RIGA TECHNICAL UNIVERSITY
Faculty of Civil Engineering
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Doctoral study program „ Civil engineering"

MECHANICAL PROPERTIES INVESTIGATION OF NON-HOMOGENEOUS AND ORIENTED FIBER-REINFORCED CONCRETE

Summary of the Doctoral Thesis

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Dr. sc. ing.
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CONFIRMATION

I certify that the thesis I have presented for obtaining the doctor degree of engineering science of the Riga Technical University is my own work. The thesis has not been submitted to any other university for obtaining the scientific degree.

Vitalijs Lusis __________________ (Signature)

Date: __________________

The thesis has been written in English. It contains introduction, 4 chapters, conclusion and bibliography, 245 figures and illustrations, in total 195 pages. There are 190 references in bibliography.

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GENERAL DESCRIPTION OF THESIS

The topicality of the theme

The use of SFRC has increased significantly in the last ten years with the high performance concrete becoming modern building material used in different types of constructions worldwide. Today FRC constructions are made by mixing in the fibers chaotically without prior organising them with regard to the purpose of construction. By designing FRC constructions it is assumed that the distribution of fibers will be even throughout the construction material with all directions of fiber orientation. It is assumed that the mixing process of FRC is aimed at obtaining maximally homogenous mix with fibers evenly distributed. However, this assumption May be invalid because the mixing process of FRC is followed by several operations including pumping the concrete mix through pipes and casting it in a mould. Laminar and even turbulent flows with significant shear deformations occur during these operations leading to uncontrolled random distribution of fibers. This contradicts the assumption that fibers are evenly distributed throughout the construction material with all directions of fiber orientation because zones with lower concentration of fibers and undesirable fiber orientation can be observed.

Justification for the PhD dissertation

Today the major development trend in the world for the concrete is fast increase of its compressive strength permitting to create lighter and more cost-effective thin-walled structures with significantly lower consumption of the concrete than using the traditional concrete. It is worth noting that together with the strength other deformative properties change as well — elasticity module grows (over 45 GPa), Poisson's ratio decreases (under 0.15) — its critical deformation decreases under 0.25–0.35 %. There is an increasing demand for concrete with high compression strength and high loadbearing capacity in the cracking stage. One of the most efficient methods permitting to fulfill the above requirements is addition of the short fibers or fibers in the concrete obtaining the FRC. Dispersion of fiber can be combined with the traditional reinforcement or used alone. Relevance of the method strongly depends on the fiber orientation in the material; it is a topic with little research done at the moment.

Importance of the topic

The existing method for the FRC application is simple: fibers are mixed together with rest of the concrete components, filled into the mould and the concrete gradually hardens. Designing of such structures as well as the relevant scientific research is based on incorrect hypothesis that fibers in the mix are oriented in three reciprocally perpendicular directions with equal probability, namely, the FRC is mechanically isotropic. And the second unnecessary aim is making efforts to obtain homogenous fiber distribution in the Volume of concrete mix. The reality sometimes is very different from the assumed hypothesis and aims. After the mixing process several operations involving significant shear strain are performed with the mix: pumping and transporting, pouring into mould, radial orientation, vibrocompressing using concrete vibrator with circumferential amplitude of the movement that creates circumferential flow of the concrete mix around it. These processes cause uncontrolled fiber movement in concrete and their orientation in specific parts of the concrete. The location of these parts is random; it depends on the position of the concrete pipe opening in relation to the structure mould. From the other side, tensile stresses are unevenly distributed in the structure; therefore the requirement to have evenly distributed reinforcing elements in the structure with these elements chaotically oriented is a priori irrational and uneconomical as the expensive fibers will be located in the zones of the structure where they will not contribute to the loadbearing function.

Scientific novelty and practical application

There have been some attempts to create fiber structures corresponding to the orientation of tensile stresses and their distribution in the concrete. However, the theoretical and practical experimental research carried out in the RTU Laboratory of Concrete Mechanics and patents of the RTU inventions confirm that it is possible to obtain fiber distribution in the concrete with methods that are economically competitive, for example, LV14257, fiber orientation in the predefined direction (fiber 1D orientation) LV14540, LV14684, LV14667, LV14849 and fiber 2D orientation in thin-walled structures: LV14308, LV14408.

The research on cracking process in non-homogenous FRC prisms (with fiber distribution in layers) under bending has been done by conducting experiments and performing numeric modelling as well as rational fiber arrangement has been determined.

The research on load-bearing capacity of the FRC with fibers oriented parallel and its cracking process under bending load has been done; higher load-bearing capacity of the non-homogenous FRC compared to the traditional FRC (with chaotic fiber distribution and orientation) has been proved.

The objectives of the thesis

To conduct a research on the load-bearing capacity of the non-homogenous FRC under bending load and to compare the results to the homogenous FRC with similar properties.

To develop technologies and devices for production of the non-homogenous FRC with high load-bearing capacity under bending load.

To use the FRC in thin-walled structures and to create thin-walled structure production technology.

Research objectives

To compare the load-bearing capacity for the non-homogenous FRC structures (beams) and for the structures made of traditional FRC (with chaotic fiber distribution in Volume of the structure) by producing the beams and testing their bending strength until failure;

To study mechanical properties of the FRC with non-homogenous fiber distribution in Volume of the structure under bending load in the cracking stage with experiments and modelling on the computer;

To develop production technology for building elements made of oriented FRC with non-homogenous fiber distribution;

To develop new production technology for the FRC shells.

Raised for defence

- Results of the experimental tests on homogenous and non-homogenous FRC with identical amount of fibers, approving the higher load-bearing capacity of the non-homogenous FRC under the bending load.
- The developed numeric model and its implementation results in modelling load-bearing capacity of homogenous and non-homogenous FRC in the cracking stage.
- Two new non-homogenous FRC production technologies as well as new technology-related devices.
- Thin-walled FRC shell production technology

THE APPROBATION OF THE RESULTS

List of relevant Conferences

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CONTENTS OF THE THESIS

PhD dissertation consists of four main chapters.

The first chapter begins with literature review, where the need for conducting a study on the mechanical properties of non-homogenous and oriented FRC was justified.

In the second chapter research methods, materials and setup were described.

In the third chapter non-homogenous and oriented FRC were tested by analysing and comparing the results as well as conducting a research of mechanical properties. In the experiments layer geometry of the SFRC specimens and percentage of fiber in the layers were changed (fibers with various geometry were used in experiments). Four point bending test results of the SFRC prisms were described. An experiment was conducted with X-ray and image analysis of the oriented SFRC. "Weak" zones of the SFRC, appearing under the impact of vibrations, were determined. Program of experiments was implemented with approbation of four different methods of fiber distribution and orientation. New fiber distribution and fiber orientation devices were approbated as well.

In the fourth chapter modelling of the experimental shell by using modelling CAD software SOLIDWORKS was done. Numeric algorithm was created using MATLAB software for estimating the load-bearing capacity of the homogenous SFRC elements and SFRC elements with fiber distribution.

Steel fiber distribution in the FRC „Process and device for manufacturing fiberconcrete non-homogeneous structural elements”

The SFRC with pre-organised fiber structure was created based on the invention patent LV14257 „Process and device for manufacturing fiberconcrete non-homogeneous structural elements” [5]. Concrete mix was poured into a mould. Then the concrete mix was levelled according to predetermined level in the mould. It was followed by sprinkling certain amount of fibers on surface of the concrete evenly and pressing the fibers into concrete mix until the predetermined level. This operation was performed by using a grid containing vertical cells of various sizes; size of the biggest is smaller than length of the fibers but size of the smallest is larger than the biggest grains of aggregates. The grid was vibrated during the pressing process. The fibers were incorporated in eight different ways; while the total amount of fibers is identical for eight groups of specimens being 60 kg/m^3, the only difference concerns their distribution.

The specimens were tested using 4PBT. The specimens with the highest concentration of fibers in the tensile zone showed higher load-bearing capacity, see Fig. 1.

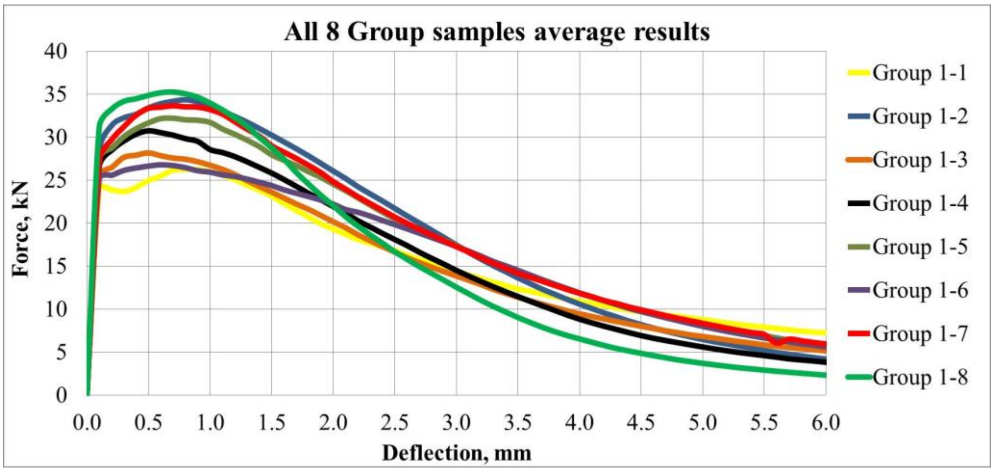


Fig. 1 Force and displacement average results for Groups 1-1 to 1-8

Deformation energy of the SFRC (F-ε) and scatter of results were determined, see Fig. 1 and 2. It is shown in the diagrams that the specimens from Group 1-1 with fibers distributed chaotically show the lowest maximum load and the lowest consumption of deformation energy in the crack opening stage compared to the layered specimens from Groups 1-2 – 1-8 with fibers only in certain layers of the specimens.

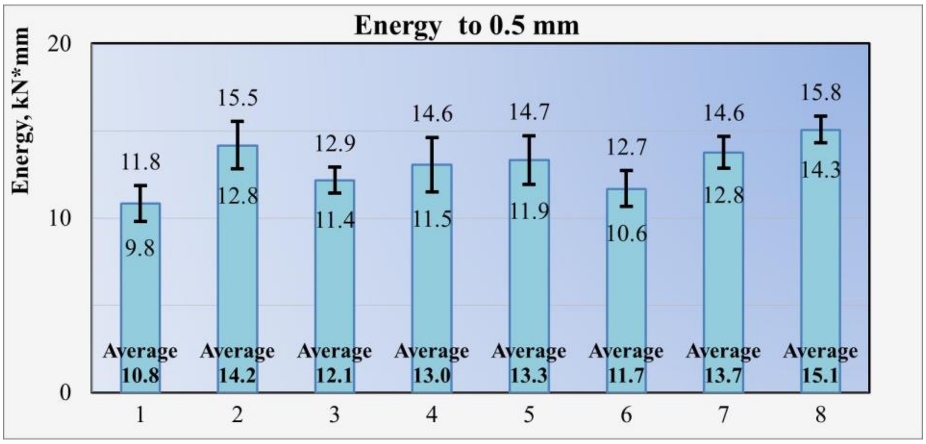
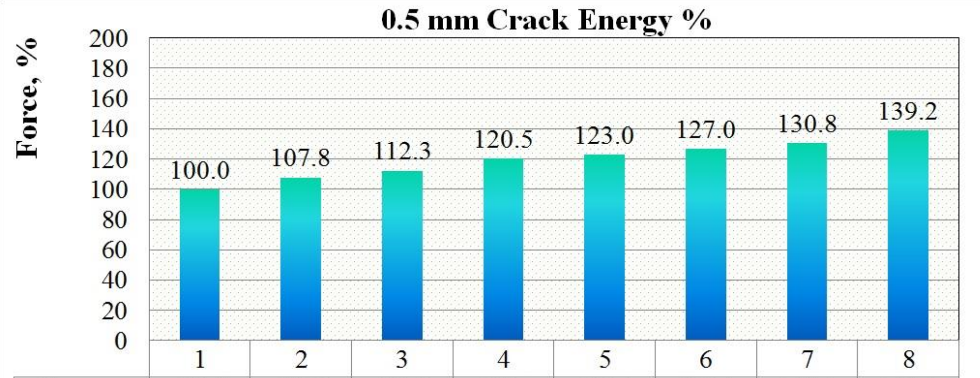


Fig. 2 Deformation energy and confidence limit Groups 1-1 – 1-8 to 0.5 mm

In the diagram of Fig. 3 the average percentage of deformation energy in Group 1-1 with deflection 0.5 mm was assumed to be 100 %; therefore the respective specimens in Groups 1-2 – 1-8 show from 107.8 % to 139.2 % compared to the flexural strength indicators for homogenous specimens.



	1	2	3	4	5	6	7	8
%	100.0	107.8	112.3	120.5	123.0	127.0	130.8	139.2
Group Nr.	1-1	1-6	1-3	1-4	1-5	1-7	1-2	1-8

Fig. 3 Percentage of deformation energy

Technology of fiber orientation in the FRC for the inventions „Method for reinforcing the fiber concrete structure” and „Technical device for fiberconcrete oriented reinforcement”

The SFRC with pre-organised fiber structure was created based on the invention patents No. LV14667, „Method for reinforcing the fiber concrete structure” [9] and No. LV14684, „Technical device for fiberconcrete oriented reinforcement” [10]. During the experiment fibers were oriented outside the SFRC structure; specimens were created with fibers placed in the predefined tensile zone of the specimens in the direction of main tensile stress trajectories as close as possible to the level of main tensile stresses.

The fibers were incorporated in four different ways/groups. Each group consisted of six specimens, in total 24 specimens with SF were prepared; the total amount of fibers was identical for all groups of specimens being 54.4 kg/m^3. In total 72 fiber "catch" sets were prepared with the fibers incorporated at the specific angle; four fiber "catch" sets were incorporated in each specimen. Consequently there was 140 fibers in each "catch" being grouped as follows: 24 "catch" sets with fiber orientation at an angle 90° in relation to the expected direction of the cracks (direction of tensile force), 24 "catch" sets with fiber orientation at an angle 75° in relation to the expected direction of the cracks (direction of tensile force). In addition, 24 "catch" sets without fibers were prepared. Fibers were incorporated in the "catch" sets alternately with the beams.

Specimens were tested using 4PBT, the test results of oriented SFRC specimens (prisms) from Groups 2-3 and 2-4 were compared with the traditional FRC from Groups 2-1 and 2-2. Specimens with the highest fiber concentration in the tensile zone of the prisms oriented in the direction of main tensile stress trajectories showed higher load-bearing capacity, see Fig. 4.

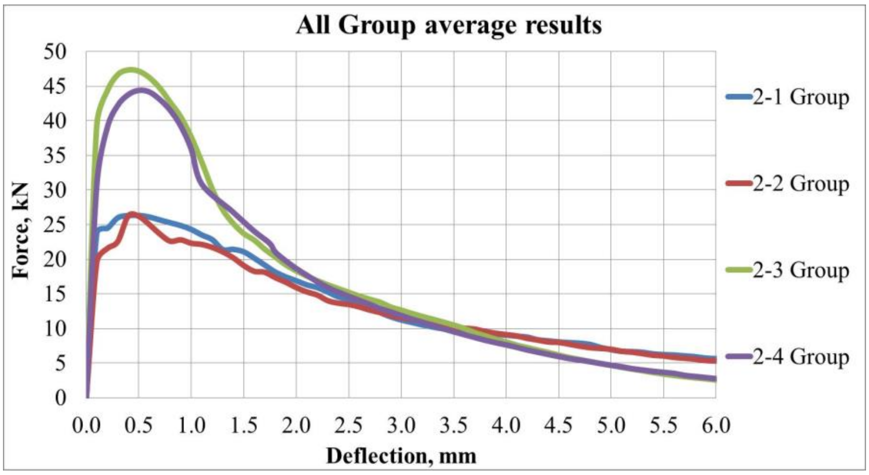


Fig. 4 Comparison of the average deflection results in all groups

Deformation energy of the FRC and dispersion were determined, see Fig. 5. It can be seen in the diagrams that the specimens from Groups 2-1 and 2-2 with fibers distributed chaotically show the lowest maximum load and the lowest consumption of energy in the crack opening stage compared to the layered specimens from Groups 2-3 and 2-4 with oriented fibers only in certain layers of the specimens.

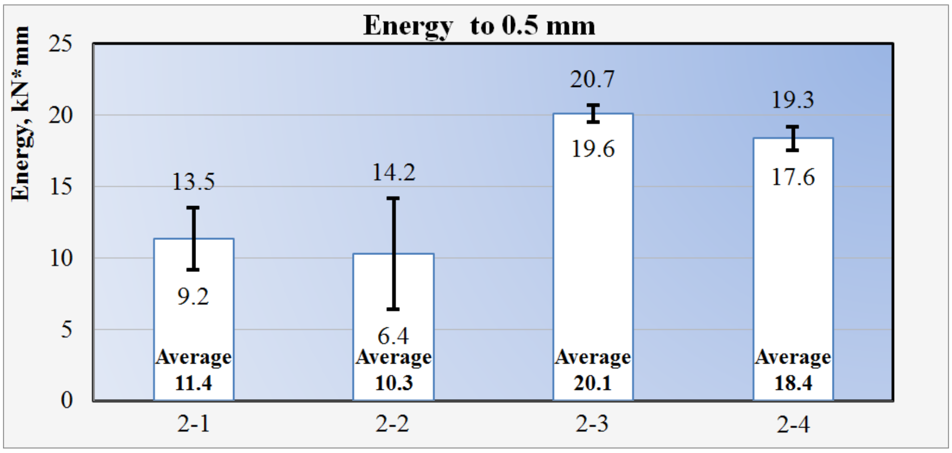


Fig. 5 Deformation energy and confidence limit to 0.5 mm

In the diagram of Fig. 6 the average percentage of deformation energy in Group 2-2 with deflection 0.5 mm was assumed to be 100 %; therefore the respective specimens in Groups 2-4 – 2-3 show from 107.8 % to 139.2 % compared to the flexural strength indicators for homogenous specimens. The highest results were obtained from the specimens in Group 2-3.

Group 2-1 and 2-2 specimens showed lower load bearing capacity in the cracking stage compared to the specimens with oriented fibers distributed in the Volume of specimens.

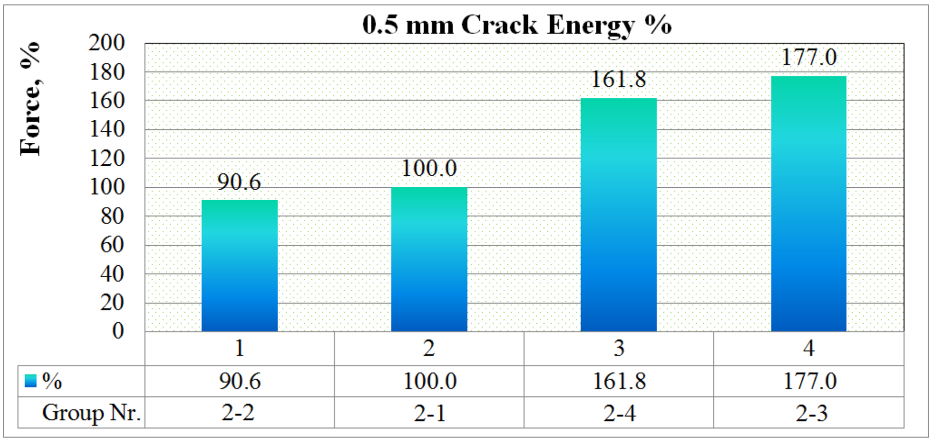


Fig. 6 Percentage of deformation energy 0.5 mm

Technological process for orientation of fibers in the FRC according to the invention „Method and device for the oriented reinforcing process of the fiberconcrete"

The SFRC with pre-organised fiber structure was created based on the invention LV14540 „Method and device for the oriented reinforcing process of the fiberconcrete" [4]. During the experiment SFRC specimens with fibers oriented in the direction of main tensile stress trajectories as close as possible to the level of main tensile stresses were created.

The fibers were incorporated in two different ways. The total amount of fibers was identical for two groups of specimens being 10 kg/m^3, the only difference concerns their distribution. Three identical prisms from each type of SFRC were prepared, 6 specimens in total. For preparation of the SFRC specimens fiber flow was directed on the existing concrete layers with the specified thickness in two layers of the structure. In the filling process mould is moved in direction of the flow with the speed equal to the fiber flow speed in relation to the orientation plate to maintain the fiber orientation during this process.

Specimens were tested using 4PBT, the test results of oriented SFRC specimens (prisms) from Group 3-2 were compared with the traditional FRC from Group 3-1 Specimens with the highest fiber concentration in the tensile zone of the prisms oriented in the direction of main tensile stress trajectories showed higher load-bearing capacity, see Fig. 7. Deformation energy of the SFRC and scatter of results were determined, see Fig. 8. It is visible in the diagrams that specimens with chaotic fiber distribution in Group 3-1 show the lower maximum load and lower consumption of deformation energy in the crack opening stage compared to the specimens of Group 3-2, where fibers are filled in layers of the specimen and oriented in the direction of main tensile stress trajectories.

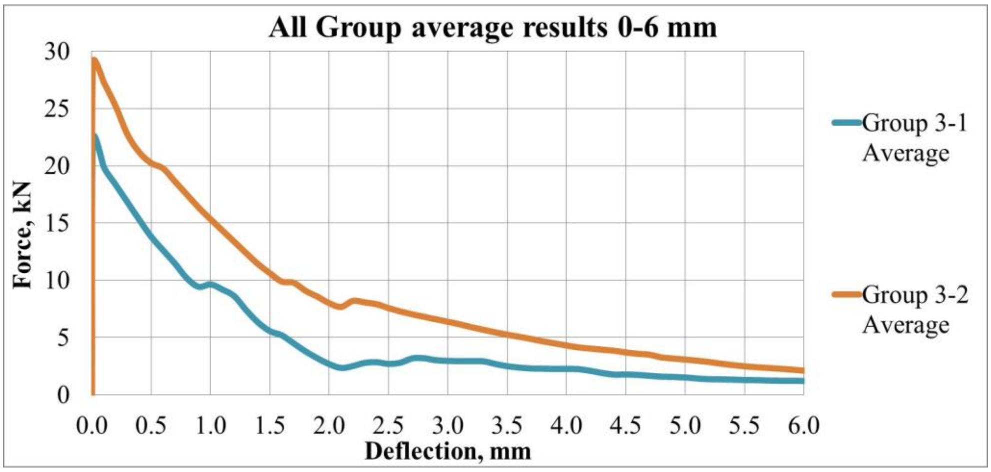


Fig. 7 Load — vertical deflection experimental graphs for specimens Group 3-1 and 3-2

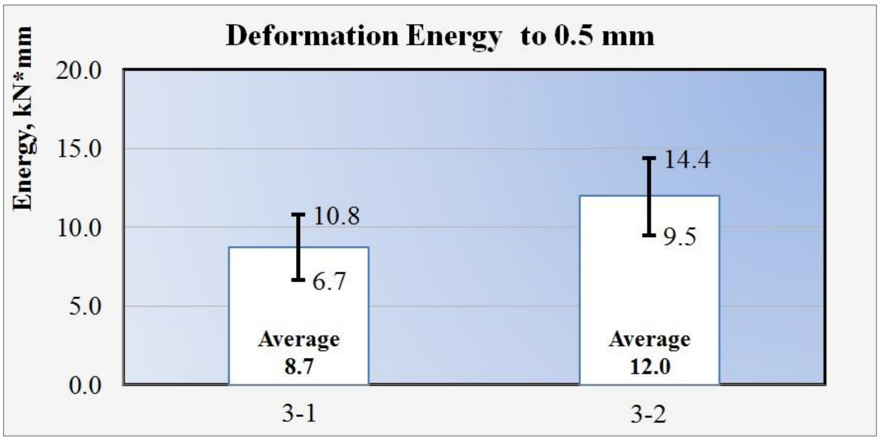


Fig. 8 Deformation energy and confidence limit Groups 3-1 – 3-2 to 0.5 mm

In the diagram of Fig. 9 the average percentage of deformation energy in Group 3-1 with deflection 0.5 mm was assumed to be 100 %; therefore the respective specimens in Groups 3-2 – 2-3 show from 107.8 % to 139.2 % compared to the flexural strength indicators for homogenous specimens. Group 3-1 specimens showed lower load bearing capacity in the cracking stage compared to the Group 3-2 specimens with oriented fibers distributed in the Volume of specimens.

The SFRC with pre-organised fiber structure was created based on the invention patent LV14325 „Technological process for orientation the fibers of fiberconcrete" [6]. During the experiment SFRC specimens were created with fibers oriented in the direction of main tensile stresses (by orienting in the ready SFRC mix) as close as possible to the level of main tensile stresses and the test results were compared with the results of traditional FRC.

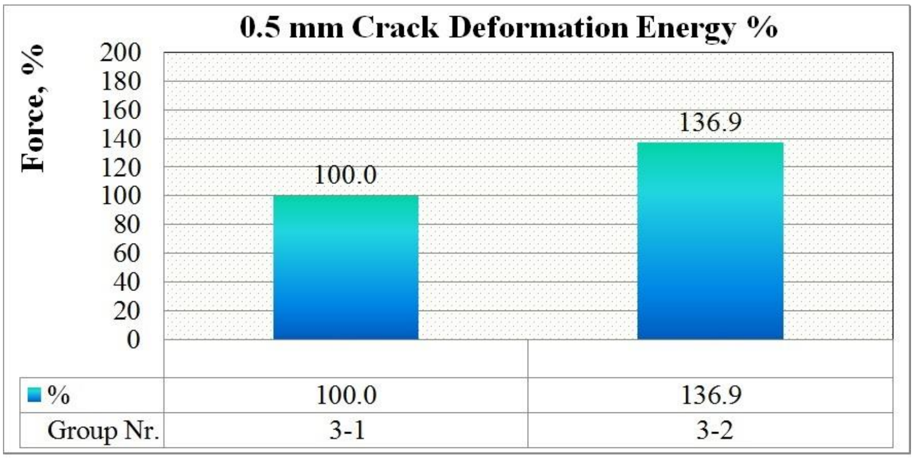


Fig. 9 Percentage of deformation energy 0.5 mm

Fiber orientation technological process according to the invention „Technological process for orientation the fibers of fiberconcrete”

Three types of SF were incorporated into prisms in two ways for three groups of specimens; their total amount being 31.25 kg/m^3 for all and the only difference lays in fiber distribution.

SFRC mass was poured into a mould to the predefined level, then fibers in the SFRC were oriented by using two „rakes” and moving them so that the bars of one "rake" would be positioned in gaps among bars of another "rake". It resulted in turning the fibers in the direction of longitudinal movement of „rakes", namely, the fibers were oriented in the direction of tensile stress. The FRC mix was vibrated in vibration exciter in order to facilitate the fiber orientation.

For creation of the SFRC specimens an innovative method of fiber orientation was used in the experiments; according to this method two „rakes” consisting parallel bars, with the distance among them exceeding the length of separate fibers, are moved in opposite directions in the concrete mix consisting fibers [6]. It resulted in turning the fibers in the direction of longitudinal movement of "rakes", namely, the fibers were oriented in the direction of tensile stress. Both "rakes" can be vibrated for the same purpose.

It can be concluded from the diagrams seen in Fig. 10–11, that specimens with chaotic fiber distribution in Group 4-1 show the lowest maximum stress and lower consumption of deformation energy in the crack opening stage compared to the specimens of Group 4-4, where fibers are divided in layers of the specimen and oriented in the direction of main tensile stress trajectories.

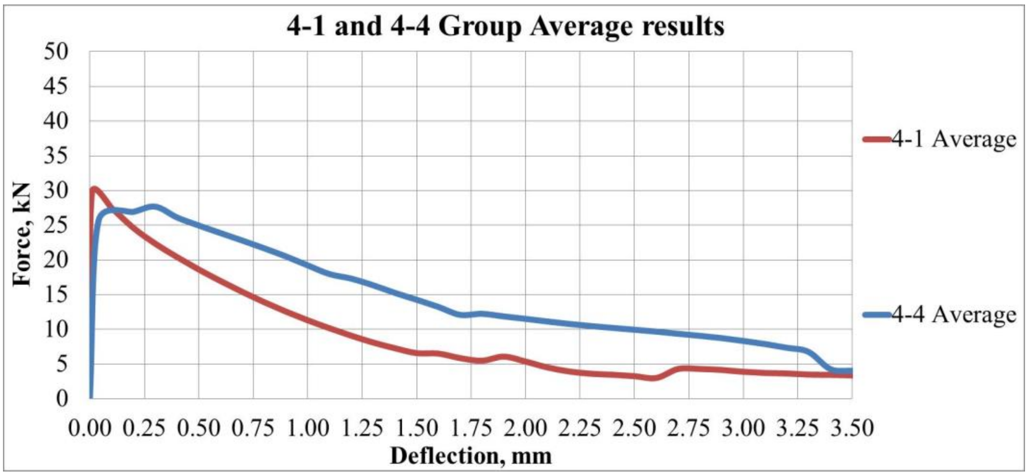


Fig. 10 Load — vertical deflection experimental graphs for specimens Group 4-1and 4-4

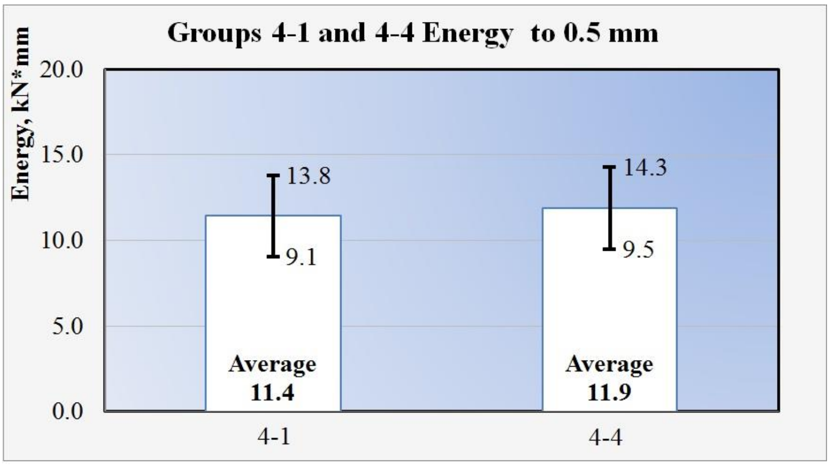


Fig. 11 Deformation energy and confidence limit Groups 4-1 – 4-4 to 0.5 mm

In the diagram of Fig. 12 the average percentage of deformation energy in Group 4-1 with deflection 0.5 mm was assumed to be 100 %; therefore for the respective specimens in Group 4-4 the deformation energy reaches 104 % compared to the flexural strength indictors of homogenous specimens.

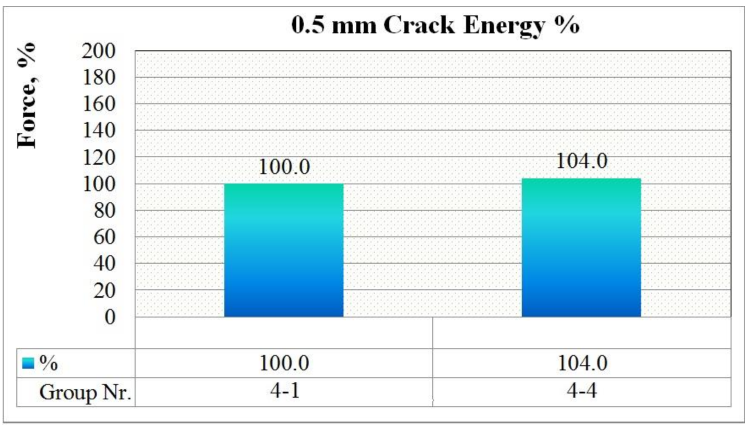


Fig. 12 Percentage of deformation energy

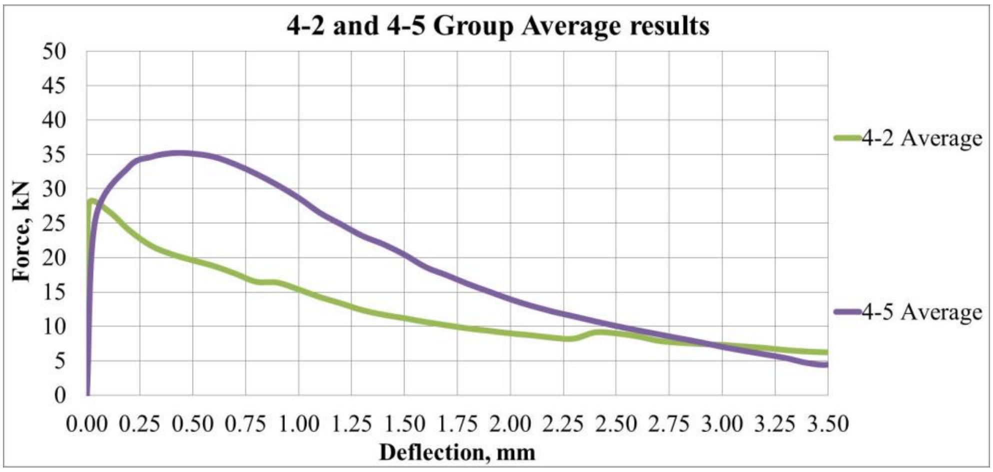


Fig. 13 Load — vertical deflection experimental graphs for specimens Group 4-2 and 4-5

Specimens with chaotic fiber distribution in Group 4-2 show lower maximum load and lower consumption of deformation energy in the crack opening stage compared to the specimens of Group 4-5, where fibers are oriented in the direction of main tensile stress trajectories, see Fig. 13–15.

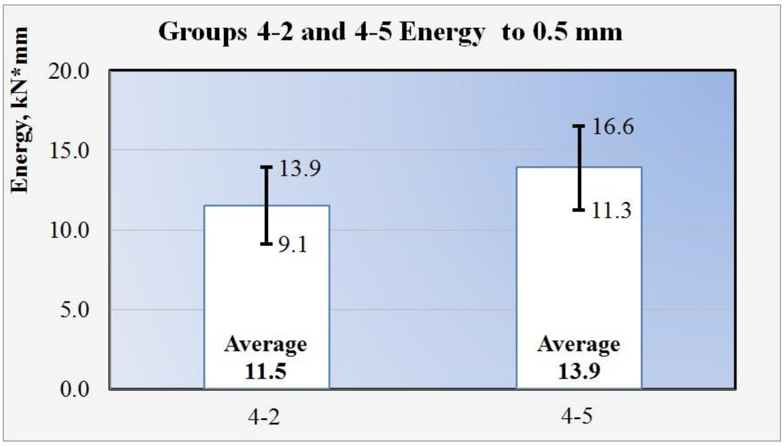


Fig. 14 Deformation energy and confidence limit Groups 4-2 – 4-5 to 0.5 mm

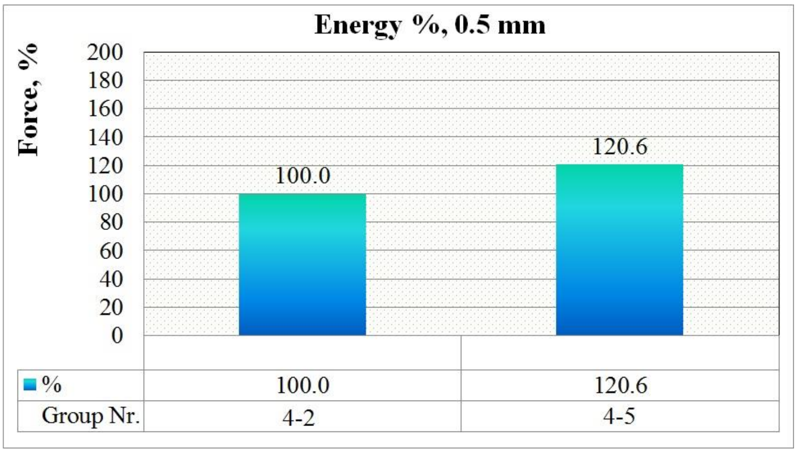


Fig. 15 Percentage of deformation energy

In the diagram of Fig. 15 the average percentage of deformation energy in Group 4-2 with deflection 0.5 mm was assumed to be 100 %; therefore for the respective specimens in Group 4-5 the deformation energy reaches 120.6 % compared to the indictors of homogenous specimens.

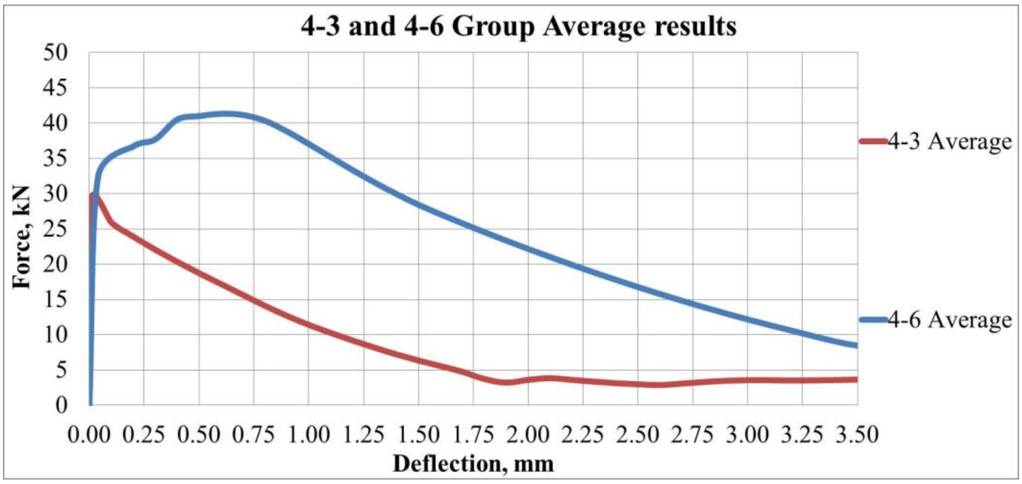


Fig. 16 Load — vertical deflection experimental graphs for specimens Group 4-3 and 4-6

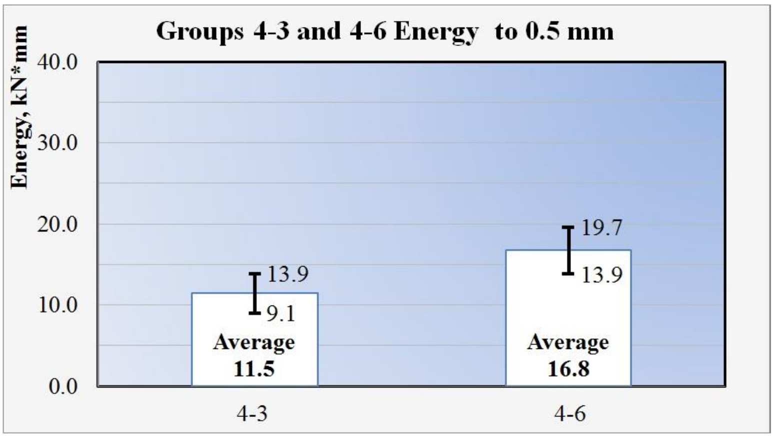


Fig. 17 Deformation energy and confidence limit Groups 4-3 – 4-6 to 0.5 mm

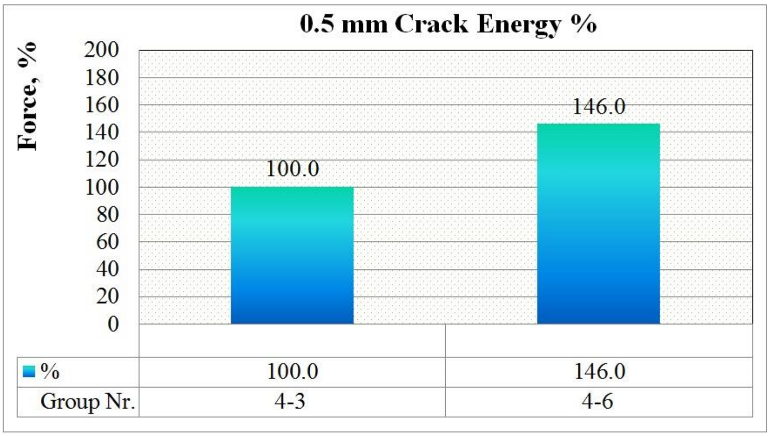


Fig. 18 Percentage of deformation energy

Specimens with chaotic fiber distribution in Group 4-3 show lower maximum load and lower consumption of deformation energy in the crack opening stage compared to the specimens of Group 4-6, where fibers are oriented in the direction of main tensile stress trajectories, see Fig. 16–18.

In the diagram of Fig. 18 the average percentage of deformation energy in Group 4-3 with deflection 0.5 mm was assumed to be 100 %; therefore for the specimens in Group 4-6 the deformation energy reaches 146 % compared to the indictors of homogenous specimens.

X-ray images of fiber reinforced concrete

Behaviour of the pre-organised fibers in the vibro-compressed FRC specimens was examined [6] after fibers have been oriented.

During the experiment two SFRC specimens were created with fibers oriented in the direction of main tensile stress trajectories: in the SFRC specimens 5-2 and 5-3 SF were oriented in the concrete mix in the direction of trajectories of main tensile stresses according to the method LV14325 as well as one specimen 5-1 with the traditional FRC. After incorporation of fibers the specimens were vibrated on the vibration exciter for 1 minute. The X-ray images of specimens were taken and the specimens were tested using 4PBT; the results and images were analysed.

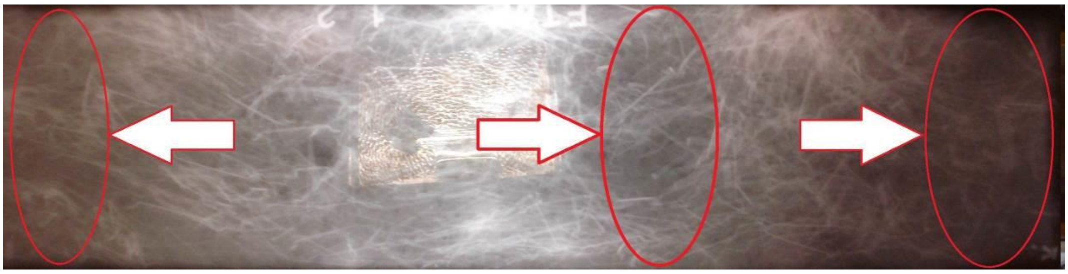


Fig. 19 SFRC specimens 5-1 X-ray image, side view [2,3]

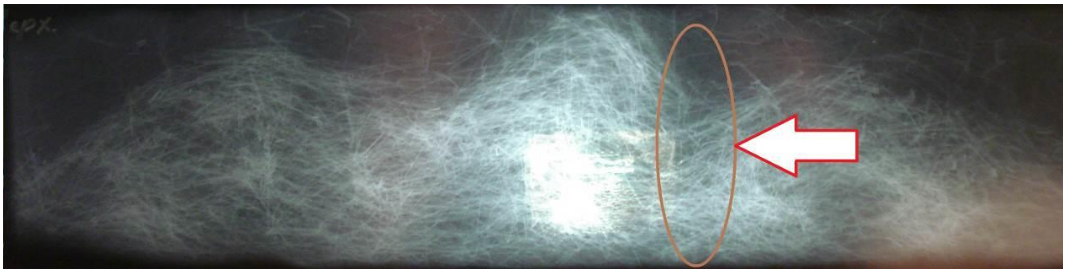


Fig. 20 SFRC specimens 5-2 X-ray image, side view [2,3]

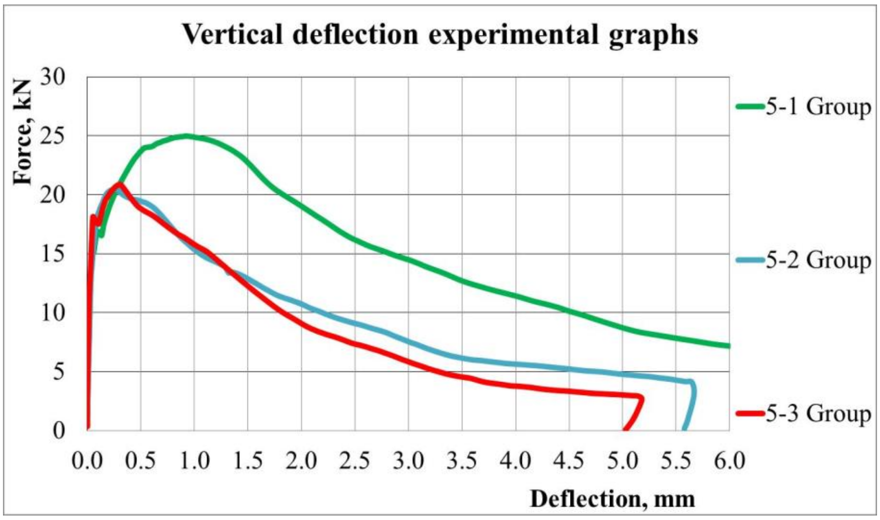


Fig. 21 Load — vertical deflection experimental graphs for specimens all Groups 0–6 mm

The "weak" zones of the specimens with the lowest concentration of fibers are clearly visible in the X-ray images, see Fig. 19–20. Four point bending tests confirmed that the vibration of specimens after fibers have been incorporated has negative impact on the fiber distribution in the specimen, see Fig. 21. Interference of the waves (standing wave) created by the vibration and reflected from the mould and the turbulence it creates in the mix

GFRC shell production technology by using pneumatic mould

Pneumatic mould was created for the production of shell structures. Approbation of a new method for thin-walled shells with 2D fiber orientation has been done corresponding to the invention patent No. LV14277 „Technological process of concrete shell production" [7].

The mould height 9 mm used in the experiments allows producing GFRC construction with 2D fiber orientation because length of the used glass fibers was 12 mm.

Fig. 22 Technological process by using pneumatic mould

Pneumatic mould design: plywood 1000 × 1000 × 9 mm, sheet of rubber 1000 × 1000 × 1 mm, frame with 9 mm high and 30 mm wide edges, air release valve. Rubber sheet was covered on flat surface. Rubber was fastened on edges over the perimeter of the shell. Mould surface was stretched and evened in order to avoid folding. Connection points between edges of the mould and surface of its base were sealed. Inner size of the mould: 940 × 940 mm, height 9 mm.

GFRC is applied on the prepared flat surface of mould and levelled. An air is pumped into the mould with an air pump until the predetermined size of the shell (height) 110 mm, see Fig. 22. To prevent rapid hardening, as soon as the intended height was reached, surface of the shell was immediately sprayed with the protective coat of water-soluble polymer emulsion, which did not allow evaporation of water. The shell was hardened not allowing mould deformations and controlling the pressure in the mould continuously during the hardening process. After 24 h the necessary technological strength of the GFRC was reached and the shell was demoulded by releasing air from the mould.

Use of the pneumatic moulds allows industrialization of the spatial structure production from concrete to a high degree; there are several advantages of their use:

1. The mould can be used repeatedly;
2. Elasticity of the form (surfaces with complicated shapes form the architectural and technological point of view are created by curving);
3. Allows producing shells with smooth inner and outer surfaces;
4. Transportation: the weight of the mould and Volume of the material is smaller compared to the wood or steel moulds.

GFRC shell production technology by using gravitation mould

Gravitation mould was created for the production of shell structures. Approbation of a new method for thin-walled shells with 2D fiber orientation has been done corresponding to the invention patent No. LV14308; „Technological process for thin concrete shells production" [8]. New GFRC shell reinforcement technology was developed and approbed corresponding to the invention patent No. LV14679 „Method for reinforcing concrete and fiberconcrete structure [1].

During the experiment weft knitted fabric made from E-glass cabled yarn was used for the reinforcement of the GFRC shell. Mould design. Two plywood frames sized 1000 × 1000 mm having a circle with diameter 900 mm (the inner diameter of the mould) sewed out in the center were prepared. The height of frame edges corresponds to the thickness of the shell 12 mm. On edge of the frame a sheet of acid- and alkali-resistant rubber (EPDM) sized 1000 × 1000 × 1 mm was attached, second frame was attached on the rubber. Frame with the attached sheet of rubber sheets was placed on the table (the circle with corresponding diameter, namely, 900 mm, made from the 12 mm plywood, was inserted in the lower frame).

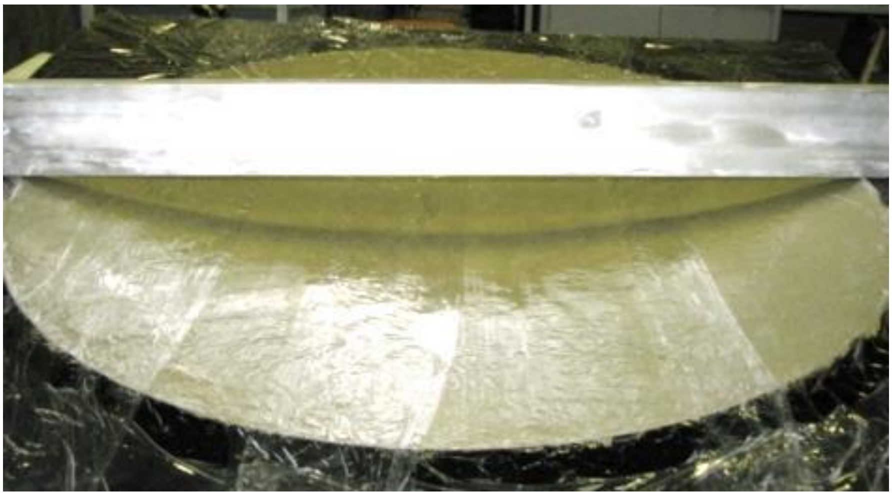


Fig. 23 Gravitation mould

Concrete was poured into mould, levelled and then processed according to the technology. Technological process consists of the following operations:

Layer of the concrete mix was applied to the flat floor of the prepared mould, which was covered with weft knitted fabrics of the E-glass fiber, followed by another layer of the concrete. This operation was repeated. Surface of the concrete was pressed and levelled. The mould filled with concrete layer was lifted (plywood circle inserted in the lower frame remained on the bench) allowing its floor, made from the elastic material, with the concrete layer in it to hang in convex form, see Fig. 23. The lifted mould with the concrete layer in it was put on supports located under frame of the mould. The shell was hardened not allowing deformation of the mould. The shell was demoulded after hardening.

The technology allows creating thin shells, moulds can be used repeatedly, it is possible to obtain GFRC shells of various shapes. Unlike pneumatic moulds, where the geometry is determined by the radial pressure of injected air, this method allows obtaining geometry of the shell corresponding to the trajectories and distribution of main tensile/flexural stress created by the vertical load (mainly dead weight) evenly distributed on the surface of the shell. It is closer to the orientation directions of main stresses created by the real construction loads without bending moment and allows creating thinner and lighter shells which are less expensive as well. By hanging in the convex form, mix is slightly pressed, which reduces possibility of early age cracking of concrete.

In the fourth chapter modelling of the experimental shell by using modelling CAD software SOLIDWORKS was done [11]. The shell was modelled with a base that is clamped in the circumference and was loaded with distributed load that is applied vertically. The difference in results depending on the shell geometry is significant for the shell with square or circle, the maximal equal stress for the shell with base circle is 2.35 times lower that for the shell with base square. According to the modelling results, the maximum tensile stress for the shell with base circle is 0.015 MPa (6.7 MPa for the shell with base square). Namely, the tensile stresses are significantly lower that the compressive stresses which is an advantage for the material like FRC excellently working under compression and poorly under tension. Compressive stress is 2.3 MPa, which is 12.6 times lower than for the shell with base square. Spherical dome of the shell is working in zero moment stress states; support is subjected to two types of effort — vertical and horizontal thrust. It means that specific construction — support cap working under tension — is necessary. In order to ensure zero moment activity of the dome with support cap it is necessary that the rotation angle normal next to the support cap of average shell surface coincides with the diametral plane rotation angle of support cap in the sectional view of the same plane.

Numeric algorithm was created using MATLAB [12] software for estimating the load-bearing capacity of the homogenous SFRC elements and SFRC elements with fiber distribution in the cracking and crack opening stage; it has been proven that the numeric modelling describes well the load-bearing capacity of non-homogenous FRC in the cracking stage. Numeric modelling results successfully approximate the experimental data. Practical application of the model can be in design of the SFRC building elements.

CONCLUSIONS

The research on load-bearing capacity of the non-homogenous FRC under the bending load has been done comparing it with load-bearing capacity of the homogenous FRC.

Technologies and devices for production of the non-homogenous FRC with high load-bearing capacity under bending load has been developed.

Two new non-homogenous FRC production technologies as well as three new FRC production devices have been developed.

New thin-walled FRC shell production technology has been developed.

The following tasks have been completed to reach the objective:

Approbation of a new technology for fiber distribution in layered FRC structures „Process and device for manufacturing fiberconcrete non-homogeneous structural elements", invention patent No. LV14257, showing the mechanical efficiency of the layered FRC.

Development of a new method for incorporation and orientation of fibers in the FRC structures (elastic base with oriented fibers is placed on the layer of concrete mixture in the predetermined level and in the intended direction); invention patent No. LV14667, „Method for reinforcing the fiber concrete structure" is received for this method. Approbation of the method has been done showing efficiency of the technology and increase of the mechanical load-bearing capacity of the structures.

Development of a new fiber orientation device (orientation is done outside the FRC structure, fibers are oriented and attached on the elastic base); the following invention patents are received: No. LV14684, „Technical device for fiberconcrete oriented reinforcement" and No. LV14849, „Device for fibers placement in fiberconcrete and its using method".

Approbation of a new fiber orientation device „Device for fibers placement in fiberconcrete and its using method" showing efficiency and increase of the mechanical load-bearing capacity of the structures by using the device.

Development of a fiber placement orientation method and device for the layered FRC structures (fiber orientation is done outside the FRC structure and fibers are oriented by streaming them over longitudinally ribbed orientation plate. The stream of oriented fibers is incorporated into the concrete mixture are incorporated in the predetermined level and according to the intended trajectories); invention patent No. LV14540, „Method and device for the oriented reinforcing process of the fiberconcrete" is received for this method and device. Approbation of the method and the device has been done showing efficiency of the technology and increase of the mechanical load-bearing capacity of the structures.

Approbation of a new fiber orientation method for FRC structures (two gratings called „rakes” are moved simultaneously in opposite directions in the concrete mix consisting fibers, in addition the above mentioned gratings are moved so that the bars of one grating would be positioned in gaps among bars of another grating); invention patent No. LV14325 „Technological process for orientation the fibers of fiberconcrete” is received for this invention; mechanical efficiency of the FRC with oriented fibers was shown.

Development of a new FRC shell production technology using gravitation moulds and 2D fiber orientation — invention patent No. LV14308 „Technological process for thin concrete shells production” and invention patent No. LV14408 „Technological process for formation the concrete saddle-shaped shells”.

Approbation of a new FRC shell production technology using gravitation moulds and 2D fiber orientation — „Technology of thin walled concrete shell production” and „Technological process of concrete shell production” invention patent No. LV14277; efficiency of the technologies was assessed.

Development of a new FRC shell reinforcement method — „Method for reinforcing concrete and fiberconcrete structure”, invention patent No. LV14679.

Approbation of a new FRC shell reinforcement method — „Method for reinforcing concrete and fiberconcrete structure”.

The created numeric model for estimating the load-bearing capacity in the cracking and crack opening stage of the homogenous FRC elements and FRC elements with fiber distribution; it has been proven that the numeric modelling describes the load-bearing capacity of non-homogenous FRC in the cracking stage.

Efficiency assessment and recommendations for use of the newly developed technologies.

TECHNOLOGICAL RECOMMENDATIONS

Bending structures have highly heterogeneous stress fields ranging from maximum tensile stress in tensile zone to maximum compression stress in compression zone and being zero near the neutral axis. For most of the statistical loaded reinforced concrete structures trajectories of the main tensile stresses are easily determinable and known in advance. It is useful to incorporate SF in the tensile zone of structure with maximum tensile stresses. Therefore with the same amount of fibers in homogenous and non-homogenous SFRC, it is possible to obtain better flexural strength results of the building element.

Significantly higher flexural strength of the non-homogenous SFRC was confirmed with bending test results of the respective specimens. They also show a positive effect, which differs from the result that could be expected: in order to obtain identical values of flexural strength, the consumption of the expensive fibers will be significantly lower for the non-homogenous SFRC.

After laboratory experiments with non-homogenous SFRC including testing the specimens as well as analysing and comparing the results, there was a positive impression about possible use of the SFRC in construction and about various methods of fiber incorporation. After the experiments and analysis of the obtained information it can be stated with certainty that by using the latest SFRC technologies — orienting, dividing fibers in certain layers — it is possible to have the desired effect, namely, the fiber orientation and distribution have significant impact on tensile strength of the SFRC. Taking into account that equal amount of SF was used in 1 m^3 of the concrete mix, by orientation and/or distribution of fibers it is possible to achieve cost-efficient solution for the building element.

Based on the research results, it has been concluded that it is possible to produce non-homogenous SFRC with various new methods.

Compared to the current practice in the use of SFRC, the following benefits can be expected from the practical use of the offered inventions in construction, allowing to:

1. Create concrete elements with fiber reinforcement that is oriented and/or distributed in layers;
2. Grind or polish the upper surface of the concrete without possible fiber pull-out and the related surface damage;
3. Simplify steel reinforcement, allowing to reduce amount of SF or completely eliminate the use of it;

4. In the case of crack appearance in the concrete, the fibers start to work in tension and pull-out; therefore the post-cracking stage can be reliably predicted that cannot be controlled by using reinforcing mesh;
5. Increase of the energy necessary for deterioration is particularly important for the military buildings that should maintain their functions after crack opening as well;
6. Control the SFRC post-cracking mechanical behaviour stage by achieving the required quasi-plastic behaviour;
7. Raise the level of mechanization (it is possible to use modern concreting installations including concrete placing with laser);
8. Increase quality of the SFRC building elements and their guaranteed properties (by reducing the scatter of properties and reducing the value of safety factor used for design purposes).

Positive effects that can be expected from using this method:

1. Lower concrete consumption and reduced weight of the structures;
2. Load reduction on the lower parts of structures that become less expensive as well;
3. Possibilities to increase the quality and the guaranteed characteristics of the SFRC structures significantly;
4. With the same consumption of expensive fibers the tensile resistance of concrete will increase resulting in higher load bearing capacity of the structures;
5. Identical concrete strength and load bearing capacity of the structure will be reached with lower consumption of fiber and concrete, thus allowing to:
    a) reduce the cost of work and labour intensity;
    b) increase productivity of the labour force;
    c) improve quality of the reinforcement work;
    d) reduce concrete consumption;
    e) reduce weight of the structures as well as load on the lower parts of the structure (lighter and less expensive solutions will be possible);
    f) shorten the time of construction work.

Based on the research results it has been concluded that it is possible to use various new methods for the production of thin-walled shells with fiber 2D orientation.

The positive features and efficiency of GFRC shell production technologies was proved during the experiments:

1. Reinforcing works on the construction site, significantly increasing the time of construction works as well as work expenses, are not necessary;
2. The moulds can be used repeatedly which reduces the construction expenses;
3. Various shapes can be obtained with the same mould;
4. Assembly of the mould is faster thus decreasing the time of construction works;
5. During the concreting process it is possible to control and ensure the thickness of the concrete layer;
6. Levelling and grinding after concreting becomes unnecessary as the surfaces of constructions are smooth;
7. It is possible to create roofs or waterproof ceilings for the constructions which would be highly complicated to produce by using the traditional methods and which would demand considerably more time, human resources and materials;
8. These technologies can be adapted for the industrial production; it increases the construction quality and facilitates the control of technological processes;
9. Moulds are mobile and relatively light;

Pre-stressed steel reinforcement supporting cap can be placed in the shells; steel can be replaced with other materials because the supporting cap works under pure tension. GFRC can be successfully reinforced by weft knitted fabric made of glass fiber yarns. The knitted fabric reinforced FRC have high application potential in the thin spatial constructions. This method allows creating domed shells with smooth inner and outer surfaces.

By combining the moulding technologies, which can be used repeatedly, domed concrete shells become a cost effective alternative to the traditional methods and moulds.

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