STEEL SHORT FIBER REINFORCED CONCRETE (SFRC) STRENGTH AND POST CRACKING BEHAVIOUR APPRECIATION BY FIBERS MOTION PREDICTION IN FRESH CONCRETE DURING CASTING

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Summary Steel fiberconcrete (SF) strength (and post-cracking behavior) is dependent on number of fibers are crossing the crack and every fiber orientation to crack's surface. Numerically are simulating (using FEM and Monte-Carlo method) all fibers motions in fresh concrete during filling the mold by SF. Structural SF fracture model was created, based on single fiber pull-out laws, which were determined experimentally (more than 700 tests). Model predictions were validated experimentally by bending tests.

INTRODUCTION

Concrete reinforced by moderate amount of short steel fibers is demonstrating elevated flexural and tensile properties, impact resistance and is behaving quasi ductile in cracked phase. Commercially are available various geometrical forms steel fibers, having length in a range from 0.6 cm to 6 cm. At the same time SF tensile (as well as bending) strength and post cracking behavior is highly dependent on fibers distributions and orientations inside the material [1-2]. Important is to recognize and be able to predict the potential internal zones formation with undesirable fibers orientations and spatial distributions in the structural element, in the case of traditional casting technologies use, without additional fibers placing and orientations control. In the present investigation numerically are simulating (using FEM) all fibers motions in fresh concrete during filling the prismatic mold by SF. Three different filling variants were investigated (filling from the middle, one fourth and from the end of the mould). Initial fibers distributions and orientations in the filling pipe were simulated using the Monte-Carlo approach. Flow modeling was executed for Newton's and viscous Bingham's liquids (which rheological parameters were measured experimentally for SF and specially prepared transparent model liquid). Potential weakest internal zone (from the point of view future load bearing capacity under four point bending conditions) with undesirable fibers orientations and spatial distributions was recognized. After SF was hardened, this zone is the place of future macro-crack. Numerical predictions were compared with performed X-ray investigations. 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). For this purpose experimental program was realized (more than 700 tests were executed) and pull-out force versus pull-out fiber length was obtained (for every fiber is embedded into concrete at depth l and under angle α (five l and five α values were investigated). Model predictions were validated by SF 15x15x60 cm prisms four point bending tests. Fracture surfaces analysis (including pulled out fibers length and orientation angle experimental measuring) was realized for every broken prism, with the goal to improve elaborated model assumptions. Rational mould filling technologies were recognized.

FRESH CONCRETE MOTION NUMERICAL SIMULATION

Filling the mould by SF, fibers are moving and rotating in the concrete flow till the end of motion, in every concrete

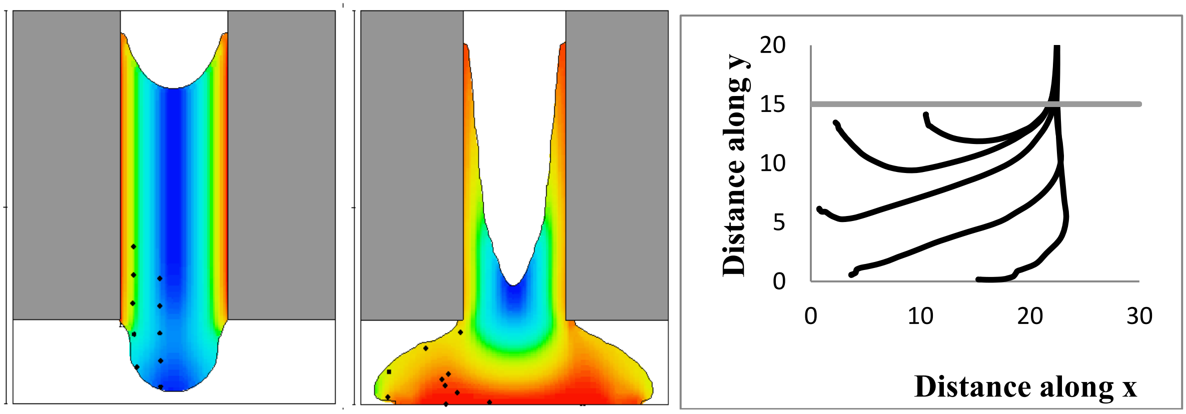

Figure 1. a),b) FEM modeling of SF casting process. Marked points are fibers midpoints. c) Fibers midpoints trajectories in SF flow.

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body internal point. Jeffery equations [3-4] are describing a rigid fiber motion (rotation) in a viscous flow. In our investigation simplified Jeffery approach was executed in combination with FEM with the goal to recognize fibers distribution and orientation in the concrete sample at every casting moment and after casting. The mould parameters was 15x15x60 cm, internal dimensions of the pipe (or falling flow cross-section dimensions) was 20x15 cm. The 2D and 3D modeling were performed (FLOW3D code was used) for three different places above the mould. Newtonian liquid 2D flow modeling results are shown in Fig.1 in the case when mould is filling by SF flow dropping at the middle of the mould. Point markers are fibers midpoints in fig.1a, b. In fig. 1.c is possible to see different fibers trajectories for fibers located in the pipe at one vertical line along the pipe. Calculated vertical velocity gradients in the filling the mould SF were obtained and were analyzed. Fibers spatial orientations were highly different from random in critical zones. In figure 2.a is shown X-ray picture of the critical zone. Fibers orientation function was introduced.

CRACK OPENING MODEL DESCRIPTION

SF prisms with four variants of internal fibers arrangements were 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 next cases fibers orientations and distributions were corresponded to prism fabrication cases pouring the mould from the middle, one fourth and from the end (as were obtained by flow numerical simulations). Variant of the structural failure model for SF prism subjected to four point bending was elaborated earlier [2] and after modification was exploited. Cracking of SF with different fibers concentrations was numerically modelled. Weakest (critical) cross-section was recognized as the cross-section with the smallest amount of fibers crossing it. Crossections orthogonal to a prism longitudinal axis were analyzed. Was supposed that macro crack will follow to the weakest (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 dependence on pulling out length and the fibre inclination angle to the crack surface) were applied. Performing numerical simulation of above mentioned crack opening process theoretical applied load- CMOD curve was obtained. Modelling result comparison with four point prism bending test (for the prism is having a critical zone (was fabricated by filling the mould at the middle) is shown in Fig.2.b. Pulled out fibers distributions according to orientation (to crack surface) and pulled out length were experimentally measured.

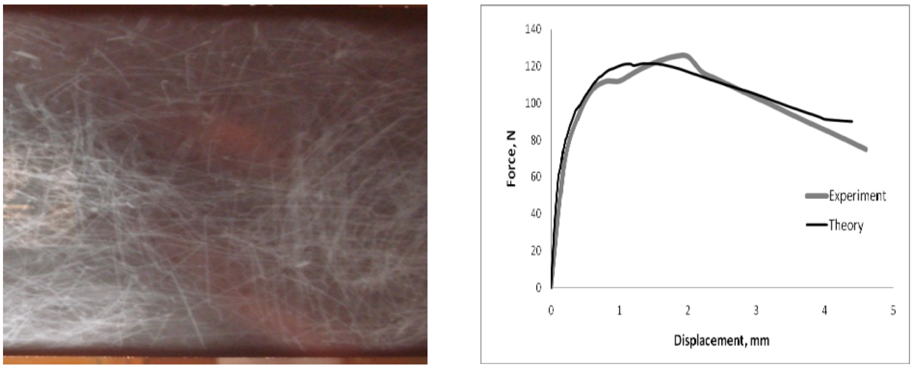

Figure 2. a) X-ray picture of fibers distribution and orientations in a weak zone. b) Crack Mouth Opening Displacement (CMOD) versus applied external load.

CONCLUSIONS

Fracture surfaces analysis shown difference for experimentally measured fibers orientations angles distributions comparing them with the case of chaotically oriented fibers. Detailed numerical analysis was realized started with SF flow modeling and internal fibers arrangement formation simulation in SF structural element. Weakest zones were recognized, crack growth model was introduced and SF prism load bearing capacity was evaluated. Experimentally were shown that zones with low content of fibers as well as with oriented fibers are the paces of potential macro-crack formation. Rational SF structural element fabrications technologies were recognized.

References

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