

FIBER CONCRETE PROPERTIES CONTROL BY FIBERS MOTION INVESTIGATION IN FRESH CONCRETE DURING CASTING

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Abstract: *Short steel fiber concrete (SF) tensile strength is dependent on fibers distributions and orientations inside the material. In the present investigation numerically are simulating (using FEM) all fibers motions in fresh concrete during the process of filling the mold by SF. Flow modeling was executed for Newton's and viscous Bingham's liquids. Potential weakest internal zone (is the place with undesirable fibers orientations and spatial distributions –the place of future macro-crack), from the point of view future load bearing capacity under four point bending conditions was recognized. Structural SF fracture model was created; material fracture process was modeled, based on single fiber pull-out laws, which were determined experimentally (for straight fibers, fibers with end hooks, and corrugated fibers).*

Key words: fibers, orientation, high strength concrete, flow.

1. INTRODUCTION

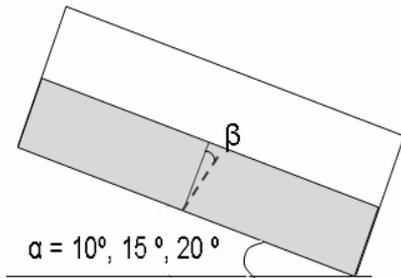
Commercially produced 0.6 to 6 cm long, with various types of geometrical and cross-section's forms steel fibers are widely used nowadays as a concrete disperse reinforcement in civil engineering applications. Steel fiber reinforced concrete (SFRC) can perform high flexural and tensile strength, impact resistance as well as a quasi ductile post cracking behavior. At the same time SFRC tensile (as well as bending) strength and post cracking behavior is highly dependent on the number of fibers crossing the weakest

crack (is bridged by fibers) and their orientation to particular crack surface [1-4]. Filling the mould by SFRC, fibers are moving and rotating with the concrete matrix till the end of motion in every concrete body internal point. Filling the same mould from the different locations SFRC samples with the different internal structures (and different strength) can be obtained. With the goal to achieve greater mechanical properties and to make material more cost effective (due to optimal use of material ingredients) is necessary to recognize potential internal zones in material with undesirable fiber orientation which can be obtained using traditional casting technologies without additional fiber placing and orientation control in material. This task can be solved in opposite way- creating internal structure (fibers distribution and orientation (see [3, 4]) in SFRC during the casting procedure and after it optimally admitting internal stretching stresses in material. In the present investigation SFRC casting was modeled as filling the mould by viscous flow. Simultaneously single steel fiber rotation and motion in the flow with internal velocity gradients were investigated experimentally and numerically (using FEM). And finally crack opening process in SFRC prism was modeled and was investigated experimentally.

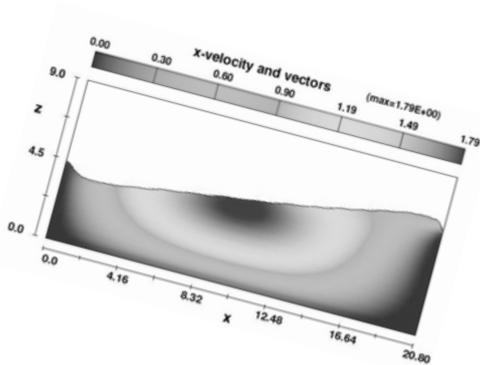
2. FIBRE ROTATION IN VISCOUS FLOW WITH VELOCITY GRADIENT

Single fiber motion in viscous flow with

velocity gradient was simulated experimentally (using model liquid with known viscosity parameters - potato-starch fluid) and numerically (using FEM code FLOW 3D). The potato-starch liquid with known viscosity coefficient was poured into the transparent container. Two groups of experiments were executed: a) with short (see Fig. 1) container (208mm long, 90mm high and 100 mm wide) and b) with long container (2400mm long, 200mm high and 200 mm wide (see Fig. 2).

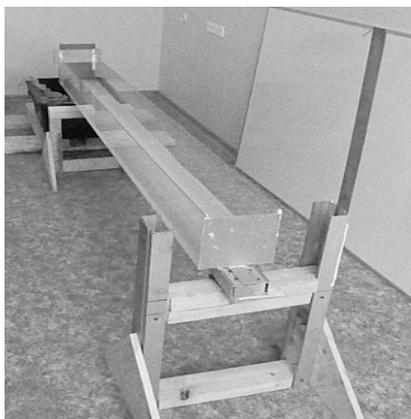


a)



b)

Fig. 1. a) experiment with short container; b) viscous fluid flow velocity (along the container) modeling result (FEM code Flow 3D simulation).



a)



b)

Fig. 2. Experimental equipment (a) long container) for fibers motion investigation in viscous flow; b) fibers in the flow.

2.1 Experiments with short container

Single steel (or polymer) fiber was inserted in the container middle part (with fluid) under the different starting angle to vertical axis. In initial position the container is placed fully horizontally. Then container's one side was lifted up from the horizontal position for required angle and test started. Movement of fiber in our fluid was observed and measured, influenced by the movement of fluid fiber starts to decline to flows direction. Fiber is turning because of movement of fluid and gravitational forces. After declination process stops time and fiber declination angle β were measured. Three experimental angles α - 10° , 15° , 20° were observed.

Above mentioned experiment was numerically simulated using FEM software FLOW-3D. Sample of calculations results is shown in Fig.1 right picture. For simplicity in the model was assumed that container stays in horizontal position and vertical and horizontal axes of gravity components are changing the angle [5]. For angle 10 degrees components of gravitational acceleration was $g_x=170,35 \text{ cm/s}^2$, $g_z=-966,10 \text{ cm/s}^2$, for 15 degrees $g_x=253,90 \text{ cm/s}^2$, $g_z=-947,57 \text{ cm/s}^2$, for 20 degrees $g_x=335,52 \text{ cm/s}^2$, $g_z=-921,84 \text{ cm/s}^2$. Container parameters(the same as in the experiment): length $l=20,8 \text{ cm}$, height $h=9 \text{ cm}$, and the height of viscous fluid in container 5 cm. The viscosity coefficient

was $\eta=486.14 \text{ g/cm}\cdot\text{s}$ (was measured), and potato-starch liquid density was used the same as a density of water $\rho=1 \text{ g/cm}^3$. When we know viscous parameters of our fluid and can approve them with numerical calculations then it was possible to go to the next step of calculations – fiber rotation calculation due to velocities variation in liquid flow. Observing forces acting on the fiber in the flow with velocity gradient is possible to conclude that the gradient of horizontal speed (1) between our observed fiber endpoints is the parameter which will establish fiber orientation (and rotation speed) in the flow:

$$\text{grad } v_x = \frac{v_1 - v_2}{l} \quad (1).$$

Here v_1 is the horizontal speed of fiber top end, v_2 is the horizontal speed of fiber lower endpoint and l is the length of fiber.

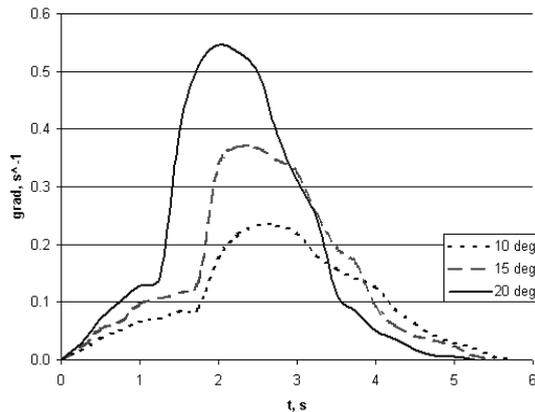


Fig. 3. Speed gradient change in the time after container was placed with declinations for 10° , 15° , 20° degrees.

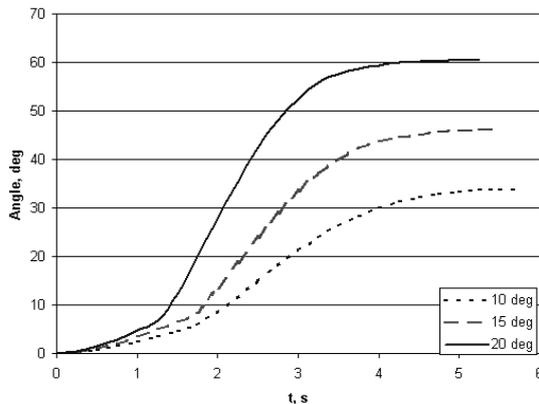
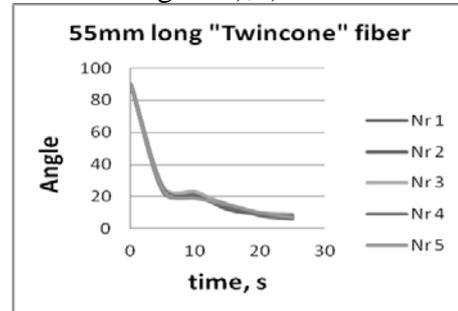


Fig. 4. Fiber angle change after declinations of container for 10° , 15° , 20° degrees.

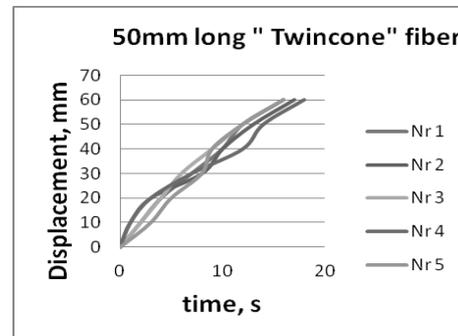
Is possible to presume speed v_2 staying equal to zero (liquid bottom layer is sticking to the container surface). Numerically calculated gradient values for our experiments were shown in Fig. 3, corresponding fiber declination history in Fig. 4.

2.2 Experiments with long container

Few steel (or polymer) fibers were inserted vertically into container middle part (with fluid) (see Fig. 2. b)). In initial position the container is placed fully horizontally. Then container's one side was lifted up from the horizontal position for required angle, simultaneously a valve on the lower end of the container was opened and test started. Movements of fibers in the fluid were observed visually and by video-camera and measured. Each fiber lower end motion distance and declination angle β was measured and was documented depending on the current time. For 50mm long 1mm thick "Twincone" steel fiber dependence are shown in Fig. 5. a),b).



a)



b)

Fig. 5. middle fiber a) declination angle and b) displacement dependence on experiment time.

2.3 Velocity gradients determination during SFRC casting

Filling the mould by SFRC, fibers are moving and rotating in the concrete flow till the end of motion in every concrete body internal point. The mould parameters was 15x15x60 cm, hole for casting (or falling flow cross-section dimensions) was 20x15 cm. The 2D and 3D modeling were performed (FLOW3D code was used). Newtonian fluid 2D flow modeling results are shown in Fig. 6. Mould is filling by SFRC flow falling at the middle of the mould.

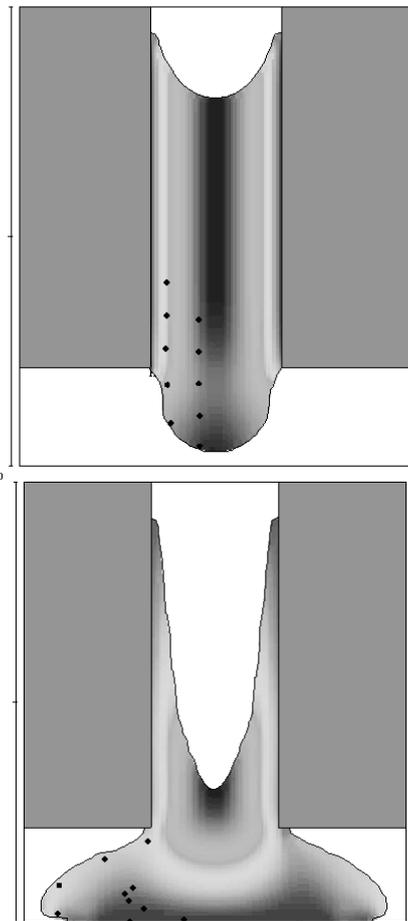


Fig. 6. FEM concrete casting process modeling. Marked points (fibers midpoints) motion in concrete during casting.

The viscosity coefficient was $\eta=5000$ GPa·s, liquid density - $\rho=2400$ kg/m³. Point markers were placed into the fluid for all flow process visualization (every marker can be observed as the particular

single fibers midpoint path in concrete body during the casting (see Fig. 6). In Fig. 7 are shown five marked points trajectories in concrete during filling the mould (till the concrete flow stops in every point). According to symmetry of the process only one half of the mould (and falling SFRC 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. Numerical simulations were performed changing the place where external flow is falling to the mould.

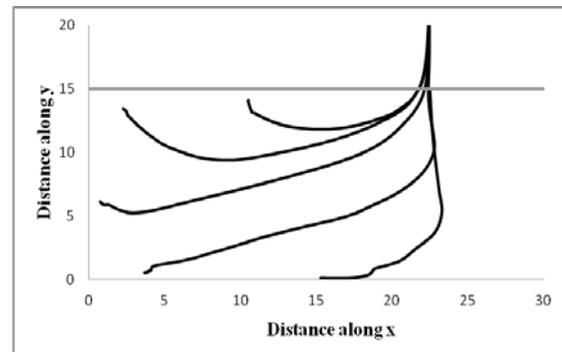


Fig. 7. Trajectories of marked points in the concrete flow during filling the mould.

Calculated vertical velocity gradients in the SFRC filling the mould were obtained and were analyzed (velocity gradient picture is shown in Fig. 8), critical zones in the concrete prism body with high velocity gradients obtained during mould casting were recognized.

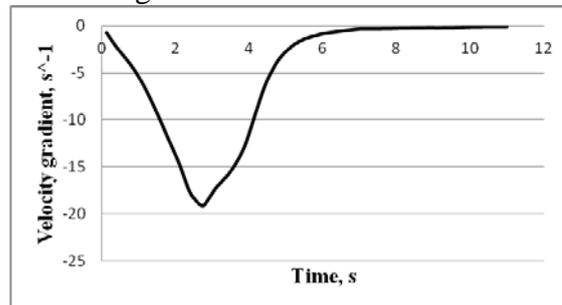


Fig. 8. Velocity gradient in the concrete flow during filling the mould ($20 < x < 25$ cm, $y=7.5$ cm).

3. DESCRIPTION OF THE MODEL

A SFRC beam with chaotic fibre orientation subjected to four point bending

was modelled. The geometry (length, form and diameter) and amount of each fibre type is included in fibre-cocktail mix is given. A random distribution function is applied to assign location of each fibre. Fibers orientation function was used depending on velocity gradients were realized in every material internal place. Fibers spatial orientation function was highly different from random (oriented along fibers flow) in critical zones. Orientation parameter was introduced. Monte-Carlo simulations were performed to obtain fibre distribution in every particular SFRC prism. After that, weakest (critical) cross-section was recognized as the cross-section with the smallest amount of fibers crossing it. The crack starts to open. Data from the database file which contains all information from the single fibre pull-out experiments (were obtained earlier) were applied. Performing numerical simulation of above mentioned crack opening process theoretical applied load - CMOD curve was obtained. Modelling result comparison with four point notched prism bending test is shown in Fig. 9.

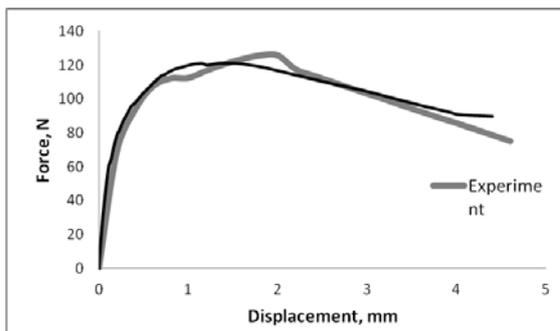


Fig. 9. Load – crack mouth opening displacement (CMOD) diagram for 4 point bending test, SFRC with fiber amount 320 kg/m³ (Tabix 50).

Fracture surfaces analysis shown high amount of fibers oriented under large angles to crack surface. Ruptured prisms crack surfaces were visually investigated. Pulled out fibers distributions according to orientation (to crack surface) and pulled out length were obtained in every case.

Fibers orientations distribution is shown in Fig. 10.

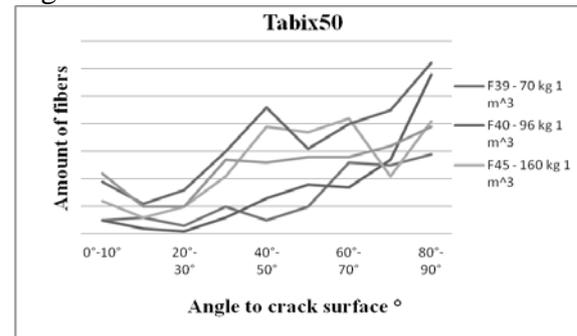


Fig. 10. Pulled out fiber end distribution according to angles to crack surface, depending on fibers Tabix50 amount in concrete.

In Fig. 11 is shown X-ray picture of the prism where potential crack place can be recognized. Place is characterized by non-homogeneous oriented fibers distribution.

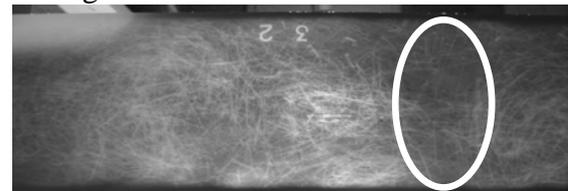


Fig. 11. SFRC prism X-ray picture. View from the flank.

4. CONCLUSIONS

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

5. ACKNOWLEDGEMENT

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6. REFERENCES

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