility to the human eye and by system "Aramis"

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