Non-Destructive Evaluation of Fibers Orientation in Fiberconcrete (with Nano Additives) Prism

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***Abstract* – There is a supposition that homogeneous distribution of spatially arbitrary oriented fibers in a volume leads to homogeneous spatially arbitrary distributed fibers orientation on the surface of the crack. At the same time, high scatter of experimental results in fiberconcrete bending tests is observed experimentally, proving non-homogeneous fibers distribution in a volume and according to spatial orientations. One possibility to solve this problem is to use fiberconcrete with internal oriented fibers structure. In this work fiberconcrete prisms with oriented (in each prism longitudinal direction) short steel fiber structure were elaborated [1]. Two metallic combs were prepared, mould with fiberconcrete was placed on the shaking table and fibers in the mould were combed. 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.**

***Keywords* – fibroconcrete, nano additives, X-ray analysis, FEM model.**

I. INTRODUCTION

Usually fibers are homogeneously distributed in concrete body having arbitrary spatial orientations [2-5]. Macro crack propagation in mechanically loaded steel fiber reinforced concrete is characterized by fibers bridging the crack, providing resistance to its opening. There is a supposition that homogeneous distribution of spatially arbitrary oriented fibers in a volume leads to homogeneous spatially arbitrary distributed fibers orientation on the surface of the crack. At the same time high scatter of experimental results in fiberconcrete bending tests is observed experimentally, proving non-homogeneous fibers distribution in a volume and according to spatial orientations. The question of how to reduce the scatter of experimental results is important. A number of test methods have been proposed, but all of them have significant problems associated with either the variability of the results and their application in structural design calculations. One possibility to solve this problem is to use fiberconcrete with internal oriented fibers structure. In the present work fiberconcrete prisms with oriented (in each prism longitudinal direction) short steel fibers structure were elaborated [1]. 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, 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 two adjacent teeth of each comb was smaller than the length of a fiber, and bigger than cross-section's size of the largest linear size of a bigger concrete aggregate. Vibration was applied during the process. Fiber orientation results were controlled by X-ray pictures analysis. Prisms with oriented and chaotically (non-oriented) distributed fibers were tested by ultrasonic device, measuring dependence of ultra-sound waves velocity on fiber orientation in the samples and fiber concentration. Ultra-sound wave velocity dependence on fiber orientation was experimentally obtained. After that all prisms were tested by 4 point bending till failure.

II. FABRICATION OF EXPERIMENTAL SAMPLES

Fiberconcrete samples with the following recipe were made experimentally:

- The 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 having dimensions 10x10x40cm were elaborated.

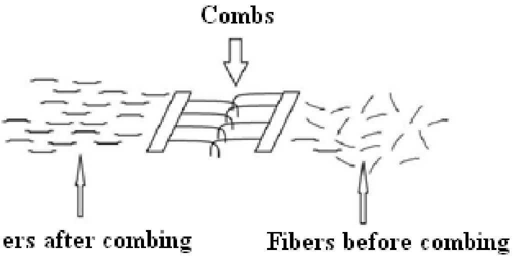

Fig.1. Fiber orientation process

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/m^3).
3. Beams with oriented fibers - fiber reinforced concrete samples were processed by the method of combing (see Fig.1 and 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).

Fig.2. Combing the fibers on the vibrating table

III. FIBER ORIENTATION

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

IV. THE USE OF ULTRASOUND IN THE CHARACTERIZATION OF FIBERCONCRETE

Determining the time of distribution of ultrasound waves in different materials can be used to indirectly characterize their mechanical properties and internal structure. In the present work attempts were made using ultrasound testing to determine the fiber orientation in fiberconcrete samples.

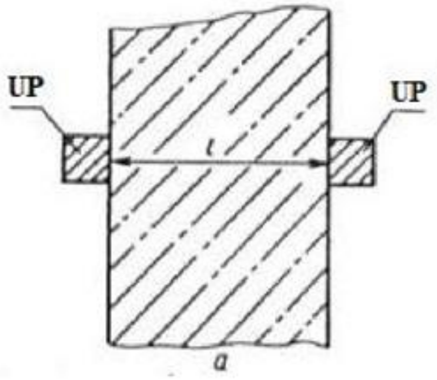

Fig.3. The scheme of concrete samples testing by sound transmission method, where UP – ultrasonic transducers.

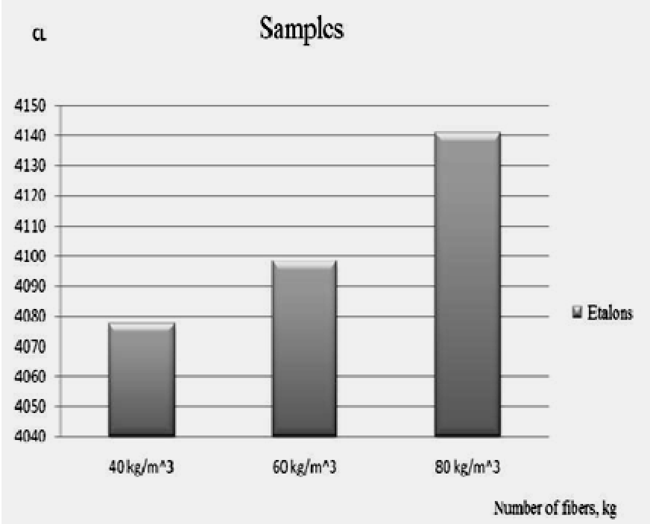

Fig.4. Correlation between ultrasound waves speed and fiber concentration in fiberconcrete with chaotic fiber distribution in fiberconcrete volume.

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

$$V = \frac{l}{t} \cdot 10^3 \qquad (1)$$

where t is time of ultrasound wave distribution in microseconds;
l – the distance between the centers of the transducer in mm.

During the test samples with chaotic fiber distribution (group of materials with chaotic fiber distribution in concrete volume) were used as the benchmarks. Experimental results were obtained for the ultrasound wave propagation velocity dependence on steel fiber content in samples. These data are shown in Fig.4.

Samples were tested by ultrasound and then were loaded by 4 point bending till rupture (see Figure 5). Applied load – deflection of each prism midpoint were measured during loading and are shown in Fig.6 a, b.

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

- ✓ 40 kg/m^3
- ✓ 60 kg/m^3
- ✓ 80 kg/m^3

From the graph it is easy to conclude that with the increase of 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 steel fiber part in the mix is higher, then the speed also increases.

V. TESTS ON FOUR POINT BENDING FIBERCONCRETE PRISMS

All 18 produced samples were tested by four-point bending (Fig. 5.) using "CONTROLS" Automax 5. Tests were carried out till macro crack opening reached 6 mm.

Fig.5. Sample test by four point bending

The first group (benchmarks with chaotically orientated fibers) of samples with applied force curves is the mid-point prism's vertical deflection curves, shown in Fig.6. In figure 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 also increases, the sample P25 with the highest content of fibers (80 kg/m3) withstood the highest load. Least amount of load was withstood by sample P10 with fiber concentration of 40 kg/m3. At the same time, the results show large dispersion.

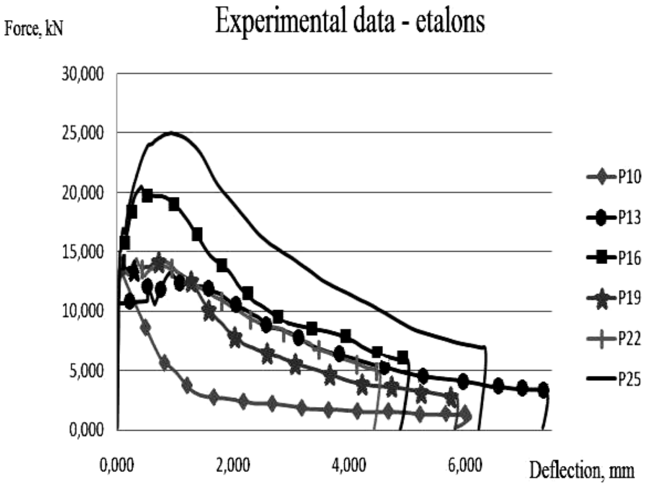

Fig.6a. Load - deflection curves for samples (P10, P13, P16, P19, P22, P25), where force was measured in kN and deflection in mm.

Highest load was withstood by sample P25 with fiber amount of 80 kg/m3 and least load was withstood by sample P10 with fiber concentration of 40 kg/m3. Sample P25 withstood maximal load equal to 25 kN and sample P10 – equal to 15.

Comparison of the three groups of results shows that despite the relatively large scatter of results laminated samples with orientated fibers in layers showed the highest load carrying capacity. Higher maximal peak load was shown by sample P25 - sample with 80 kg/m3 fibers quantity with oriented fibers in plies. It can be concluded that not only the amount of fibers affects the load bearing capacity, but also fiber orientation.

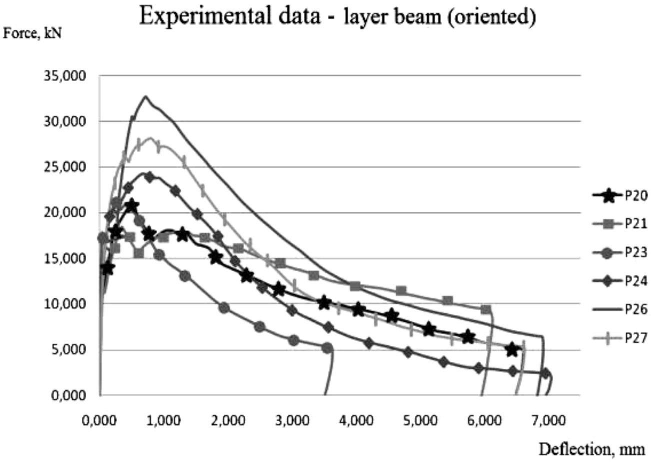

Fig.6b. Load - deflection curves for samples (P10, P13, P16, P19, P22, P25), where force was measured in kN and deflection in mm.

VI. NUMERICAL MODELING

In parallel to experimental study, the non-homogeneous fiberconcrete prisms subjected to four-point bending were modeled numerically (using finite element method (FEM) program ANSYS [6]) with the goal to show internal stress fields in the beam before 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;
- beam with cracks and oriented fibers;

For benchmark specimens having chaotic fibers distribution in the sample volume fiberconcrete Young's modulus was determined in experiments with ultrasound wave velocity determination.

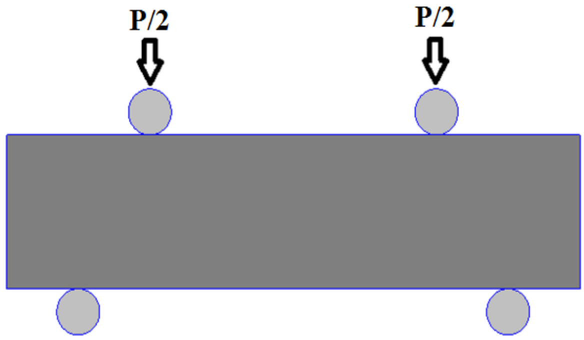

Fig.7. (a) Samples on four point bending

Numerical results for beam with fiber concentration 40 kg/m^3 are shown in Figures 7b-e.

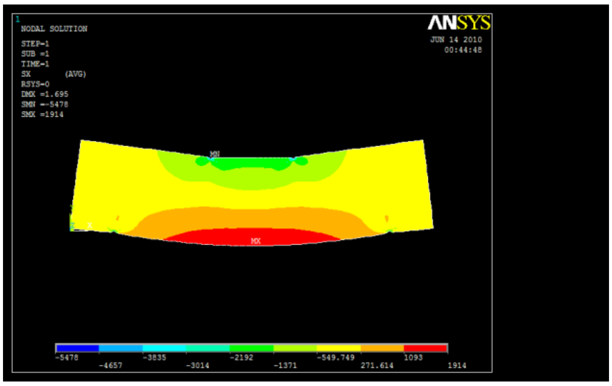

Fig.7. (b) Normal stress σ_{vv} distribution in the sample during bending

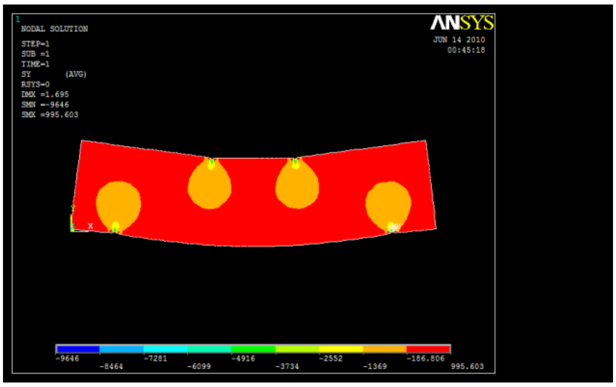

Fig.7. (c) Normal stress σ_{vv} distribution in the sample during bending

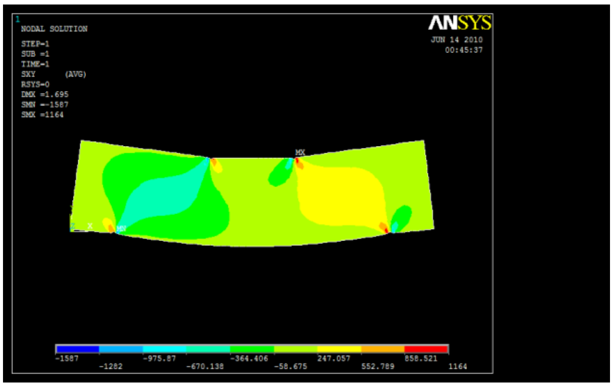

Fig.7. (d). Tangential stress τ_{vv} distribution in the sample during bending

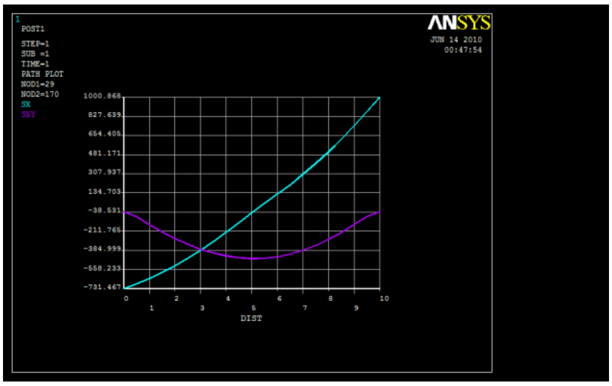

Fig.7. (e). Normal and tangential stresses distribution through thickness of the beam (in the middle between the left and the top support of applied load).

In the layered samples fiberconcrete Young's modulus was calculated according to the "rule of mixture" formulas (Young's modulus for concrete without fibers was taken equal to 30GPa). Poisson's ratio $\upsilon = 0.2$. Beam loading case is shown in Fig. 6a. The stress distribution is shown in Fig. 6b-e. Three fiberconcrete beams were considered: fiber concentration - 40 kg/m3, fiber concentration - 60 kg/m3; fiber concentration - 80 kg/m3.With the goal to numerically simulate stress fields in the beam with open macro crack, crack was modeled by an isotropic layer having relatively low Young's modulus (3Gpa). Beam with a crack is shown in Fig. 8a.

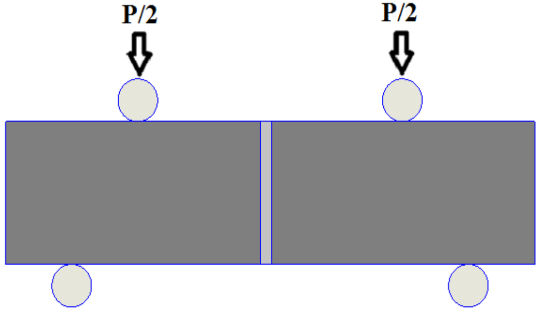

Fig.8.(a). Beam with crack (crack is modeled as a soft layer) under four point bending.

Stress distribution in beam (with oriented layer) with crack is shown in Fig. 8b-e.

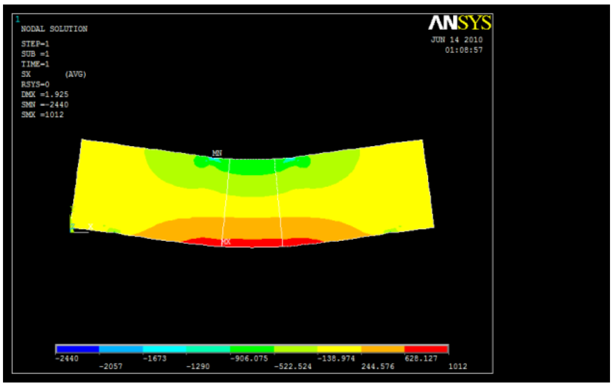

Fig. 8. (b) Normal stress σ_{vv} distribution in the (fibers are oriented) sample under bending.

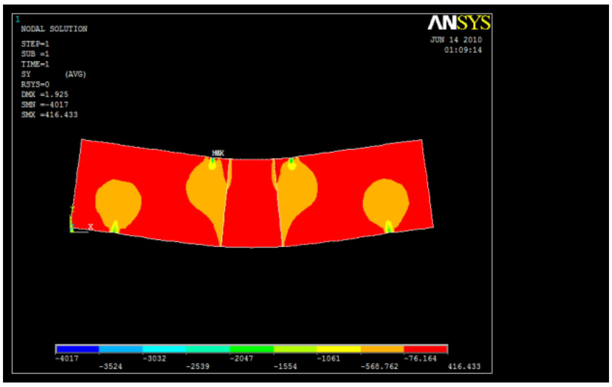

Fig.8. (c) Normal stress σ_{vv} distribution in the (fibers are oriented) sample under bending.

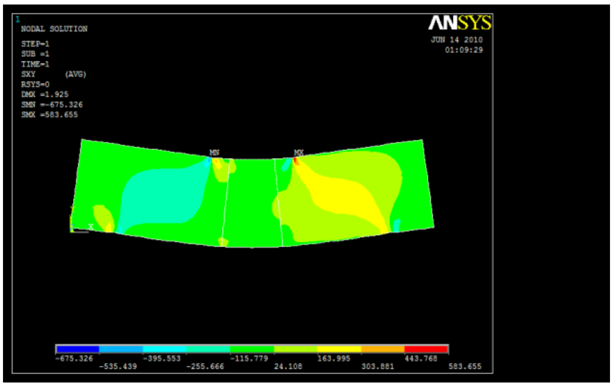

Fig.8. (d). Tangential stress τ_{vv} distribution in the (fibers are oriented) sample under bending

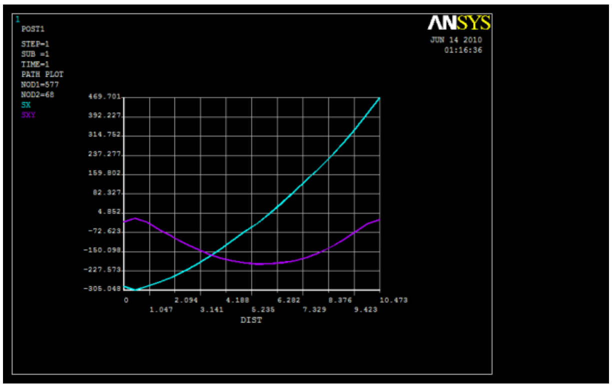

Fig.8(e). Normal and tangential stress distribution (fibers are oriented) through the thickness of the beam (in the middle between the left and the top support of applied load)

VII. CONCLUSIONS

The non-destructive methods:

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

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

1) Samples had chaotic fiber distribution in the sample volume.
2) Samples had oriented fiber structure - fibers were processed by orientation procedure.

Because fiber concretes under investigation contained relatively small amounts of fibers (up to 3.5 % of volume), the ultrasound method showed low sensitivity (high dispersion of results) regarding fiber content change and their orientation. It was found out that the X-ray method may 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) FEM model was created. Simulation data showed most loaded areas in the prisms during loading and cracking of fiberconcrete beams.

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Vitālijs Zaharevskis, Andrejs Krasnikovs, Oskars Liniņš, Anita Geriņa-Ancāne, Šķiedru orientācijas noteikšana fibrobetona (ar nano-piedevām) prizmās ar nesagraujošām metodēm.

Pieņemsim, ka telpiski patvaļīgi orientētu šķiedru homogēns sadalījums tilpumā pieved pie šķiedru telpiski homogēnas patvaļīgas šķiedru orientācijas uz plaisas virsmas. Tajā pašā laikā eksperimentāli tika fiksēta augstu eksperimentālo rezultātu izkliede fibrobetona pārbaudē uz lieci, rezultāti norāda uz šķiedru nevienmērīgu sadalījumu tilpumā saskaņā ar telpisko orientāciju. Viena no iespējām dotās problēmas risināšanai ir fibrobetona ar iekšēji orientētu šķiedru struktūru izmantošana. Dotajā darbā tika izstrādātās fibrobetona prizmas ar īsu tērauda šķiedru orientētu struktūru (katras prizmas garenvirzienā). Tika sagatavotās divas metāliskās ķemmes, matricu ar fibrobetonu novietoja uz vibrogalda, rezultātā šķiedras matricā tika izķemmētās. Šķiedru orientācijas rezultāti tika kontrolēti ar rentgena analīzes un ultraskaņas ierīces palīdzību. Visas prizmas tika noslogotās uz 4-punktu lieci un rezultātā iegūtās slogojuma līknes uz plaisas virsmai.

Виталий Захаревский, Андрей Красников, Оскар Лининьш, Анита Гериня-Анцане. Определение ориентации волокон в призмах фибробетона (с нано добавками) неразрушающимb методами.

Предположим, что однородное распределение пространственно произвольно ориентированных волокон в объеме приводит к пространственно однородной произвольной ориентации распределенных волокон на поверхности трещины. В то же время экспериментально зафиксирован разброс высоких экспериментальных результатов в проверке фибробетона на изгиб, результаты говорят о неоднородном распределении волокон в объеме в соответствии с пространственной ориентацией. Одна из возможностей для решения этой проблемы заключается в использовании фибробетона с внутренне ориентированной структурой волокон. В данной работе были разработаны фибробетонные призмы с ориентированной структурой коротких стальных волокон (в продольном направлении каждой призмы). Были подготовлены два металлических гребня, матрицу с фибробитоном расположили на вибрационном столе, в результате чего волокна в матрице были расчесаны. Результаты ориентации волокон контролировались с помощью рентгеновского анализа и ультразвуковым устройством. Все призмы были нагружены на 4-х точечный изгиб и в результате получены кривые нагрузки на поверхности трещины.