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Using Digital Image Correlation for Investigation of Low-Strain Fiber Concrete Cracking

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Abstract: The purpose of this paper is to illustrate the capabilities of Digital Image Correlation (DIC) used for determining of crack evolution process in fiber-reinforced concrete. The study clearly demonstrates that modern measurement tools, such as DIC can provide much more valuable and accurate results compared to conventional measurements. Using DIC the development of cracks at low-strain levels was captured at relatively low computational and financial costs.

Keywords: Fiber Concrete; Digital Image Correlation; DIC; Micro-Cracks; Strain Field.

1 Introduction

Fiber-reinforced concrete (FRC) contains fibrous material which increases its structural strength and reduces shrinkage induced micro-cracking [2, 11]. It has also a positive impact on the moisture transport properties, which in turn have the major influence on durability and integrity of a structure. For instance, high permeability provides an ingress for water, chlorides and other corrosive agents and consequent corrosion of steel bars. These properties predispose the usage of FRC in special applications such as waterproofing layers used for protection of basements, tunnel shells or heavy loaded industrial floors. The most important requirement on FRC is the crack width, because it primarily affects waterproof capability and consequent penetrating of pollutants into the structure. Building codes specify a maximum crack width in order to ensure mechanical structural integrity.

Experiment loading of FRC specimens by means of four-point-bending destructive tests can provide standard stress-strain (or rather force-displacement) diagrams, but investigation of the full-field displacements and consequent cracking mechanism is not feasible by means of conventional tools, such as strain gauges or LVDTs. Measurement of the deformation on the whole surface requires employing optical monitoring, such as DIC.

2 Digital Image Correlation

Digital image correlation is an effective and practical tool for full-field deformation measurement, which has been commonly accepted and widely used in the field of experimental mechanics. In essence, DIC is an image-based deformation measuring technique based on digital image processing and numerical computation. It directly provides full-field displacements and strains by comparing the digital images of the specimen surface obtained before and after deformation. DIC is non-contact optical technique based on tracking deformation and displacement of a heterogeneous pattern applied on a flat sample surface [6]. The DIC measurement system was developed by Peters and Ranson [9] at the University of South Carolina in the 1980s. At the beginnings the DIC suffered from insufficient computational power, but today together with development of efficient computational algorithms [7] led to high versatility of this method namely macro-level problems, such as formation of cracking various patterns in masonry walls [1, 10], to investigate deformation of textiles [4] or fatigue failure of polymer materials [12].

3 Experimental Analysis

Cement paste with w/b = 0.4, using CEM I 42.5R containing 2 % by mass of polymer micro-fibers were added. Six specimens with standard dimensions of 160 × 40 × 40 mm were cast into prismatic molds (one was reference sample - without fibres) and cured at relative humidity of 60 ± 10 % and 20 ± 2 °C for two days and then submerged in water for 28 days. Experimental analysis consisted of four-point-bending tests, and deformation fields were monitored using planar DIC (DIC-2D) method. Black dots were randomly sprayed onto the surface, see Fig. 1 for details. The distribution of the dots, such as size and density, was chosen based on previous experience and literature study [1,8].

The tests were displacement-controlled, the rate of loading was set to 0.020 mm min^{-1} and the monitoring of applied force was accomplished using MTS Alliance RT 30 kN load cell. Acquisition of digital images was carried out by high-resolution digital DSLR camera Canon EOS 70D equipped with EF-S 18-135 mm f/3.5-5.6 IS STM zoom lens and the shots were taken every five seconds. Location of camera was chosen in 60 cm distance from the monitored surface. To avoid any major distortion of the results, the camera had to be placed parallel to the specimen surface and in line with the specimen axes and the focal length was set to 55 mm. To ensure required light conditions, two powerful 20 W LED spotlights were used. The shots were taken in 5-second intervals during the entire test.

4 Evaluating Results

Images were saved into RAW ($.CR2$) file format. Shooting in RAW file format was chosen in order to avoid noise and the possibility of subsequent adjustments of white balance. Images were processed by Adobe Photoshop Lightroom 5.5, namely 8-bit gray-scale transformation, white balance and slight contrast changes were carried out. Export was done without any size compression, dimensions of digital images were 5472 × 3648 px. Independent monitoring of displacement was done by one LVDT which was attached in the midspan of the testing beam. Fig. 2 shows the results of all tests - one sample was eliminated, because of visible damage was present.

Evaluation of images for purpose of DIC analysis was done by Ncorr [3] DIC tool and the post-processing was carried out using Ncorr_post tool [5].

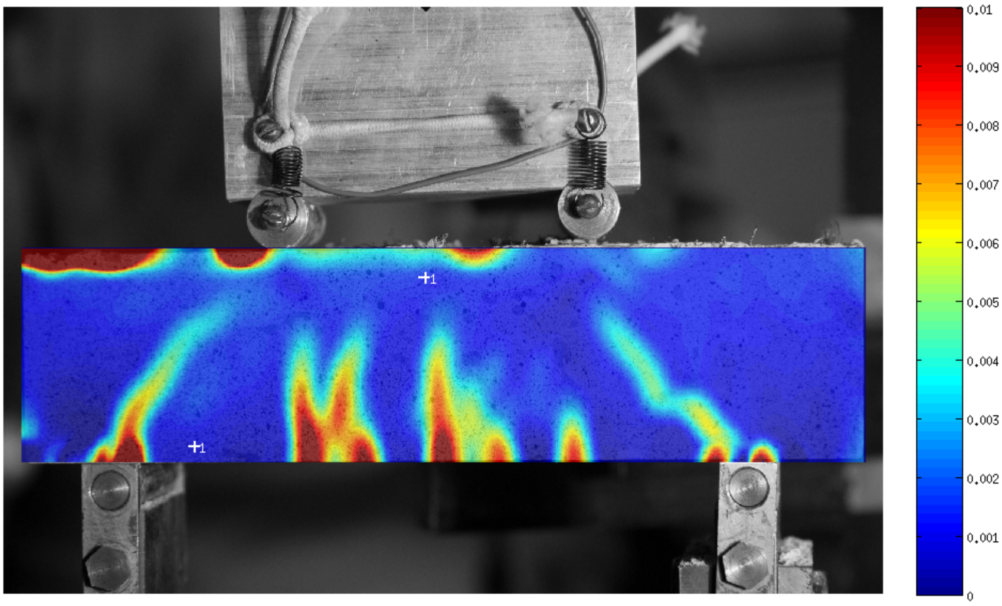

Fig. 1: Map of maximum principal strain, development of smeared cracks.

5 Results and Discussion

The full-field displacement monitoring using DIC allows bridging the gap between calculations using finite element codes and experimental analysis. The results of the analysis (Fig. 1, 2) indicate that DIC-2D is capable

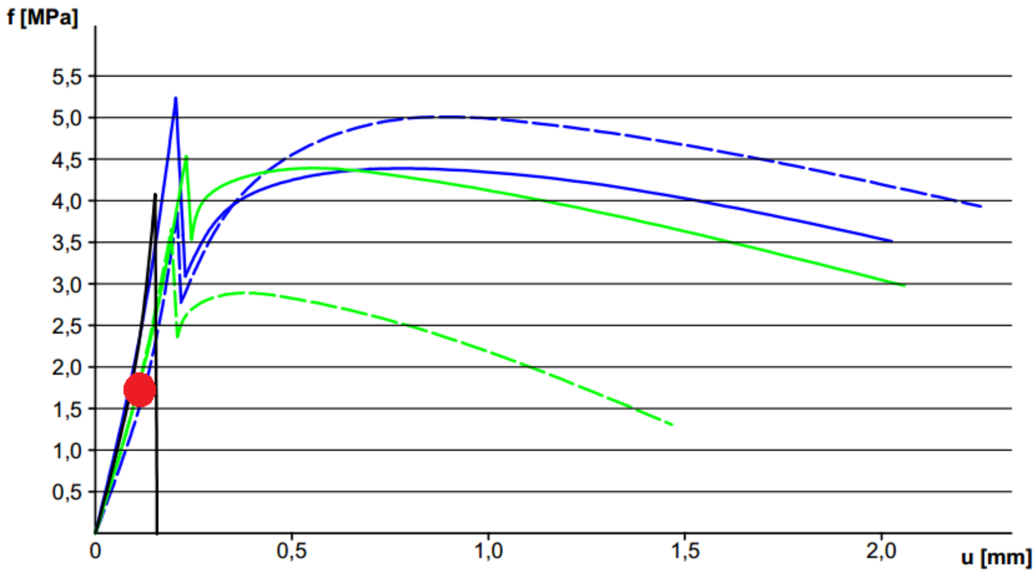

Fig. 2: Force-displacement diagram for all samples with fibres (in colors) and reference sample (black). Red dot indicates a growth of micro-cracks, as indicated in Fig. 1 growth observable by DIC.

of full-field displacement measurements and enables to effectively observe the strain localization and crack initiation, as demonstrated on the four-point bending tests of FRC. The results provide detailed information about localized crack-growth evolution, and the crack width can be measured using virtual extensometers. Such data can be efficiently used for verification of numerical models dealing with crack growth in FRC under external load.

The image-acquisition frequency must be adjusted individually to capture the development of rapid crack development as was the case of the non-reinforced reference specimens. The development of high-frame-rate cameras could further contribute to the use of DIC in experimental investigation of material behavior.

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