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SHORT FIBERS DISTRIBUTION INVESTIGATION IN FIBER CONCRETE

ĪSO ŠĶIEDRU TELPISKĀ SADALĪJUMA IZPĒTE FIBROBETONOS

Keywords:
fibers, orientation, high strength concrete, flow

INTRODUCTION

Traditional concrete is brittle; it's deformations to fracture are small and tensile strength is times lower comparing with compressive one. Steel rebars are traditional reinforcement in concrete with the goal to carry tensile loads. Rebars are covering small part of the structural element crossections as a result element parts without reinforcement are subjected to cracks formation. Solution here may be concrete with dispersed reinforcement – fiber concrete. During last few years steel fiber reinforced concrete has been used mainly for tunnel linings, industrial floor slabs and similar applications. At the same time the field of its applications is continuously expanding. Although there is no question about the contribution of fibers to enhance concrete post cracking tensile load bearing capacity, the question of how to reduce experimental results scatter is still under debate. A number of test methods have been proposed, but all have significant problems associated with either the variability of the results and their application in structural design calculations [1]. Commercially produced 0.6 to 6 cm long, with various types of geometrical and crossection's formssteel fibers are widely used nowadays as a concrete disperse reinforcement in civil engineering industry. Steel fiber reinforced high strength concrete (SFRHSC) can perform high flexural and tensile strength, impact resistance as well as a quasi ductile post cracking behavior. At the same time SFRHSC tensile (as well as bending) strength and post cracking behavior is highly dependent on fiber distribution and orientation in material [1-4].

With the goal to achieve higher 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 can be obtained using traditional concrete construction members casting technologies without additional fiber placing and orientation control in material. This task can be solved in opposite way- creating internal SFRHSC structure (fibers distribution and orientation (see [3, 4]) during the casting procedure and after it optimally bearing internal stretching

stresses in material. In the present investigation SFRHSCcasting 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 SFRHSCprism was modeled and was investigated experimentally.

FIBRE ROTATION IN VISCOUS FLOW WITH VELOCITY GRADIENT

Single fiber motion in viscous flow with velocity gradient was simulated experimentally (using model liquids with known viscosity parameters -potato-starch fluid and glycerol) and numerically (using FEM code FLOW 3D). The model liquid with known viscosity coefficient was poured into the transparent container. Single steel 50 mm long and 1mm in diameter fiberwas 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 is turned sideways 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 *b* were measured. Three experimental angles *a* - 10°, 15°, 20°were observed. Above mentioned experiment was numerically simulated using computer program FLOW-3D. For simplicity in the model was assumed that container stays in horizontal position and vertical and horizontal axes of gravitycomponents are changing the angle [5]. For angle 10 degrees components of gravitational acceleration wasg_x=170,35 cm/s^2, g_z=-966,10 cm/s^2, for 15 degrees g_x=253,90 cm/s^2, g_z=-947,57 cm/s^2, for 20 degrees g_x=335,52 cm/s^2, g_z=-921,84 cm/s^2. Container parameters(the same as in the experiment): length l=20,8 cm, height h=9 cm, and the height of viscous fluid in container 5 cm. The viscosity coefficient was η=486.14 g/cm·s, forpotatostarch liquid,density was used the same as a density of water ρ=1 g/cm^3. Results show that greater declination of container gives bigger declination of the fiber.

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 – fiberrotation 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 establishfiber orientation

(and rotation speed) in the flow.

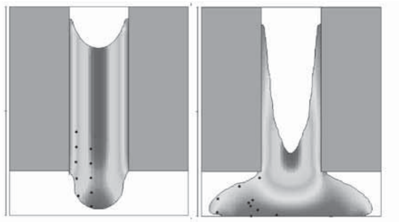
$$grad\ v_x = \frac{v_1 - v_2}{l} \tag{1}$$

Herev_1 is the horizontal speed of fiber top end, v_2 is the horizontal speed of fiberlower endpoint and l is the length of fiber. Is possible to presumespeed v_2 staying equal to zero (liquid bottom layer is sticking to the container surface).

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. The mould parameters was 15 x 15 x 60 cm, output opening 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 below. Mould is filling by SFRHSCflow falling at the middle of the mould.

Figure 1. FEM concrete casting process modeling. Marked pointsmotion in concrete during casting.



The viscosity coefficient was η=5000GPa·s,liquidden sity-ρ=2400 kg/m^3. Point markerswere 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. 1).

Figure 2. Trajectories of marked points in the concrete flow during filling the mould.

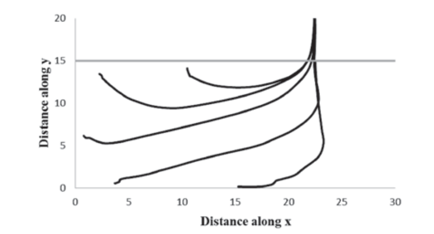
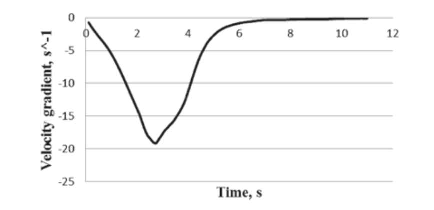


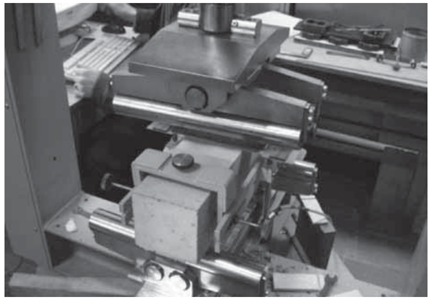
Figure 3. Velocity gradient in the concrete flow during filling the mould(20<x<25 cm, y=7.5 cm).



In figure 2 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 fallingS-FRHSC 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 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. 3, Critical zones in the concrete prism body with high velocity gradients obtained during mould casting were recognized.

FIBERS DISTRIBUTION AND ORIENTATION IN MACROCRACK'S CROSSECTION

Figure 4. Fiberconcrete prism (sample number F55) testing under four point bending conditions. Midpoint vertical deflection as well as crack opening (crack mouth opening deflection CMOD) was measured.



Performed simulations were shown, that during filling the mould distances between fibers are changing as well as two fibers are rotating with different velocity if they are located in different parts of the flow crossection. As a result fiberconcrete prisms potentially may have two typed of non-homogenites – a) areas with low or rich fibers content; b) areas with dominant fibers orientation, different from random. Investigation of such non-homogenites has practical interest because SFRHSC beam was produced by filling quasi-homogeneous fiberconcrete throw pipe symmetrically in the central part of prismatic mould (as is shown in Figure 1 will leadto both types non-homogenites formation throw the thickness of the obtained SFRHSC prism. If after that we will applied to the prism bending loads (see Fig. 4.) it will leads to numerous cracks formation in stretched part of the prism (concrete is brittle, its rupture deformations are very small and fibers are not stretched in material at loading beginning stage, their contribution in lads bearing of fiberconcrete is small).

Figure 5. Both fracture surfaces for one prism. Is possible to see many fibers oriented close to parallel to crack surface. SFRHPC with Tabix 50 (50 mm long undulater round crossection steel fibers), Dramix 30 (30 mm long ends hooked round crossection steel fibers), Dramix 13 (13 mm long straight round crossection steel fibers) and Dramix 6 (6 mm long straight round crossection steel fibers) fibers cocktail.

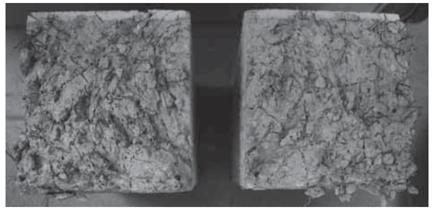
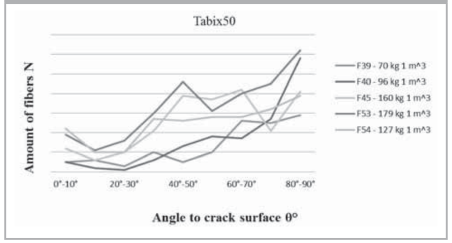


Figure 6. Pulled out fiber ends distribution according to angles to crack surface, depending on fibers Tabix 50 amount in concrete (measured in accordance to first method).



Cracks are opening and linking forming few macro-cracks which are crossing all beam crossection's stretched part. Macro-crack is crossing weak zone is feeling lower resistance to opening and is becoming major macro-crack is leading to beam rupture. Weak zone is an area in material with a) low amount of fiber or b) majority of fibers oriented in the range of small angles values to crack surface. Fibers distributions according to pulled out length and angle to crack surface were performed experimentally. Two techniques were executed. First-prism with macro-crack was bended till crack mouth opening 15 mm, after that prism was separated into two pieces by stretching. Ruptured prisms crack both surfaces (see Fig. 5) were visually investigated, pulled out fibers distributions according to orientation (to crack surface), location at crack surface and pulled out length were investigated. Second-prism with macro-crack was bended till crack mouth opening CMOD was reached 6 mm, after that prism one side at a distance 40 mm close to crack surface was cut by diamond saw. Concrete in a prism slice (40 mm thick) from one side of the crack was mechanically crumbled and pulled out fibers distributions according to orientation (to crack surface) and location at crack surfacewere determined. Fibers orientations distribution measured according to first approach are shown in Fig. 6 and according to second in Fig. 7. Comparing figures 6 and 7 we see that first method is overestimating number of fibers oriented in the direction of major normal stretching stress direction. Steel fibers initially inclined to the direction of pulling out force were plastically bended into direction orthogonal to crack surface. It happens if we are bending the beam till crack mouth opening is 15 mm and after that is separating it into two pieces by stretching. At the same time first method is preferable if we want to obtain fibers distribution according to pulled out length and location at crack surface (counting fibers on both flanks of the crack (see Fig. 8, 9). In figure 10is shown X-ray picture of the prism were potential crack places can be recognized. Weak zone Ais characterized by lower amount of fibers. In the weak zone B fibers are mainly oriented orthogonal to the main tensile stress (during bending).

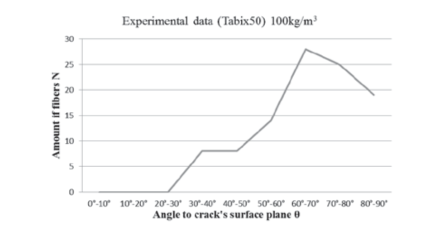


Figure 7. Angles to crack surface distribution for pulled out fibers ends (measured in accordance to second method).

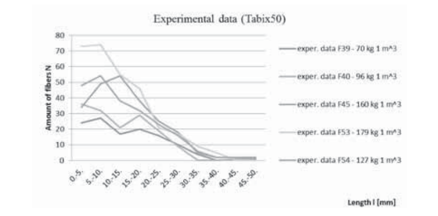


Figure 8. Fibers ends distribution according to pulled out lengths (measured in accordance to first method).

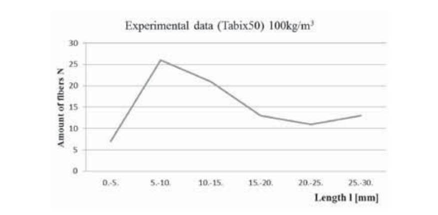


Figure 9. Fibers ends distribution according to pulled out lengths (measured in accordance to second method).

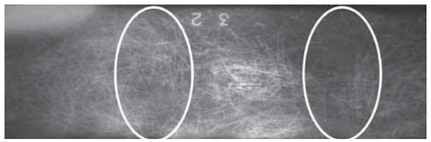


Figure 10. SFRHSC prism X-ray picture. View from the flank. A – weak zone with low amount of fibers; B – weak zone with fibers mainly oriented orthogonal to the main tensile stress (during bending).

Flow simulations comparison with experimentally observed weak zones shown correlation between zones location place in numerical flow experiment and experimentally observed macro-crack position.

FIBERCOCNRETE INTERNAL STRUCTURE INVESTIGATION BY X-RAY METHOD

Fiberconcrete prisms were tested by X-ray method with a goal to identify weak zones location.

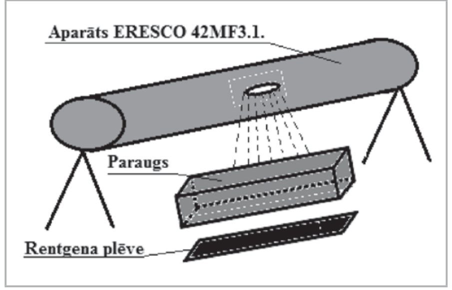


Figure 11. X-ray investigation of fiberconcrete using device ERESCO 42MF3.1.

Industrial X-ray device ERESCO 42MF3.1 was used. Fiberconcrete prism with dimentions 40 x 10 x 10 cm was mounted on an envelope with X-rays sensitive film (see Fig. 11) and was exposed 10 minute under X-rays. Every sample was exposed from the top and from a side. Obtained pictures are shown in Fig. 12a-d. Weak zones are marked by ellipses.

Figure 12a. X-ray picture for K2 sample (vuew from above).

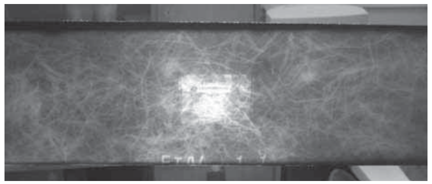


Figure 12b. X-ray picture for K2 sample (vuew from a side).

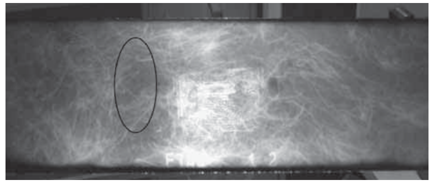


Figure 12c. X-ray picture for K5 sample (vuew from above).

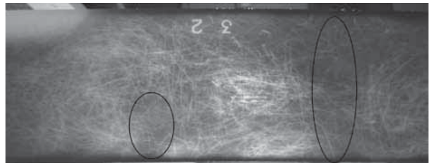
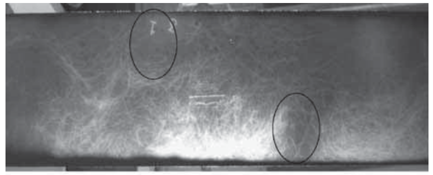


Figure 12d. X-ray picture for K5 sample (vuew from a side).



MACRO-CRACK OPENING MODEL UNDER APPLIED BENDING LOADS

In theoretical modelling we were started with material having evenly in the volume distributed fibers with random orientation. A SFRHSC beam subjected to four point bending was modeled. Each fibers type is included in fiber cocktail, geometry (length, form and diameter) as well as amount in volume unit is known. The Monte-Carlo simulation method was used to obtain fibers distribution in sample volume as well as every particular fiber orientation. If in the volume must be placed N fibers we were realized such procedure: we started with the first fiber: *x*, *y* and *z* the coordinates of the fiber midpoint were defined as

$$x = L_1 * F_1(\beta),\ F_1(\beta)\epsilon[0,1];$$

$$y = L_2 * F_2(\beta),\ F_2(\beta)\epsilon[0,1];$$

$$z = L_3 * F_3(\beta),\ F_3(\beta)\epsilon[0,1]$$

$F_i(\beta), i = 1,2,3$ are functions of random parameter $\beta\epsilon[0,1]$. If we are observing random fibers distribution in the volume, $F_1(\beta) = \beta;\ F_2(\beta) = \beta;\ F_3(\beta) = \beta.$ Similar way were obtained two fiber orientation angles α_1 and α_2. This procedure was repeated for all N fibers.

Figure 13. Concrete prism body fulfilled by fibers using Monte-Carlo procedure. Each point is a single fiber midpoint. Macro crack plane is a plane which is crossing by lowest number of fibers (weak zone).

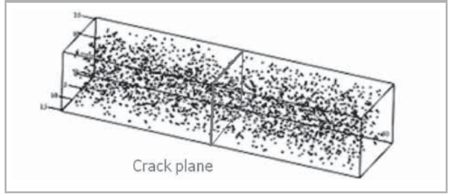
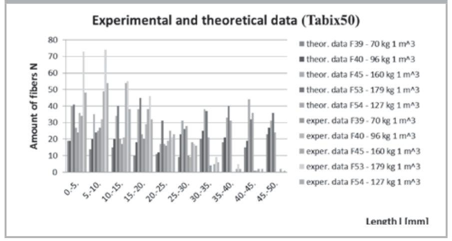
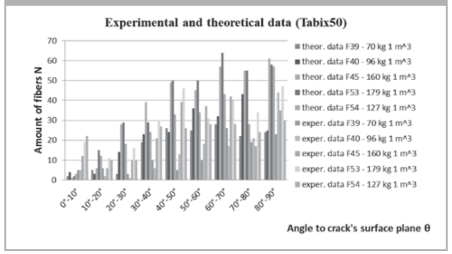


Figure 14a. Numerical and experimental fibers distributions (according to pulled out length) (Tabix 50) caunted on one crack' s side.



After that macro crack plane was recognized as a plane with lowest number of crossing it fibers in the middle side of the prism area between two upper supports (see Figure 13).

Figure 14b. Numerical and experimental fibers distributions (according to fibers angle to crack surface) (Tabix 50) caunted on one crack' s side.



NUMERICALLY OBTAINED FIBERS DISTRIBUTIONS (ACCORDING TO PULL-OUT LENGTH AND ANGLE TO CRACK'S PLANE) COMPARISON WITH EXPERIMENT

Figure 14c. Numerical and experimental fibers distributions (according to pulled out length) (Dramix 30) caunted on one crack's side.

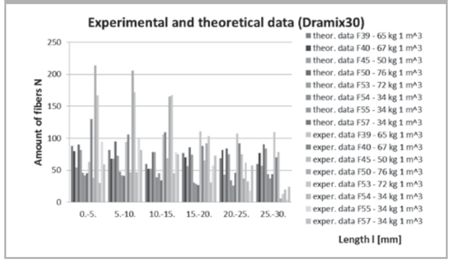
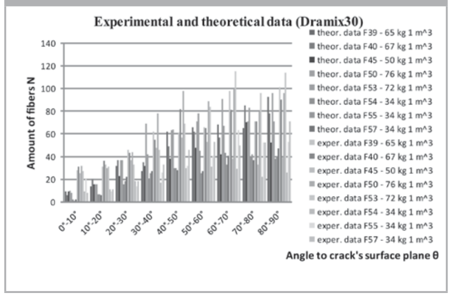
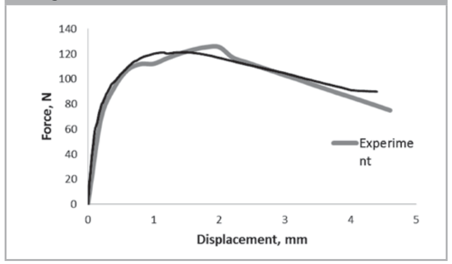


Figure 14d. Numerical and experimental fibers distributions (according to fibers angle to crack surface) (Dramix 30) caunted on one crack' s side.



Numerically obtained fibers distributions comparison according to pulled out length with experimentally measured (on both sides of the crack), for the prisms with similar Tabix 50 (undulated steel fibers 50 mm long and 1mm in diameter) and Dramix 30 (end hooked 30 mm long and 0.48 mm in diameter) fibers amounts are shown in figure 14a, 14c. Similar distributions according to fibers angle to crack surface are shown in figure 14b, 14d. Experimentally moulds were filled by fiberconcrete dropping the fiberconcrete flow at the middle of the mould. Flow crossection was approximately 20 x 15 cm. Figures 14a-d show difference in fibers distributions obtained experimentally and predicted theoretically according to random fibers distribution in the weak zone. As the first reason here is possible to mention influence of the borders of the mould, is obvious that fiber which midpoint is located in a layer with the thickness less than one half of the fiber length from the mould's wall, is forced to be aligned to the its surface. Another important reason is fibers orientation (as was shown above) as well as fibers formation clusters in the low. Elaborated theoretical model [1] use in combination with realistic (obtained from experiment) fibers distributions allowed to predict prism cracking as well as post-cracking behavior with high accuracy (see Figure 15). Information about single fiber pull-out micromechanics were used [2].

Figure 15. Load –crack mouth opening displacement (CMOD) diagram for 4 point bending test, SFRHPC with fiber amount 320 kg/m^3 (Tabix 50).



CONCLUSIONS

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. Fibers distributions according to pull-out length and angle to crack surface were obtained experimentally and numerically based on assumption about random fibers distributions in macro-crack crossection. Experimental data comparison with the modeling was shown difference between theoretical and experimentally obtained results.

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ABSTRACT

Steel fiber reinforced high-strength (SFRHSC) concrete post cracking load –bearing capacity (and strength) is dependent on the number of fibers crossing weakest crack (bridged by fibers) and their orientation to particular crack surface. Filling the mould by SFRHSC, fibers are moving and rotating moving with the concrete matrix till the end of motion in every concrete body internal point. 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 performed, as well as single fiber planar motion and rotation numerical and experimental investigation in viscous flow. 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 15 x 15 x 60 cm prisms 4 point bending tests.

ABSTRAKTS

Augstās stiprības fibrobetona (ASF), pēcplaisāšanas nestspēja (un stiprība) ir atkarīga no to šķiedru daudzuma kuras šķērso vājāko plaisu (savieno plaisas malas), un no to orientācijas attiecībā pret konkrētas

plaisas virsmu. Aizpildot formu ar ASF, kuram ir pievienotas tērauda šķiedras, šķiedras tajā pārvietojas un griežas, kustoties kopā ar betona masu līdz kustības beigām betona ķermeņa katrā iekšējā punktā. Pie vienas un tās pašas formas aizpildes darot to no dažādiem galiem, var iegūt fibrobetona paraugus ar atšķirīgām iekšējām struktūrām (un ar atšķirīgu stiprību). Tika veikta plūsmas skaitliskā modelēšana (izmantojot Ņūtona un Bingama plūsmas modeļus), kā arī tika izpildīti vienas šķiedras plakanas kustības un griešanas skaitliski un eksperimentāli pētījumi viskozā šķidrumā. Tika iegūtas prizmatisku paraugu rentgena fotogrāfijas, kā arī ir izanalizētas šķiedru iekšējas pozīcijas un to orientācijas. Tāpat tika identificētas šķiedru pozīcijas un orientācijas plaisas šķērsgriezumā, un dotie rezultāti tika salīdzināti ar rezultātiem, kuri ir iegūti pie skaitliskas modelēšanas. ASF (kurš ir armēts ar tērauda šķiedrām) sabrukšanas strukturālais modelis tika noteikts uz vienas šķiedras izvilkšanas no matricas likumiem, kuri tika iegūti eksperimentāli. Modeļa noteikto parauga stiprību un plaisāšanas ainu pārbaudīja salīdzinot to ar četru punktu lieces eksperimentiem uz prizmām ar izmēriem 15 x 15 x 60 cm.

АБСТРАКТ

Несущая способность (и прочность) высокопрочного бетона, армированного стальными волокнами, зависит от числа волокон (соединяющих берега трещины), пересекающих слабейшую трещину и от их ориентации по отношению к поверхности трещины. При заполнении формы высокопрочным бетоном, армированным стальными волокнами, волокна перемещаются и вращаются, двигаясь вместе с бетонной матрицей до конца движения в каждой внутренней точке бетонного тела. При заполнении одной и той же формы с разных концов, могут быть получены образцы высокопрочного бетона, армированного стальными волокнами, с различными внутренними структурами (и с различной прочностью). Было выполнено численное моделирование потока (используя жидкостные модели Ньютона и Бингама), а также были выполнены численные и экспериментальные исследования плоского движения и вращения одного волокна в вязкой жидкости. Были получены рентгеновские снимки призматических образцов, а также проанализированы внутреннее расположение волокон и их ориентации. Также были идентифицированы позиции и ориентации волокон в поперечном сечении трещины, и данные результаты сравнивались с результатами, полученными при числовом моделировании. Структурная модель разрушения высокопрочного бетона, армированного стальными волокнами, была создана на основе законов вытягивания одного волокна из бетонной матрицы, которые были получены экспериментально. Численные прогнозы были подтверждены экспериментально на призмах с размерами 15 x 15 x 60 см, которые были протестированы на четырёхточечный изгиб.

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CONCRETE SHELLS REINFORCED BY GLASS FIBERS

BETONA ČAULAS STIEGROTAS AR STIKLA ŠĶIEDRĀM

Key words:
glass and carbon fibre reinforced concrete, glass, carbon fibre bundles.

INTRODUCTION

Concrete is brittle material, if we want to fabricate thin wall (few centimetres) construction elements (thin wall shells) made out of concrete we are forced to use a small diameter densely placed reinforcement. One solution can be -short AR glass fibers homogeneously distributed in the concrete, another –few layers of knitted AR glass fibre fabrics (fulfilled by concrete) and placed at even distance one to another throw the thickness of the structure. Let start with short glass fibre concrete, If we want to predict fibre concrete material cracking and post-cracking behaviour, and at the same time are looking for material with elevated tensile strength properties and quasi-plastic (with few % deformation without loosing load bearing capability) material post-cracking behaviour, the study of single fibre and fibre bundle pull-out mechanisms out of cement matrix is important. Publications discussed this problem are described in [1-4]. Fracture experimental investigation for glass, steel and carbon short fibre concretes [1] was recognized main micro-mechanisms of fibre bridging cracks in material. In present paper, investigation of single and few non-metallic fibres micro-mechanics embedded into concrete matrix under external loads were performed numerically (using FEM approach) and experimentally. Micromechanical data were used for fiberconcrete cracking and post-cracking behaviour based on elaborated structural model.

Another option is use of knitted AR glass fibre fabrics (fulfilled by concrete) and placed at even distance one to another throw the thickness of the structure.

Figure 1. Short glass fiber concrete is evenly placed on the surface of rubber membrane (pneumatic mould).