NON-DESTRUCTIVE EVALUATION OF FIBER ORIENTATION IN FIBERCONCRETE PRISM

Arturs Macanovskis [*], Vitalijs Zaharevskis [**], Andrejs Krasnikovs [*,]**
[*]Riga Technical University
Institute of Mechanics
E-mail: artursmacanovskis@inbox.lv
[**]Riga Technical University
Institute of Mechanics
E-mail: vitalijs.zaharevskis@rtu.lv
[*,**] Riga Technical University
Institute of Mechanics and Concrete Mechanics Laboratory
E-mail: Krasnikovs.Andrejs@gmail.com

ABSTRACT

Macro crack propagation in mechanically loaded steel fiber reinforced concrete is characterized by fibers bridging the crack, providing resistance to its opening. Suppose about homogeneous distribution of spatially arbitrary oriented fibers in a volume is leading to homogeneous spatially arbitrary distributed fiber orientation on the surface of the crack. At the same time, high experimental results scatter in fiberconcrete bending tests is experimentally observed, proving non-homogeneous fiber distribution in a volume and according to spatial orientations. One possibility to solve this problem is to use fiberconcrete with internal oriented fiber structure. In this work fiberconcrete prisms with oriented (in each prism longitudinal direction) short steel fiber structure were elaborated (Lapsa et al., 2010). Two metallic combs were prepared, a mould with fiberconcrete was placed on the shaking table and fibers in the mould were combed. The fiber orientation results were controlled by X-ray analysis and by ultrasonic device. All prisms were loaded by 4 point bending and Load bearing – crack opening curves were obtained.

Key words: steel fibers, concrete prisms, non-destructive testing, four point bending

INTRODUCTION

Usually fibers are homogeneously distributed in concrete body having arbitrary spatial orientations (Laranjeira et al., 2010; Gettu et al., 2005; Krenchel, 1982; Krasnikovs; Kononova, 2009).
Macro crack propagation in mechanically loaded steel fiber reinforced concrete is characterized by fibers bridging the crack, providing resistance to its opening. Supposition about homogeneous distribution of spatially arbitrary oriented fibers in a volume is leading to homogeneous spatially arbitrary distributed fiber orientation on the surface of the crack. At the same time, high experimental results scatter in fiberconcrete bending tests is experimentally observed, proving non-homogeneous fiber distribution in a volume and according to spatial orientations. The question of how to reduce experimental results scatter is important. A number of test methods have been proposed, but all have significant problems associated with either the variability of the results or their application in structural design calculations. One possibility to solve this problem is to use fiberconcrete with internal oriented fiber structure. In the present work fiberconcrete prisms with oriented (in each prism longitudinal direction) short steel fiber structure were elaborated (Lapsa et al., 2010). Precise amount of fibers was mixed with concrete and fresh fiberconcrete was placed into a mould. Two specially elaborated metallic combs (see Fig.1.) were prepared, a mould with fiberconcrete was placed on the shaking table and simultaneously fibers in the mould were combed. This operation was executed few times. Displacement between each comb two adjacent teeth was smaller than the length of a fiber, and was bigger than the cross-section size of a bigger concrete aggregate largest linear size. Vibration was applied during the process. The fiber orientation results were controlled by X-ray picture analysis. The prisms with oriented and chaotically (non-oriented) distributed fibers were tested by an ultrasonic device, measuring the ultra-sound wave velocity dependence on the fiber orientation in the samples and fiber concentration. The ultra-sound wave velocity dependence on fiber orientation was experimentally obtained. After that all prisms were tested by 4 point bending till failure.

EXPERIMENTAL SAMPLES FABRICATION

Experimentally fiberconcrete samples with the following recipe were made:

- First type of cement 42,5
- Sand (fraction 0 - 2.5 mm)
- Sand (fraction 0 - 1 mm)
- Dolomite filler

- Micro silica
- Dramix fibers
- Water

27 prismatic samples were elaborated having dimensions 10x10x40 cm.

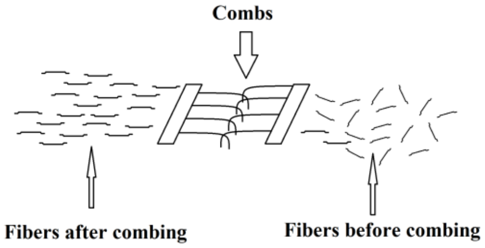

Figure 1. Fiber orientation process

The samples were divided into 4 groups:
1) Benchmarks- specimens having chaotic fiber distribution in the sample volume (fiber content was 40, 60 and 80 kg/m3).
2) Laminated beams (non-oriented) - fibers were located in two layers, the first non-oriented (fiber content was 20 kg/m3), and the second layer was non-oriented (fiber content was 60, 100 and 140 kg/m3).
3) Beams with oriented fibers - fiber reinforced concrete samples were processed by the method of combing (see Fig.1and Fig.2).
4) Laminated beams (oriented) - fibers were located in two layers, the first non-oriented (fiber content 20 kg/m3), the second layer oriented (fiber content 60, 100 and 140 kg/m3).

Figure 2. Combing fibers on the vibrating table

FIBER ORIENTATION

To get oriented fibers two combs were used by which fibers were oriented and a steel form placed on a vibrating table. In Fig. 1 the combing scheme can be seen, while in Fig. 2 you can see the real process. Combing occurred when two combs were dragged in opposite directions and that way fibers were oriented in a concrete mix.

USE OF ULTRASOUND IN CHARACTERIZATION OF FIBERCONCRETE

Determining the time of distribution of ultrasound waves in different materials

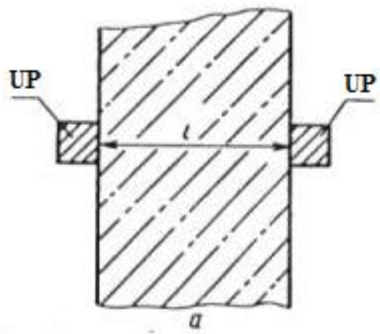

Figure 3. Scheme of concrete sample testing by sound transmission method,
where UP – ultrasonic transducers

their mechanical properties and internal structure can be indirectly characterized. In the present work attempts were made using ultrasound testing to determine the degree of fiber orientation in fiberconcrete samples.

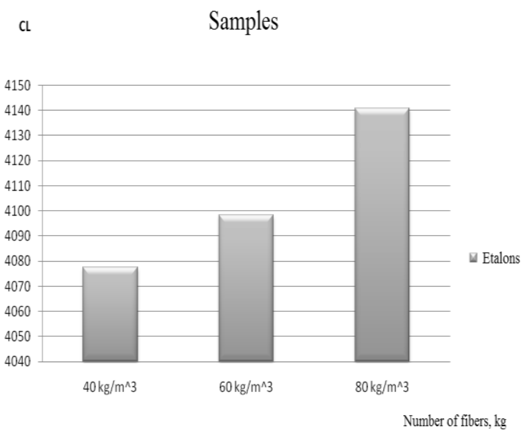

Figure 4. Correlation between ultrasound wave speed and fiber concentration in fiberconcrete with chaotic fiber distribution in fiberconcrete volume

Ultrasound converters were placed on opposite sides of the sample determining the ultrasound wave velocity (see Fig. 3.). The ultrasound wave velocity (v),m/s, is given by the formula 1

$$v = \frac{l}{t} * 10^3 \quad (1)$$

where: t is time of ultrasound wave distribution in microseconds;
l – distance between the centers of the transducer in mm.
During the test on samples with chaotic fiber distribution (the first group of materials - the

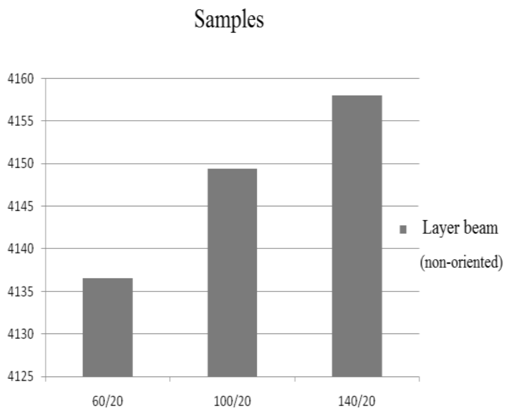

Figure 5. Correlation between ultrasound wave speed and fiber concentration in layered fiberconcrete with chaotic fiber distribution in each layer volume

benchmarks) the results were obtained for the ultrasound wave propagation velocity dependence on the steel fiber content in samples, which are shown in Figure 4.

The graph compares three samples with different amount of fibers per m^3, as follows:

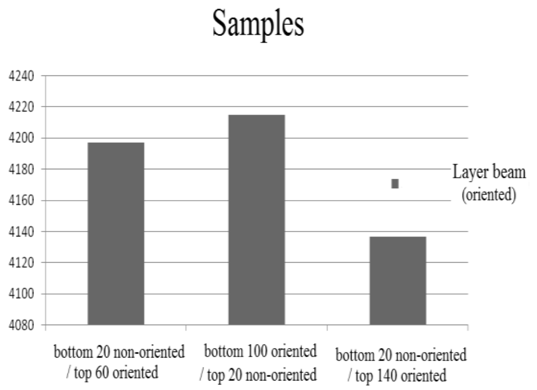

Figure 6. Correlation between ultrasound wave speed and fiber concentration in layered fiberconcrete with oriented fiber distribution in each layer volume

From the graph it is easy to conclude that with increasing of the fiber concentration the velocity of waves increases. Explanation of such phenomenon is as follows: ultrasound velocity in steel is greater than in concrete and if the steel fiber part in the mix is higher, then also the speed increases.

In Fig. 5 the testing results for samples consisting of layers with non-oriented fibers (samples from the second group) are shown. The trend to increase the wave propagation speed increasing the fiber concentration was maintained. In Fig. 6 the results of layered samples testing comprising oriented fibers (samples from the fourth group) are shown. In the following figure it is possible to see that with increasing of the fiber concentration, the rate of increase remains at the beginning and is decreasing later. The reason here is the fact, that in the samples located on the vibrating table, uncontrolled standing waves were created in the sample body forming fiber density non-homogeneous distribution along the longitudinal axis of the sample what highly affected the experimental results, reducing the speed of wave propagation. This picture is easy to recognize in x-ray photos that were done and possible to see in Figures 7 and 8.

FIBROCONCRETE SAMPLE X-RAY INVESTIGATION

With the goal to perform fiberconcrete sample internal structure control, the samples were subjected to X-ray study. X-ray sample pictures from the fourth group (viewed from the side shown in Figure 7, and viewed from the top in Figure 8) are presented. The pictures show a pronounced effect of vibration on the fiberconcrete internal structure, vibration creates non-predictable fiber density non-homogeneous distribution along the longitudinal axis of the sample. The sample vibration time does not exceed 1 minute.

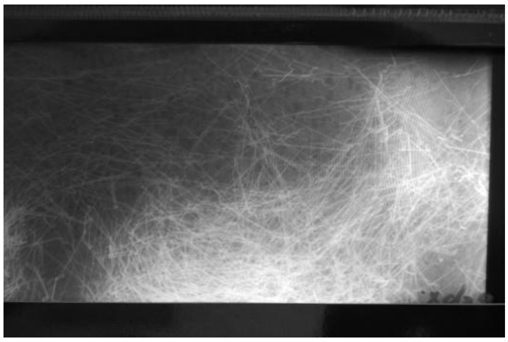

Figure 7. X-ray image of fiber distribution in oriented layered fiberconcrete (sample from the fourth group, view from a side)

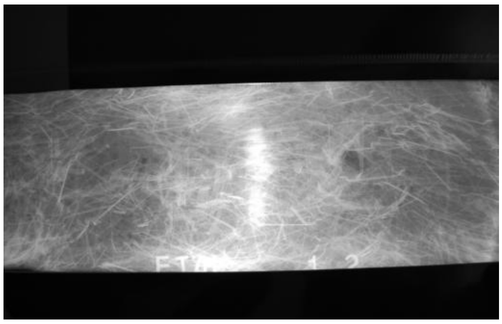

Figure 8. X-ray image distribution of fibers in oriented layered fiberconcrete (sample from the fourth group, view from above)

TESTS ON FOUR POINT BENDING FIBERCONCRETE PRISMS

All 18 samples that were made were tested by four-point bending (Fig. 9.) using "CONTROLS" Automax 5. The tests were continued till the macro crack opening reached 6 mm.

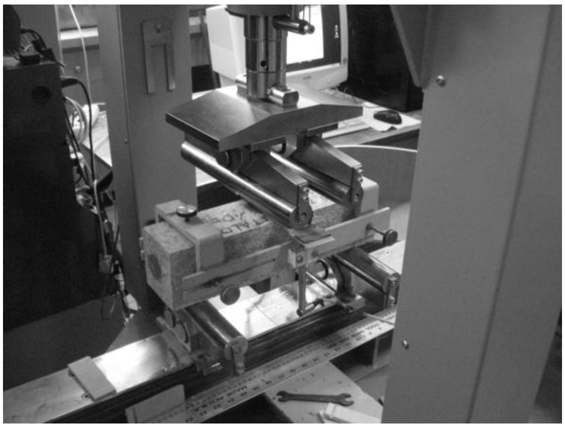

Figure 9. Sample test by four point bending

The first group (benchmarks with chaotically orientated fibers) sample curves applied force - the mid-point prism vertical deflection are shown in Fig.10a. In figure the testing results for samples with different amounts of fibers 40 kg/m3- samples P10, P13, with 60 kg/m3- samples P16, P19, with 80 kg/m3- samples P22, P25 are shown. As it can be seen from the graphs, if the fiber amount increases the load carrying capacity is increasing too, the sample P25 with the highest content of fibers (80 kg/m3) withstood the highest load. Least amount of load withstood the sample P10 with fiber concentration of 40 kg/m3. At the same time, the result has large dispersion.

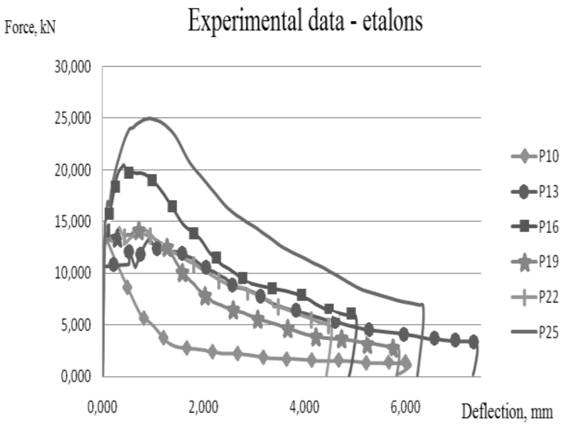

Figure 10. (a) Load - deflection curves for samples (P10, P13, P16, P19, P22, P25), where force was measured in kN and deflection in mm

Layered beam (with non-oriented fibers in layers) with the fiber concentration 40 kg/m3 - samples P11, P12, with 60 kg/m3- samples P14, P15, with 80 kg/m3- samples P17, P18. The four-point bending curves: applied force - the mid-point of prism vertical deflection are shown in Fig.10b.

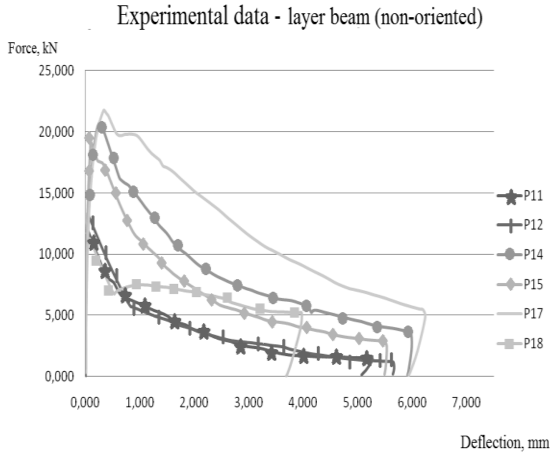

Figure 10. (b) Load - deflection curves for samples (P11, P12, P14, P15, P17, P18) - layered samples with not oriented fibers in layers, where force was measured in kN and deflection in mm

According to Fig. 10b it can be concluded, that the highest load bearing capacity in bending was shown by the sample P17, the sample with a higher concentration of fibers, and the sample P11 which withstood the lowest load had the lowest amount of fibers. The peak load for the sample P17 was 22 kN and for the specimen P11 the peak load was 12 kN. The experimental data that were obtained for laminates with oriented fibers in layers are shown in Fig. 10c. The graphs belong to the beams with various quantities of fibers: 40 kg/m3- samples P20, P21, 60 kg/m3- samples P23, P24, 80 kg/m3- samples P26, P27.

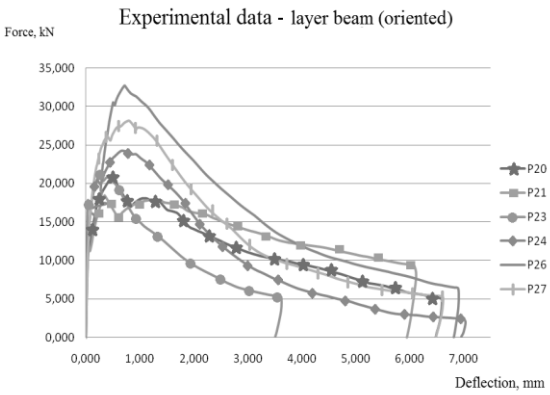

Figure 10. (c) Load - deflection curves for samples (P20, P21, P23, P24, P26, P27) - layered samples with oriented fibers in layers, where force was measured in kN and deflection in mm

The sample P26 with the fiber amount of 80 kg/m3 withstood the highest load and the sample P21 with fiber concentration of 40 kg/m3 withstood the least load. The sample P26 withstood the maximal load equal to 26 kN and the sample P21 equal to 18.
Comparison of the three groups of the results shows that despite the relatively large scatter of the results laminated samples with orientated fibers in layers showed the highest load carrying capacity. The sample P27 - sample with 80 kg/m3 fiber quantity with oriented fibers in plies showed higher maximal peak load. It can be concluded that not only the amount of fibers is affecting the load bearing capacity, but also the fiber orientation.

NUMERICAL MODELING

In parallel to the experimental study, the non-homogeneous fiberconcrete prisms subjected to four-point bending were modeled numerically (using the finite element method (FEM) program ANSYS (Release…)) with the goal to show internal stress fields in the beam before the macro crack opening and after that. 2D beam FEM model was created with dimensions 40x10 cm. The model was realized for:

- ✓ beam with non-oriented fibers;
- ✓ beam with oriented fibers;
- ✓ laminated beam (top layer fiber concentration - 20 kg/m3, bottom layer fiber concentration - 60 kg/m3);
- ✓ laminated beam (top layer fiber concentration - 20 kg/m3, bottom layer fiber concentration - 100 kg/m3);
- ✓ laminated beam (top layer fiber concentration - 20 kg/m3, bottom layer fiber concentration - 140 kg/m3);
- ✓ beam with cracks and non-oriented fiber

beam with cracks and oriented fibers;

- ✓ laminated (oriented fibers) beam with crack.

For benchmark specimens having chaotic fiber distribution in the sample volume fiberconcrete Young's modulus was determined in the experiments with ultrasound wave velocity determination. In layered samples fiberconcrete Young's modulus was calculated according to "rule of mixture" formulas (Young's modulus for concrete without fibers was taken equal to 30GPa). Poisson's ratio υ = 0.2. Laminated beam loading case is shown in Fig. 11a. The stress distribution is shown in Fig. 11b-e. Three fiberconcrete beams were considered: laminated beam (top layer had fiber concentration - 20 kg/m3, bottom layer had fiber concentration - 60 kg/m3); laminated beam (top layer had fiber concentration - 20 kg/m3, bottom layer had fiber concentration - 100 kg/m3); laminated beam (top layer had fiber concentration - 20 kg/m3, bottom layer had fiber concentration - 140 kg/m3).

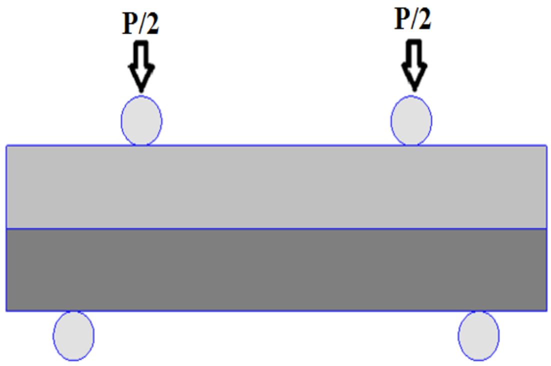

Figure 11. (a) Layered samples on four point bending

The numerical results for laminated beam (if the top layer had fiber concentration 20 kg/m3 and the bottom layer had fiber concentration 60 kg/m3) are shown in Figures 11b-e.

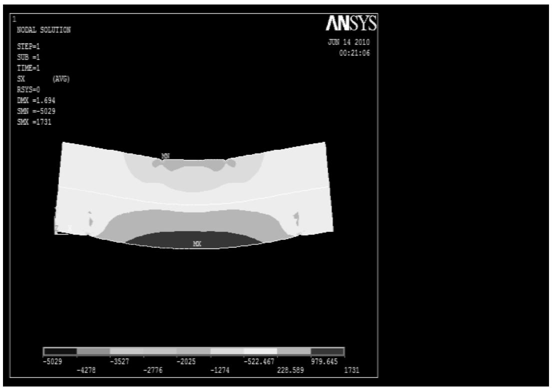

Figure 11. (b) Normal stress σ_{xx} distribution in the layered sample during bending

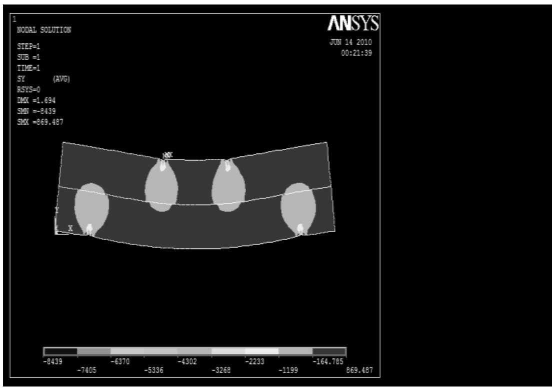

Figure 11. (c) Normal stress σ_{yy} distribution in the layered sample during bending

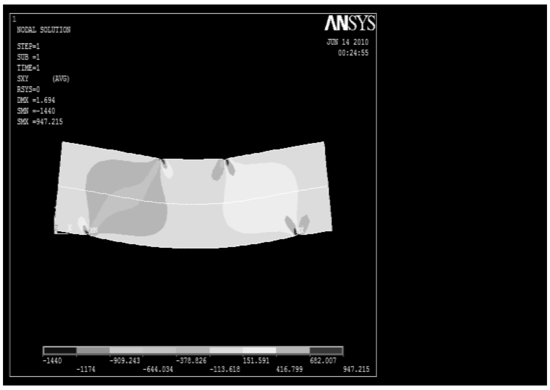

Figure 11. (d). Tangential stress τ_{xy} distribution in the layered sample during bending

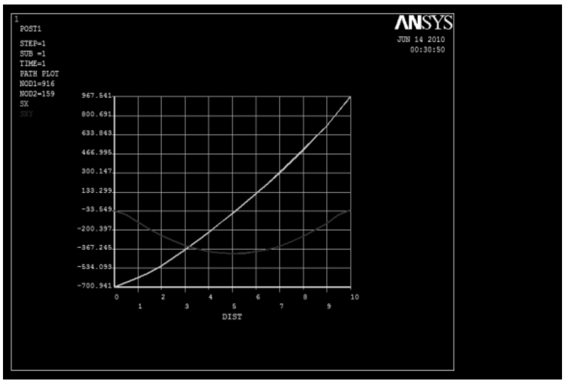

Figure 11. (e). Normal and tangential stress distribution through thickness of the beam (in the middle between the left and the top support of the applied load)

With the goal to numerically simulate stress fields in the beam with open macro crack, the crack was modeled by an isotropic layer having relatively low Young's modulus (3Gpa). Laminated beam with a crack is shown in Fig. 12a.

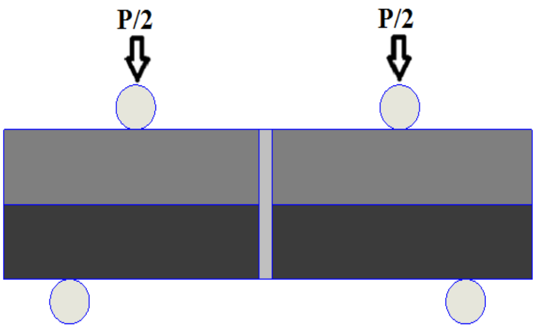

Figure 12. (a). Layer beam with crack (crack is modeling as a soft layer) under four point bending

Stress distribution in laminated beam (with one non-oriented layer and one oriented layer) with crack is shown in Fig. 12b-e.

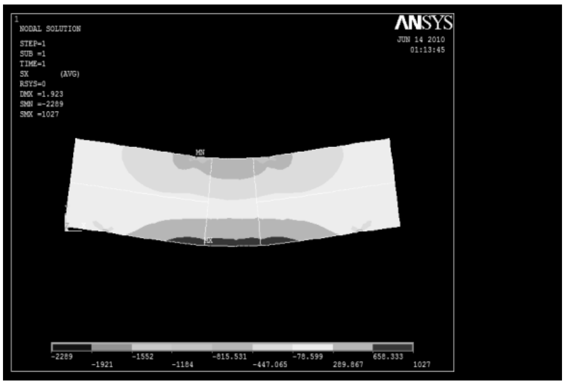

Figure 12. (b) Normal stress σ_{xx} distribution in the layered (fibers are oriented) sample under bending

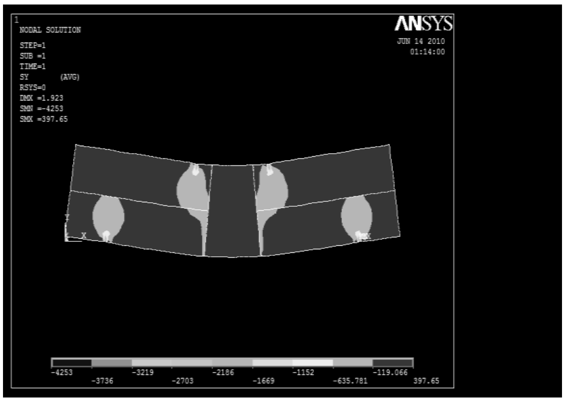

Figure 12. (c) Normal stress σ_{yy} distribution in the layered (fibers are oriented) sample under bending

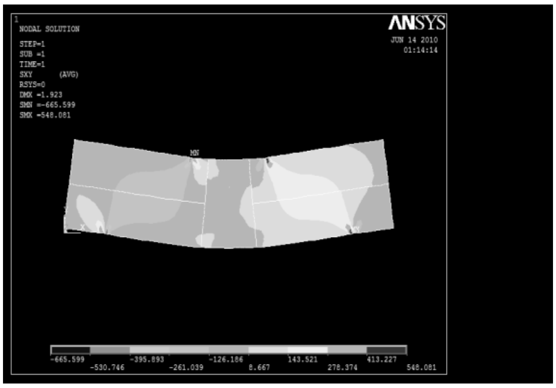

Figure 12. (d). Tangential stress τ_{xy} distribution in the layered (fibers are oriented) sample under bending

CONCLUSIONS

The non-destructive methods:

a) Ultrasound wave velocity method;
b) X-rays analysis;

were experimentally used in investigation of the possibility to obtain anisotropy in fiberconcrete. Fiberconcrete samples were elaborated and investigated:

1) Samples with chaotic fiber distribution in the sample volume.
2) Laminated samples (non-oriented) - fibers were located in two layers, the first non-oriented, and the second layer was non-oriented.
3) Samples with oriented fibers - fibers were processed by orientation procedure. 4) Laminated samples (oriented) - fibers were located in two layers, the first non-oriented, the second layer - oriented.

Because fiber concretes, that were under investigation, contained relatively small amounts of fibers (up to 3.5 % of volume) the ultrasound method showed low sensitivity (high dispersion of results) to the fiber content change and their orientation. It was found that by the X-ray method it is possible to give most thorough information about the internal structure of the sample. In order to explain the results of the measurements fiberconcrete beams (chaotic oriented, oriented, layered, layered-oriented) FEM model was created. The simulation data showed the most loaded areas in the prisms during loading and cracking of the fiberconcrete beams.

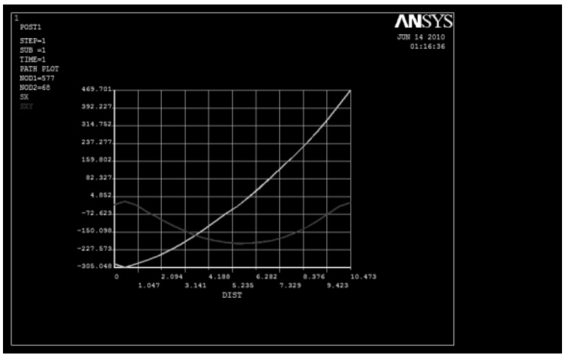

Figure 12. (e). Normal and tangential stress distribution (fibers are oriented) throw the thickness of the beam (in the middle between the left and the top support of applied load)

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