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Internal Structure Formation in High Strength Fiber Concrete during Casting

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Abstract**—**Post cracking behavior and load –bearing capacity of the steel fiber reinforced high-strength concrete (SFRHSC) are dependent on the number of fibers are crossing the weakest crack (bridged the crack) and their orientation to the crack surface. Filling the mould by SFRHSC, fibers are moving and rotating with the concrete matrix flow till the motion stops in each internal point of the concrete body. Filling the same mould from the different ends SFRHSC samples with the different internal structures (and different strength) can be obtained. Numerical flow simulations (using Newton and Bingham flow models) were realized, as well as single fiber planar motion and rotation numerical and experimental investigation (in viscous flow) was performed. X-ray pictures for prismatic samples were obtained and internal fiber positions and orientations were analyzed. Similarly fiber positions and orientations in cracked cross-section were recognized and were compared with numerically simulated. Structural SFRHSC fracture model was created based on single fiber pull-out laws, which were determined experimentally. Model predictions were validated by 15x15x60cm prisms 4 point bending tests.

Keywords**—**fibers, orientation, high strength concrete, flow

I. INTRODUCTION

COMMERCIALLY produced steel fibers, having length in a range from 0.6 cm to 6 cm and various types of geometrical forms andcrossection’sshapes, are widely used nowadays in civil engineering industry, as the concrete disperse reinforcement.High strength concrete reinforced bysteel fibers (SFRHSC) is demonstrating high flexural and tensile strength, impact resistance as well as a quasi ductile behaviorin cracked phase. At the same time SFRHSC tensile (as well as bending) strength and post cracking behavior is highly dependent on a fiber distribution and orientation inside the material [1-4]. Important is to recognize and be able to predict the potential internal zones with undesirable fiber orientation and spatial distribution in the volume of the construction member, in the case of traditional casting technologies use,without additional fiber placing and orientation control [5-7,11]. This task can be solved in opposite way- creating internal SFRHSC structure (fibers distribution and orientation [8, 9] during the casting procedure. In the present investigation SFRHSC casting was investigated numerically (viscous flow FEM approach was used) . Simultaneously single steel fiber rotation and motion in the flow with internal velocity gradients were investigated experimentally and numerically (using FEM) [10]. And finally crack opening process in SFRHSC prism subjected to 4 point bending conditions was modeled and was investigated experimentally.

II. FIBRE ROTATION IN VISCOUS FLOW WITH VELOCITY GRADIENT

Single fiber motion in viscous flow with velocity gradient was simulated experimentally (using model liquid -potato-starch fluid with known viscosity parameters) and numerically (using FEM code FLOW 3D). Viscosity coefficient values were obtained experimentally by dropping metal ball method [10]. The potato-starch liquid with known viscosity coefficient was poured into the transparent container. Single steel 50 mm long and 1mm in diameter fiber was inserted in the container middle part (with fluid) under the different starting angle to the vertical axis (fluid was so viscous then the fiber angle change from the fiber placing moment till the test start was negligible). In initial position the container was placed fully horizontally (see Fig.1 left picture).

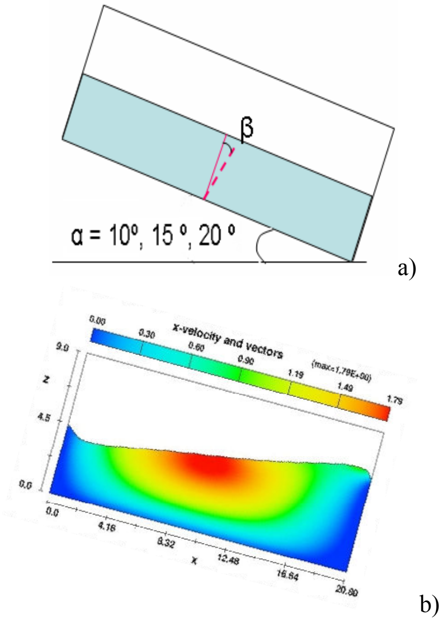

Fig. 1 Experimental single fiber motion in viscous flow: a) experiment; b) viscous fluid flow velocity (along the container) modeling result (FEM code Flow 3D simulation)

Then container was turned sideways from the horizontal position for required angle $\alpha$and test started. Fiber position and declination angle βat every time moment are influenced

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by the movement of the fluid. Movement of the fiber in the fluid was recorded by video-camera with a timer (in such way fiber position and declination angle β were measured and recorded in the time). In experimentsthree angleα - 10°, 15°, 20°values were used.

III. Viscous Fluid Numerical Simulation Single Fiber Horizontal Speed and Rotation Angle Dependence Of The Velocity Gradient

Above mentioned experiment was numerically simulated using computer program FLOW-3D. Calculation result for initial angle α=10° and time moment from the beginning of the test t= 3 sec. isshown in Fig.1 right picture.Container parameters was (the same as in the experiment): length l=20,8cm, height h=9 cm, and the height of viscous fluid in the container 5 cm. The viscosity coefficient was η=486.14 g/cm·s, andpotato-starch liquid density was ρ=1 g/cm^3. Numerically calculated horizontal speed gradient values (in the vertical plane crossing the midpoint of the fiber) for our experiments are shown in Fig.2, and numerically simulated corresponding fiber declination history (fitted to experiments) in Fig.3.

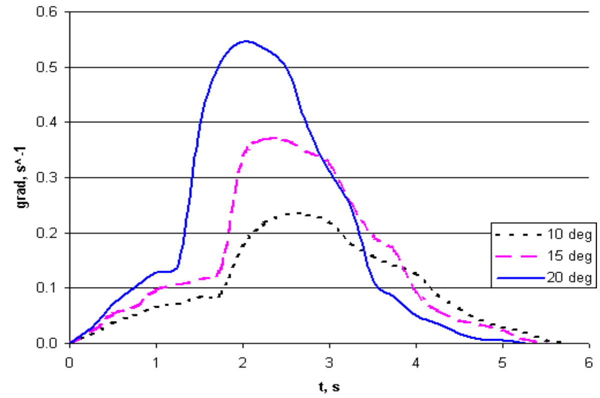

Fig. 2 Speed gradient change in the time after container was placed with declinations for 10°, 15°, 20°degrees

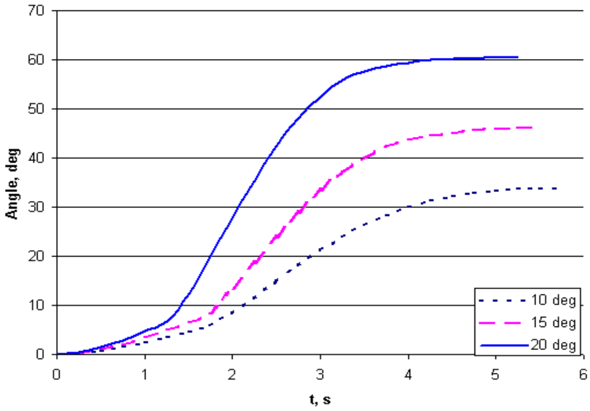

Fig. 3 Fiber angle change after declinations of container for 10°, 15°, 20°degrees

Observing forces acting on the fiber in the flow with velocity gradient was made decision about possibility to conclude that the gradient of horizontal speed (1) between our observed fiber endpointscan be the parameter which will establish fiber orientation (and rotation speed) in the flow (simplified version of Jeffery [6,7,11] approach in the case of planar flow with low Reynolds parameter value). Similar approach was used for single fiber in the concrete flow.

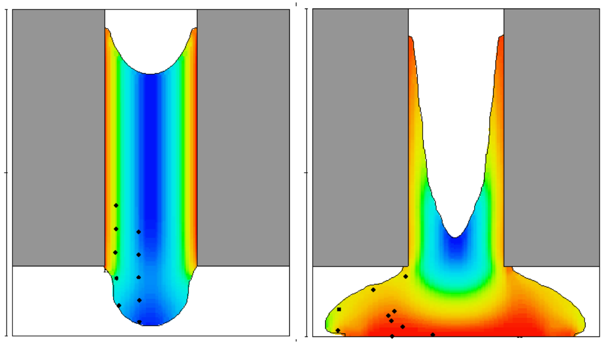

Fig. 4 FEM concrete casting process modeling.Marked points motion in concrete during casting

IV. VELOCITY GRADIENTS DETERMINATION DURING SFRHSC CASTING

Filling the mould by SFRHSC, fibers are moving and rotating in the concrete flow till the end of motion in every concrete body internal point. Performing rigid fibers motion in viscous flow traditionally is numerically simulating using Jeffery formulas [6,7,11]. In our investigation above mentioned simplified Jeffery approach was executed with the goal to recognize fibers distribution and orientation in the concrete sample after casting. The mould parameters was 15x15x60 cm, width of the flow (or falling flow cross-section dimensions) is 20x15 cm. The 2D and 3D modeling were performed (FLOW3D code was used). Newtonian fluid 2D flow modeling results are shown below. This is the case when mould is filling by SFRHSC flow falling at the middle of the mould. The viscosity coefficient was η=5000 GPa·s, liquiddensity - ρ=2400 kg/m^3. Point markers were placed into the fluid for all flow

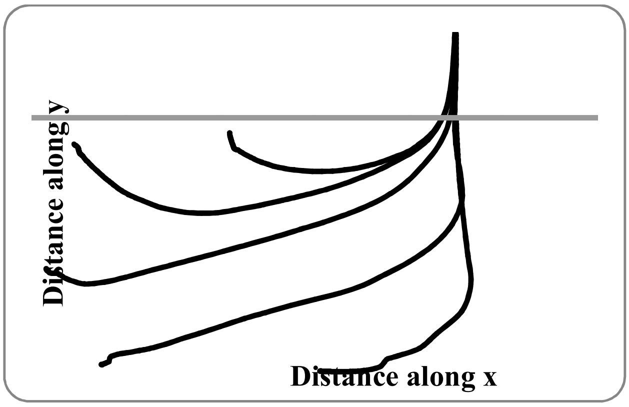

Fig. 5 Trajectories of marked points in the concrete flow during filling the mould

process visualization (every marker can be observed as the particular single fibers midpoint path in concrete body during the casting (see Fig.4). In Figure 5 are shown five marked points trajectories in concrete during filling the mould (till the concrete flow stop in every point). According to symmetry of the process only one half of the mould (and falling SFRHSC flow) is shown, horizontal coordinate x=0 corresponds to left border of the mould, vertical coordinate y=0 corresponds to the bottom of the mould.

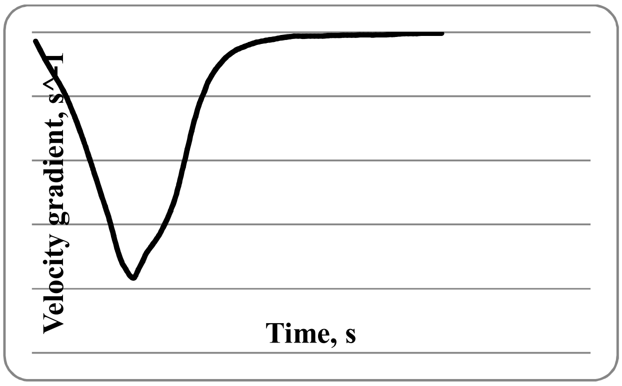

Fig. 6 Velocity gradient in the concrete flow during filling the mould (20<x<25 cm, y=7.5 cm)

Numerical simulations were performed changing the place were external flow is falling to the mould. Calculated vertical velocity gradients in the SFRHSC filling the mould were obtained and were analyzed (velocity gradient picture is shown at Fig.6), critical zones in the concrete prism body with high velocity gradients obtained during mould casting were recognized.Fibers orientation function was used.Fibers spatial orientation function was highly different from random (oriented along fibers flow) in critical zones. Orientation parameter was introduced.

V.SFRHSC FIALURE UNDER 4 POINT BENDING

A SFRHSCprism with two variants of internal structurewas numerically investigated. In the first case fibers were supposed are chaotically oriented and spatially distributed in the volume (Monte-Carlo method was used). In the second case fibers orientation and distribution were corresponded to situation of critical zone formation in the concrete sample (numerically simulated bySFRHSC flow (as is mentioned earlier in this paper). Structural failure model for SFRHSC prism subjected to four point bending was elaborated earlier [3,4] and was exploited. Cracking of concrete with different fibers concentrations as well as with fibre cocktails was numerically modelled. Difference between two cases- prisms with chaotically distributed fibres and prisms with critical zones in the sample body (were obtained during casting procedure) was recognized in the case of differently made concrete samples (cases when concrete is filling the mould from the end of the mould and in the middle of the mould).

VI. CRACK GROWTH MODEL DESCRIPTION

Crossections are orthogonal to a prism longitudinal axes were analyzed. After that, weakest (critical) cross-section was recognized as the cross-section with the smallest amount of fibers crossing it. Was supposed that macro crack will follow to theweakest (critical) cross-section. The crack starts to open. Data from the database file which contains all information from the single fibre pull-out experiments (single fibre pull-out curve –pull out force dependance on pulling out length and the fibre inclination angle to the crack surface [3,4]) were applied.Performing numerical simulation of above mentioned crack opening process theoretical applied load- CMOD curvewas obtained. Modelling result comparison with four point notched prism bending test (for the prism model having critical zones) is shown in Fig.7. Pulled out fibers distributions according to orientation (to crack surface) and pulled out length were measured. Fibers orientations distributions are shown at Fig.9 (for different samples). In figure 10 is shown X-ray picture of the prism were potential crack place can be recognized. Fracture surfaces analysis shown difference for experimentally measured fibers orientation angle distribution comparing it with the case of chaotically oriented fibers to the crack surface (see Fig.8,9) and was in agreement with simulation made using critical zones approach.

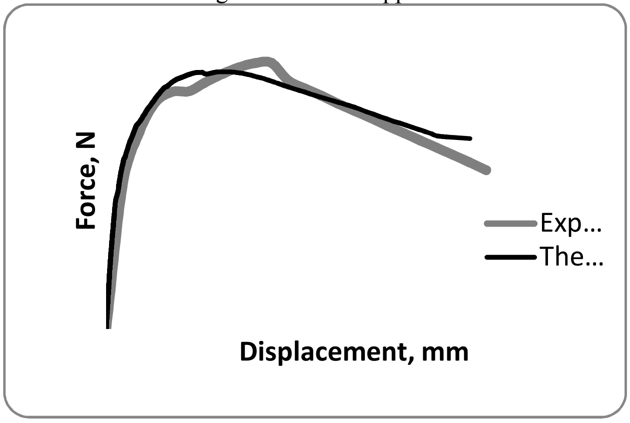

Fig. 7 Load –crack mouth opening displacement (CMOD) diagram for 4 point bending test, SFRHPC with fiber amount 320 kg/m^3 (Tabix 50)

Fig. 8 Both fracture surfaces for one prism. Is possible to see many fibers oriented close to parallel to crack surface.SFRHPC with Tabix50, Dramix30, Dramix13 and Dramix6 fibers (fibers cocktail)

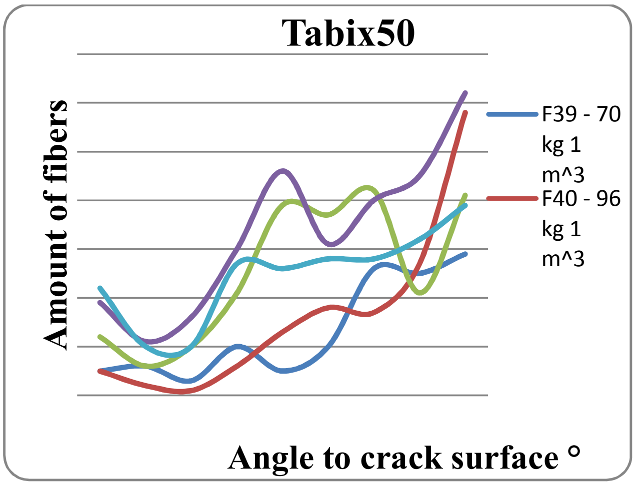

Fig. 9 Pulled out fiber end distribution according to angles to crack surface, depending on fibers Tabix50 amount in concrete

Fig. 10 SFRHPC prism X-ray picture.View from the flank

VII. CONCLUSION

Detailed internal structure formation in SFRHPC structural elements was performed. Fiberconcrete flow was simulated and investigated numerically in the casting process with the goal to recognize zones in obtained SFRHPC structural elements with oriented fibers. Experimentally were shown that zones with oriented fibers are the paces of potential macro-crack formation.

ACKNOWLEDGMENT

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