Scientific Journal of Riga Technical University
Transport and Engineering. Mechanics.

2010
Volume 33

Investigation of Fiber Orientation in Viscous Fluid

Maris Eiduks, *Riga Technical University*, Andrejs Krasnikovs, *Riga Technical University*,
Ervins Dunskis, *Riga Technical University*, Olga Kononova, *Riga Technical University*

***Abstract* - This is early stage investigation is related to determination of fresh steel fibre reinforced concrete (SFRC) flow speed gradients, are presumed to be the key parameters for computer modelling of steel fibres orientation in form casting process. The aim of the research is to elaborate the computer model for steel fibre orientation evaluation in the casting process, which would be a good option for prediction the concrete mechanical properties, optimization of casting process and costs due to proper use of ingredients. Fibre orientation in fibre reinforced concrete is important for obtaining best mechanical properties in the place where it's necessary. Task can be solved as: to obtain optimal fibre concentration and orientation or to use right casting way of concrete with the goal to reach required mechanical properties in necessary location of the composite construction element.**

As the example were observed the case of trench filling by the fibre concrete. During performed numerical simulations were obtained distributions of vertical and horizontal velocities in real time scale. To confirm the possibility of determining the orientation of fibres by speed gradients in viscous fluid was simulated behaviour of a single fibre in an inclined container with a viscous transparent liquid (potato-starch solution). For precise modelling of potato-starch liquid, coefficient of dynamic viscosity has been determined. The experiments made on the fibres in an inclined container showed satisfactory agreement with the simulation results. Accordingly to calculations the velocity gradients can be used for determine the position and orientation of fibres in fibre-reinforced concrete members production.

***Keywords* - steel fibre orientation, viscosity, fibre concrete casting, SFRC, coefficient of viscosity, numerical modelling.**

I. Introduction

Nowadays in civil engineering industry as a concrete reinforcement is widely used 0.6 to 6 cm long steel or other material fibres with various types of forms and crossection's diameters. Such materials main advantage is that fibre reinforced concrete is pumpable, filling the mould without necessity of traditional (steel bars or ropes) reinforcement placement into construction body. Fibers may be metallic (steel) and non-metallic (glass, polymer, carbon). Steel fibres are widely used. Steel fibre reinforced concrete (SFRC) has very good stiffness, flexural and tensile strength, impact resistance as well we can obtain a quasi ductile behaviour for cracked material. Of course sometimes both types of reinforcements (dispersed steel fibers and traditional steel rebars) can be used together to achieve superior strength and durability properties.

With the goal to achieve greater mechanical properties and to make material more cost effective (due to optimal use of material ingredients) would be very attractive to predict or to have possibility to control fibre orientation and distribution in material during the casting process and after it, because in most cases potential risk zones are known and if fibre orientation during the casting process of SFRC could be controllable, then would be possible to achieve needed properties in most risky places, like it is done in producing the other composites.

Main goal of this investigation was to understand and to evaluate important parameters change in SFRC casting processes, to work out recommendations for oriented SFRC properties prediction and to elaborate mentioned phenomena structural model.

II. Description of Casting Model and Process

In project *Sustainable Construction of Underground Transport* Infrastructures (*SCOUT)* research of possibility of SFRC use for tunnel walls has been successfully done, but in various tests, which were performed during previously mentioned project, one problem that appeared is that mechanical properties of the end product are very much dependent on casting ways, that is, how fibres are arranged after casting in product body. It was hard to obtain homogenous material with more or less oriented fibres, what decreases material mechanical properties.

In mentioned project a machine which is digging a trench and almost at the same time casting SFRC in that just created mould was observed and developed. Machine has four major parts – main unit that drives other parts, digging part, which can dig various kinds of soils, even rocks, then transport mechanism that transports ground material up to surface and casting module with the tube which fills mould with SFRC from the bottom. All these parts are moving further while casting. For schematic view of casting process see Fig. 1.

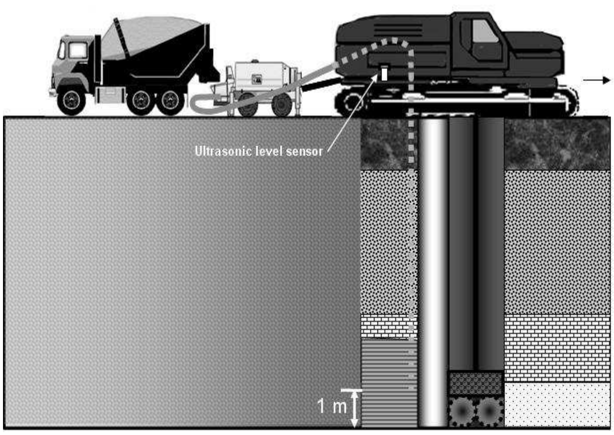

Fig. 1. Casting machine with ground digging and SFRC casting elements (SCOUT courtesy)

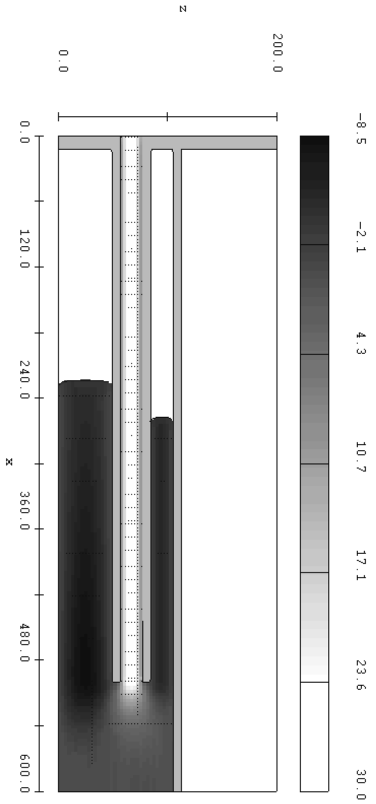

Fig. 2. Distribution of vertical speeds of fresh concrete after 60 seconds after casting start

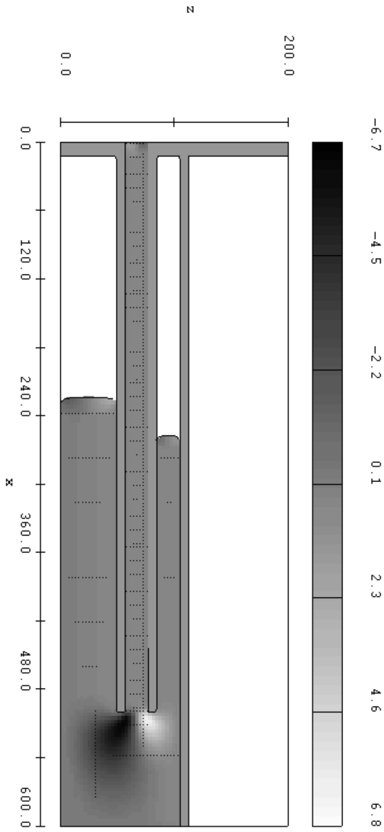

Fig. 3. Distribution of horizontal speeds of fresh concrete after 60 seconds after casting start

For casting of fresh concrete 2D fields of vertical (Fig. 2) and horizontal (Fig. 3.) velocities distributions after 60 sec. are shown. In this case trench size is 5 m deep and 2 m long. Pipe's crossection internal size is 20 cm, pump pressure 2 atm, horizontal velocity of the excavation machine is 0,5 cm/sec. Concrete density is 2400 kg/m^3, coefficient of viscosity 500 Pa·sec [1]. For better understanding how flow velocities gradients in SFRC are oriented fibers, orientation of single fibre in the flow with fixed velocity gradient were investigated.

III. Creation of model for fibre motion and orientation in moving liquid

Because the concrete is not transparent we needed to chose other, similar fluid with relatively high viscosity and if possible with good transparency, for visual understanding of fibre movement in it.

For natural experiments viscous fluid which was produced from potato-starch was chosen. This liquid has viscous nature and is easily prepareable. So we needed to make experiments for determination of its viscous properties - dynamic coefficient of viscosity. This property can be calculated after average experimental data are collected. Viscosity of fluid was determined thru experiments with glass ball (d=1,6 cm) which was dropped into fluid and sinking time was measured. A number of experiments were done and average speed of balls sinking was calculated.

As a result from 20 measurement attempts we got, that average sinking speed is ν_{av}=0.391 cm/s.

Then from formula which describes the ball speed in viscous fluid [2]

$$v = g\,\frac{\rho_b - \rho_f}{\eta}\,\frac{2R^2}{9}, \qquad (2)$$

where: ρ_l – density of the glass ball;
$\rho_{\check{s}}$ – density of the fluid;
R – radius of the glass ball;
η – dynamic coefficient of viscosity;
g – free fall acceleration,

is possible to obtain liquid dynamic coefficient of viscosity η=486.14(g/cm·s)= 48.61 (Pa·s).

Now data which can be used in numerical modelling is obtained and realistic computer model can be adapted.

In literature can be found different rheological models were relation between the shear stress τ and the shear strain rate $\dot{\gamma}$ in cement-based materials is described. We used simplest of them namely Newton's for our numerical investigation. In Newton's viscous fluid model [3] shear stress τ is calculated as shown in formula (3).

$$\tau = \eta\dot{\gamma} \qquad (3)$$

Newton model is appropriable for very flowable SRFC (such as was observed for self compacting concretes (SCC)). Increasing fibre content (or using non-SC concretes), material is obtaining τ_0 – motion starting yield stress, below which fresh SRFC is staying in stable state.

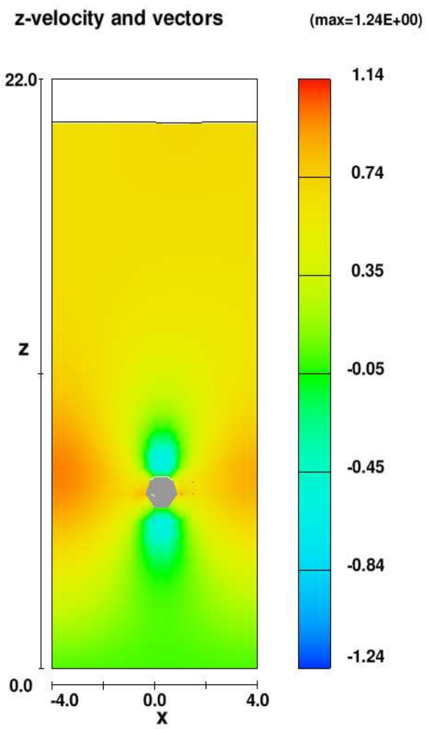

Fig. 4. Distribution of vertical speeds in viscous fluid after ball is dropped in and sinks under its own weight

Modelling of glass ball sinking process was performed by FLOW3D (see Fig.4.). Acquired data was comparable to natural experiment results. Average speeds were the same.

IV. Fibre rotation due of movement of liquide - experimental part

Now when viscous properties are known and approved thru computer calculation we can start experiment that was planned for understanding of fibre orientation in moving fluid. The same potato-starch with known dynamic coefficient of viscosity was poured into transparent container. As an experimental fibre was used steel fibre of 50 mm length and 1m in diameter. Container was field with potato-starch fluid such a way that the fibre when putted vertically was fully under the fluid surface, see Fig.6.

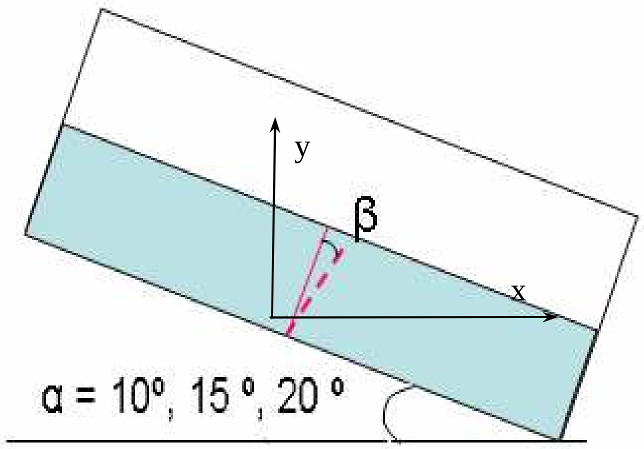

Fig. 6. Experimental model of fibres turn in fluid

In initial position fibre is in vertical position and the container is placed fully horizontally. Then container is turned sideways from horizontal position for required angle and test started. Movement of fibre in our fluid was observed and measured. Influenced by the movement of fluid fibre starts to decline to flows direction. Fibre is turning because of movement of fluid and gravitational forces. After declination process stops time and fibres top declination angle β were measured. Three experimental angles α - 10°, 15°, 20° were chosen, for each angle several attempts were done.

Acquired results were measured and average data was calculated and collected in table (see Tab.1).

TABLE 1

RESULTS OF NATURAL EXPERIMENTS OF FIBRE TURNING ATTEMPTS

α	*10*	*15*	*20*
β	43º	49º	62º
β	34º	44º	56º
β	41º	47º	51º
β	38º	43º	50º
β	34º	47º	58º
$\beta_{average}$	38º	46º	55º

Results show that greater declination of container gives bigger declination of fibre. That can be explained that, fluid moves more to the declination side when greater declination is done as well as with bigger angle gravity forces are working on fibre to decline it more.

V. Determination of horizontal speeds of viscous fluid

Previously mentioned experiment was numerically simulated using computer program FLOW-3D. Calculation results are shown in figures (Fig.7.-9.).

For ease of modelling was assumed that container stays horizontal, but vertical and horizontal axes of components of gravitational acceleration are changing angle [4].

For angle 10 degrees components of gravitational acceleration are gx=170,35 cm/s2, gz=-966,10 cm/s2, for 15 degrees gx=253,90 cm/s2, gz=-947,57 cm/s2, for 20 degrees gx=335,52 cm/s2, gz=-921,84 cm/s2. Container parameters: length l=20,8 cm, height h=9 cm, and the height of viscous

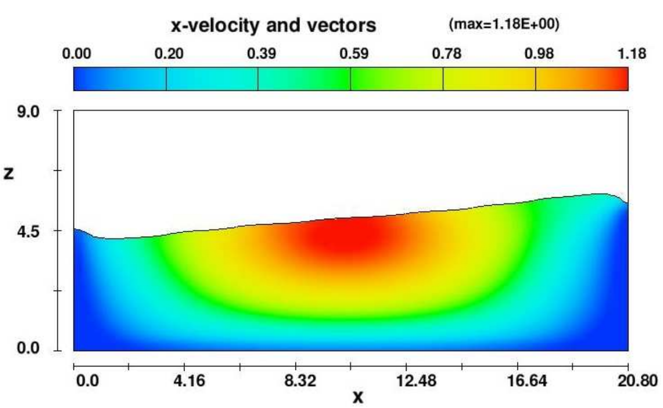

Fig. 7. Distribution of horizontal velocity after 3 seconds of container inclination to 10º and flow start

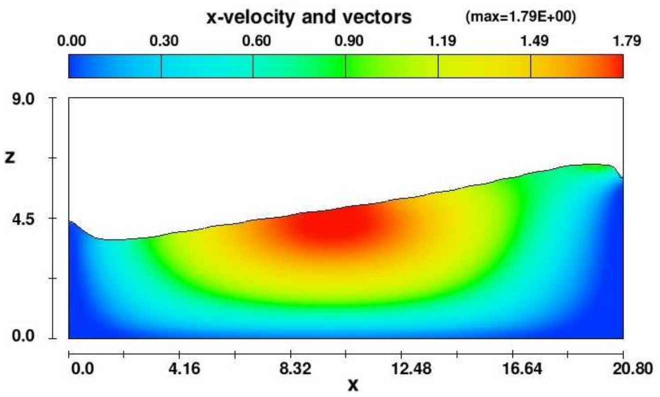

Fig. 8. Distribution of horizontal velocity after 3 seconds of container inclination to 15º and flow start

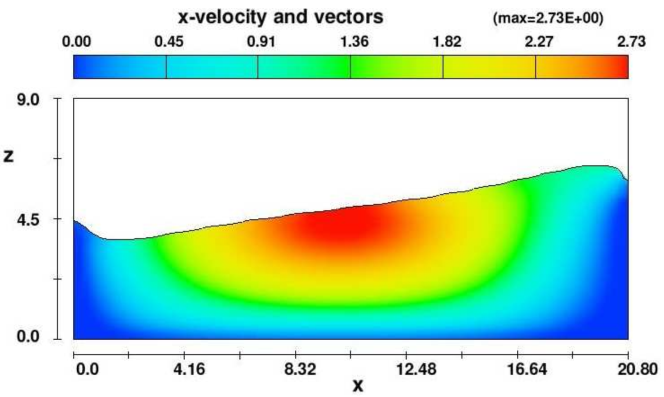

Fig. 9. Distribution of horizontal velocity after 3 seconds of container inclination to 20º and flow start

fluid in container 5 cm. The dynamic viscosity coefficient was determined earlier and it was η=486.14 g/cm·s, as a density of liquid potato-starch was used the same as density of water ρ=1 g/cm3.

VI. Dependence of fibre rotation on velocity gradients

When we know viscous parameters of our fluid and can approve them with numerical calculations then it was possible to go to next step of calculations – fibre orientation due of flow of liquid. These calculations afterwards can be used for fibre flow orientation prediction.

We presumed that gradient of horizontal speed (5) between fibre endpoint speeds is the parameter which will describe fibre orientation in flow.

$$grad\ v_x = \frac{v_1 - v_2}{l} \qquad (5)$$

where v1 is the horizontal speed of fibres top and v2 horizontal speed of fibres lower endpoint and l is length of fibre. Speed v2 is presumed that it stays equal to zero, because of conditions of experiment – it was presumed that at the modelling of viscous fluid because of boundary conditions between container and fluid our fluid sticks to container and because of that speed of lower part of fibre has zero velocity.

The simulation results at small angles of inclination of the container showed a linear dependence of slope fibre (final position) in a viscous fluid from the angle of inclination of the container. The simulation results and experimental data showed a good degree of convergence, as shown in Fig. 12.

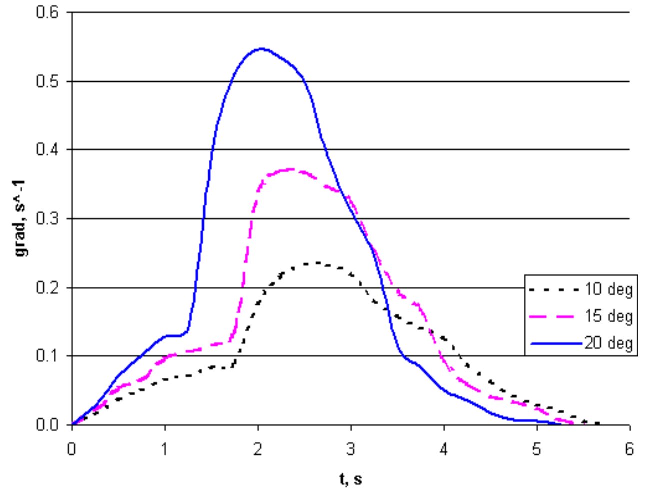

Fig. 10. Gradient of speed change in time after container declinations for 10°, 15°, 20° degrees

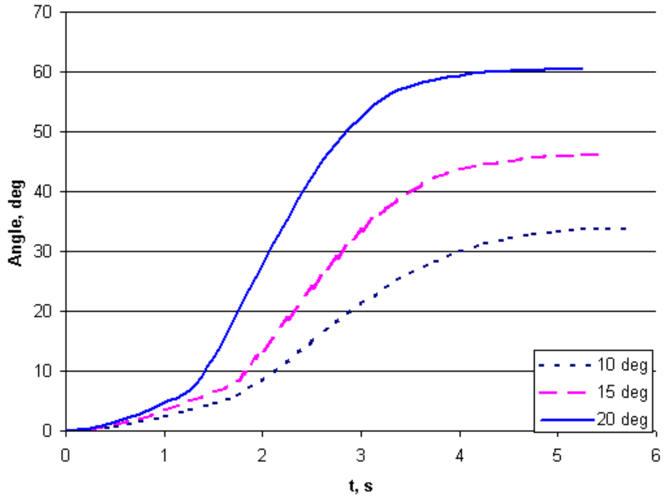

Fig. 11. Fibre angle change after declination of container for 10°, 15°, 20° degrees

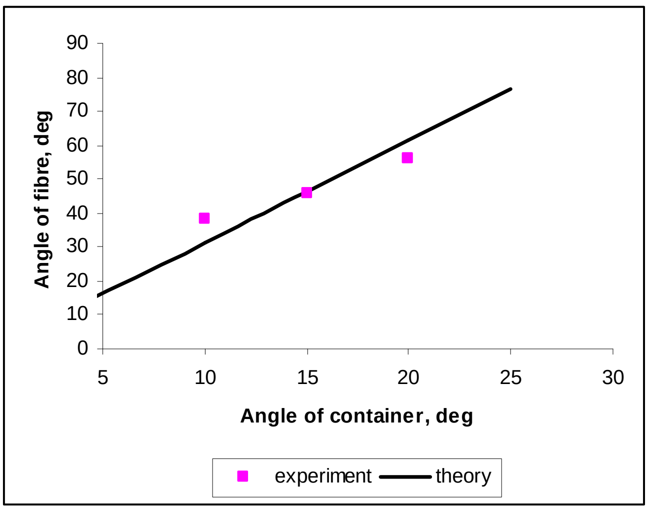

Fig. 12. Comparison of experimental data and modelling results.

VII. Conclusion

Since the simulation results showed good agreement with experimental data, the same calculations for velocity gradients can be used to determine the orientation of fibres in pouring of fresh concrete into the trench (Fig. 1). The results of simulation speeds of fresh concrete can be used to determine the relationship gradients of horizontal and vertical velocity at a time and the value of area under the curve gradient determines the angle of the fibre. When moving along the tube at an initial vertical orientation of the fibre or with an initial horizontal orientation at the location of fibre just in the center of the pipe turning fibres will not occur because of the equality of vertical velocity and zero gradient. Consequently, the zone of greatest risk of fibre will turn the tube end region, where fresh concrete goes into the trench, because there are changes in the velocity gradients are maximal.

References

1. **Eiduks, M., Kononova, O., Krasņikovs, A.** Fiber concrete viscous flow numerical simulation. *RTU zinātniskie raksti. 6. sēr., Mašīnzinātne un transports.* - 28. sēj. (2008.), 121.-131. lpp.
2. **Кошкин, Н.И., Ширкевич, М.Г**. *Справочник по элементарной физике*. 1960.
3. **Валландер, С.В**. *Лекции по гидроаэромеханике*. 1978.
4. **Roussel, N., Geike,r M.R., Dufour, F., Tharane, L.N., Szabo, P.** Computational modeling of concrete flow: General overview. *Cement and Concrete Research,* N 37 (2007), p. 1298 – 1307.

Maris Eiduks, M.sc.ing., lecturer, postgraduate student, Riga Technical University, Institute of Mechanics. Address: 6k-311 Ezermalas Street, Riga, LV-1006, Latvia. E-mail: maris.eiduks@rtu.lv

Andrejs Krasnikovs, Dr.sc.ing., Professor, Head of Laboratory of concrete mechanics, Riga Technical University, Institute of Mechanics. Address: 6k-317 Ezermalas Street, Riga, LV-1006, Latvia. E-mail: akrasn@latnet.lv

Ervīns Dunskis, B.sc.ing., Master student, Riga Technical University, Institute of Mechanics. Address: 6k-305 Ezermalas Street, Riga, LV-1006, Latvia.

Olga Kononova, Dr.sc.ing., Assoc.Professor, Riga Technical University, Institute of Mechanics. Address: 6k-115 Ezermalas Street, Riga, LV-1006, Latvia. E-mail: olga.kononova@rtu.lv

Māris Eiduks, Andrejs Krasnikovs, Ervīns Dunskis, Olga Kononova. Šķiedru orientācijas pētījumi viskozā vidē
Pētījums ir saistīts ar šķiedrbetona šķiedru plūsmas ātruma gradienta pētījumiem formu pildīšanas procesā. Tiek piedāvāts kontrolēt šķiedru orientāciju iepildes procesā, kontrolējot šķiedrbetona plūsmas ātrumu gradientu, kas pēc pētnieku domām ir izmatojams šķiedru orientācijas noteikšanai, tādā veidā iegūstot orientētu šķiedrbetonu, kas gan uzlabotu tā īpašības, gan ļautu optimizēt izmantojamo šķiedru daudzumu. Mērķis ir izstrādāt datormodeli, kas būtu derīgs šķiedru orientācijas vadīšanai un noteikšanai sapildītā formā.
Veicot datormodelēšanu svaiga šķiedrbetona formēšanas procesam caur iepildes cauruli, ir iegūti vertikālo un horizontālo ātrumu sadalījumi jebkurā procesa laika posmā.
Lai apstiprinātu domu, ka ir iespējams prognozēt šķiedras orientāciju betona plūsmā ar šķiedras pagrieziena ātruma gradientiem, tika noteiktas ar eksperimentu izvēlēta viskoza šķidruma īpašības. Tika veikts eksperiments ar vienas šķiedras pagriešanos caurspīdīgā viskozā šķidrumā, kā arī modelēts process datorprogrammā. Eksperimentālie rezultāti uzrādīja apmierinošu sakritību ar datorsimulācijā iegūtajiem rezultātiem. Tādējādi var secināt, ka šķiedru pagriešanās ātruma gradienti var tikt izmantoti šķiedru orientācijas noteikšanai šķiedrbetonā.

Марис Эйдукс, Ардрей Красников, Эрвин Дунскис, Ольга Кононова. Исследование ориентации волокна в вязкой жидкости
Данная работа представляет собой предварительное исследование, связанное с определением градиента скорости волокна в потоке свежего бетона, который предположительно является одним из ключевых параметров для компьютерного моделирования ориентации стального волокна в процессе заливки. Целью исследования является получение компьютерной модели для прогнозирования ориентации стального волокна в конкретном процессе заливки, которая была бы полезным параметром для прогнозирования конкретных механических свойств, оптимизации процесса заливки и сокращения расходов при правильном использовании ингредиентов. Ориентация волокна в армированных бетонах важна для получения лучших механических свойств с оптимальной концентрацией волокна. Для процесса заливки свежего бетона в траншею были получены распределения вертикальной и горизонтальной скорости в любой момент времени (компьютерное моделирование).
Для подтверждения возможности определения ориентации волокна по градиентам скоростей было проведено моделирование поведения одного волокна в наклонном контейнере с вязкой прозрачной жидкостью – крахмалом. Для успешного моделирования был определен коэффициент динамической вязкости жидкого крахмала. Результаты эксперимента по поведению волокна в наклонном контейнере показали удовлетворительное совпадение с результатами моделирования. Соответственно, расчет по градиентам скоростей может быть использован и для определения положения волокна при заливке фибробетона.