FRACTURE OF LAYERED FIBERCONCRETE WITH NON-HOMOGENEOUS FIBER DISTRIBUTION

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Abstract. The aim of the present research is to create a fiberconcrete construction with non-homogeneous fiber distribution in it. Traditionally fibers are homogeneously dispersed in concrete, but in many situations fiberconcrete with homogeneously dispersed fibers is not optimal (majority of the added fibers are not participating in the load bearing process). Layered beams with different short fibers content in plies were fabricated. The beams were tested under four point bending conditions. Increasing external applied load macro-crack is started at the bottom side of the beam. This is why the maximal fiber content in the prepared beams was concentrated at the bottom side of the beam. Prediction results were discussed.

Keywords: concrete, steel fibers, non-homogeneous fiber reinforced concrete.

Introduction

The weight reduction of concrete structures has recently gained importance in regard to the increased demands on construction material savings and on further savings related to transportation. The motivation is not only economical but also environmental influenced sustainable development which is becoming more important. In the present work fiberconcrete layered samples were prepared, containing different fiber content in the layers with the goal to investigate the possibility to increase the material load bearing capacity under bending loading conditions as well to decrease fiberconcrete strength scatter. The samples were prepared containing different concentrations of fibers (30 $kg \cdot m^{-3}$ and 60 $kg \cdot m^{-3}$) and were tested under four point bending loading conditions. In the specimens of Group 1 and 2 fibers were dispersed in all specimen volume, in the specimens of Groups 3, 4, 5, 6, 7 and 8 they were distributed in various layers with specified amount of fibers in each of them.

Materials and methods

In the present investigation prisms with dimensions of 100×100×400 mm were elaborated, the prisms contained non-homogeneous layered fiberconcrete. The technology of specimen preparation can be found in the Latvian patent LV14257 „Process and device for manufacturing fiberconcrete non-homogeneous structural elements" [1]. Three identical prisms of each type of non-homogeneous fiber reinforced concrete were prepared. The prisms were tested under four point bending conditions using Controls Automax 5 loading machine. All specimens with fibers were made of high strength concrete HSC containing steel-hooked fibers Dramix RC-80/30-BP with a length 30 mm, diameter of 0.38 mm, fiber aspect ratio 80, and tensile strength 1020 MPa.

Verification of the mechanical properties was realized by the 4-point bending test method. The test samples were tested after 28 days after sample preparation. Resistance strain gauges were placed on the test samples. Load was applied in 0.25 kN steps for a period of 60 s. The groups of the specimens used in the experiments are presented in Table 1. Group 1and 2 consist of fiber reinforced concrete with fibers homogeneously dispersed in the sample volume (Fig. 1, a). For specimens of Groups 3, 4, 5, 6, 7 and 8 fibers are distributed in different layers with various fiber concentrations and orientations. Fibers were added to the mix during the concrete mixing process and moulds were filled by such fiberconcrete. These prisms were used as reference.

As it is seen in Table 1, while the total amount of fibers is identical for all eight groups of the specimens, the difference is in their distribution.

These specimens can be designated as layered prisms. For the specimens in Groups 3 and 4 the moulds were gradually filled with the concrete mix according to the description of each group. Then the fibers were uniformly scattered on the concrete surface in the mould and pressed into concrete (Fig. 1, b, c and d). For the specimens in Group 3 and 4 the mould (Fig. 1, b) was filled with concrete mix till depth 25 mm, then the fibers (1/2 of the total amount of fibers (30 $kg \cdot m^{-3}$or 60 $kg \cdot m^{-3}$)) were uniformly scattered on the concrete surface in the mould and were pressed into the concrete, than concrete without fibers was added to the mould till the common depth of 50 mm and the second half of the total amount of fibers (30 $kg \cdot m^{-3}$ or 60 $kg \cdot m^{-3}$)) was uniformly scattered on the concrete surface in the mould and pressed into the concrete till the depth of 25 mm measuring from the concrete surface. The fibers were pressed by a steel disk set, mounted on the shaft, into the concrete along the whole length of the prism. After that each mould was filled up to the top, with concrete without fibers, forming the upper 50mm thick layer without fibers.

Table 1

Specimen groups used in experiments

Group No.	Distribution and concentration of fibers
Group No.1. and Group No.2.	Fibers were added to the concrete mix into the mixer and were mixed (we suppose that the fibers are homogeneously distributed in each specimen volume). Classical method with fiber concentration 30 $kg \cdot m^{-3}$ in group No.1. and group No.2. concentration 60 $kg \cdot m^{-3}$.
Group No.3. and Group No.4.	1. The mould was filled with concrete till 25 mm depth, then – 1/2 of the total amount of fibers (30 $kg \cdot m^{-3}$) group No.3 and group No.4 (60 $kg \cdot m^{-3}$) were uniformly distributed on the surface of the concrete in the mould and pressed into concrete covering the whole thickness of the concrete layer 25 mm; 2. Then concrete was added into the mould till the total depth 50 mm and next – 1/2 of the total amount of fibers (30 $kg \cdot m^{-3}$) and group No.4 (60 $kg \cdot m^{-3}$) were uniformly distributed on the surface of the concrete in the mould and pressed into concrete till the depth 25 mm; 3. 50 mm of concrete without fibers was added into the mould.
Group No.5. and Group No.6.	1. The mould was filled with concrete till 55 mm depth, then all fibers (30 $kg \cdot m^{-3}$) and group No.6 (60 $kg \cdot m^{-3}$) were uniformly distributed on the surface of the concrete in the mould and pressed into concrete till the depth 25 mm; 2. 45 mm of concrete without fibers was added into the mould.
Group No.7. and Group No.8.	1. The mould was filled with concrete till 25 mm depth, then – 2/3 of the total amount of fibers (30 $kg \cdot m^{-3}$) and group No.8 (60 $kg \cdot m^{-3}$) were uniformly distributed on the surface of the concrete in the mould and pressed into concrete covering the whole thickness of the concrete layer 25 mm; 2. 75mm of concrete without fibers was added into the mould and – 1/3 of the total amount of fibers (30 $kg \cdot m^{-3}$) and group No.8 (60 $kg \cdot m^{-3}$) distributed and pressed into concrete on the depth 25 mm.

For the specimens in the Group 5 and 6 the mould (Fig. 1, c) was filled with concrete mix up to 55 mm depth and all fibers were uniformly scattered on the concrete surface in the mould and were pressed into the concrete at the depth equal to 25 mm. The fibers were pressed by a tool, consisting of set steel disks mounted on the shaft and rolled, and vibrated during motion along the mould. Finally, the mould was filled by concrete mix, without fibers up to 100 mm.

For the specimen in the Group 7 and 8 the mould (Fig. 1, d) was filled with concrete mix without fibers till 25 mm depth, then the fibers (1/2 of the total amount of fibers) were uniformly scattered on the concrete surface in the mould and were pressed into concrete till the depth 25mm, after that a layer of 75 mm of concrete mix was added without fibers and finally the fibers (last half of the total amount of fibers) were uniformly scattered on the concrete surface in the mould and were pressed into the concrete till 25 mm depth. The measured density of the fiber reinforced concrete samples ranged from 2370 to 2430 $kg \cdot m^{-3}$ (2400 $kg \cdot m^{-3}$ in average) and according to the concrete compressive strength testing results the sample average compressive strength corresponds to the compressive strength class C70/85. All specimens, namely, the fiber reinforced concrete prisms were tested under four point bending conditions using Controls Automax 5 testing machine. During the testing vertical deflection at the center of the prism (only one macro crack was observed in each experiment) was measured directly by the mounted linear displacement transducers in real time regime [2]. Sensors were connected through the data acquisition unit to the computer where the obtained data were recorded and were available after the experiments.

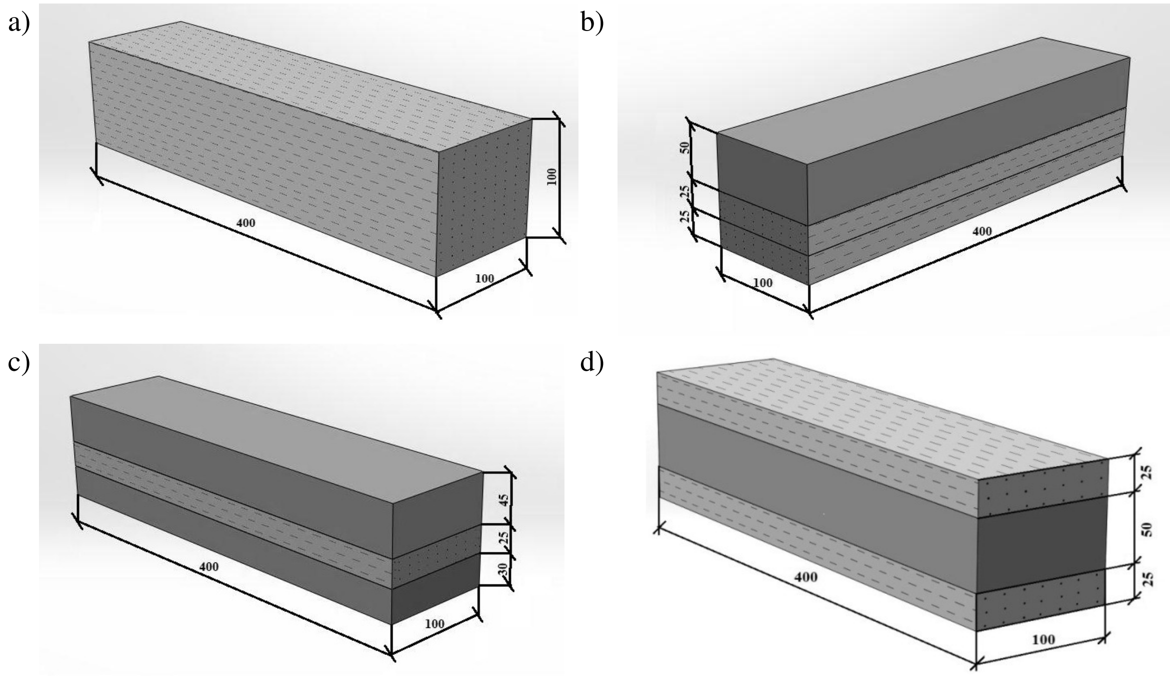

Fig. 1. **Groups of the specimens used in the experiments:** a – Group 1 and Group 2 with fibers homogeneously dispersed in the specimen volume; b – Group 3 and Group 4 with different concentrations of fibers in each specimen layer; c – Group 5 and Group 6 with different concentrations of fibers in each specimen layer; d – Group 7 and Group 8 fiber location in specimens

Experimental results and discussion

The specimens were tested under four point bending conditions till the macro crack opening was reached 6 mm. The graphs for applied load – vertical deflection measured at the center of each prism for the specimens of Group 1 and 2 are shown in Fig. 2, a. The diagram shows the experimental curve of each specimen as well as the average value curve. Three stages are seen in each curve; the first of them is linear elastic deflection (corresponds to deflection under 0.01mm). In this stage fiber reinforced concrete prisms become deformed without visible crack openings. Fibers in the concrete are not fully loaded and do not bear significant load [3]. The next stage begins with curve deviation from the straight line and terminates reaching the maximum value on the curve (with prism middle point deflection reaching 0.75-1 mm). In this stage micro cracks in the concrete are growing and linking forming macrocrack. The macro crack is formed perpendicularly to the longitudinal axis of the prism.

In reality we have few macro cracks and only one of them starts to open. The fibers crossing the macro cracks begin to bear load, while the cracks are still invisible on the outer surface of the specimen (it is possible to recognize from pull-out diagrams [2]). The crack with the lowest load carrying capacity (one with the lower amount of fibers crossing the macro crack, or the crack with crossing it fibers located and oriented in a less optimal way) starts to open. It proceeds the following way: the fibers bearing load detach from the concrete and start pulling out from one or both sides. Individual load carrying capacity of a single fiber depends on its orientation towards the crack plane and how far it is extracted.

Experimental observation of fiber pull-out micromechanics [2-4] recognized that the maximum load carrying capacity of a single fiber depends on its orientation towards the direction of pulling out force and how much the fiber has been pulled out. Another factor is the fiber declination angle to the direction of pulling out force. The observations showed that the current value of pulling out force decreases proportionally to the size of the crack opening. Load bearing – vertical deflection at the center of the prism for the specimens of Groups 1, 2, 3, 4, 5, 6, 7 and 8 are shown in Fig. 2, a-d. Group 3 and 4 samples in the experiment showed the best result, because the concentration of fibers in the bottom part of the prism is two times higher comparing with the reference prism in Groups 1 or 2.

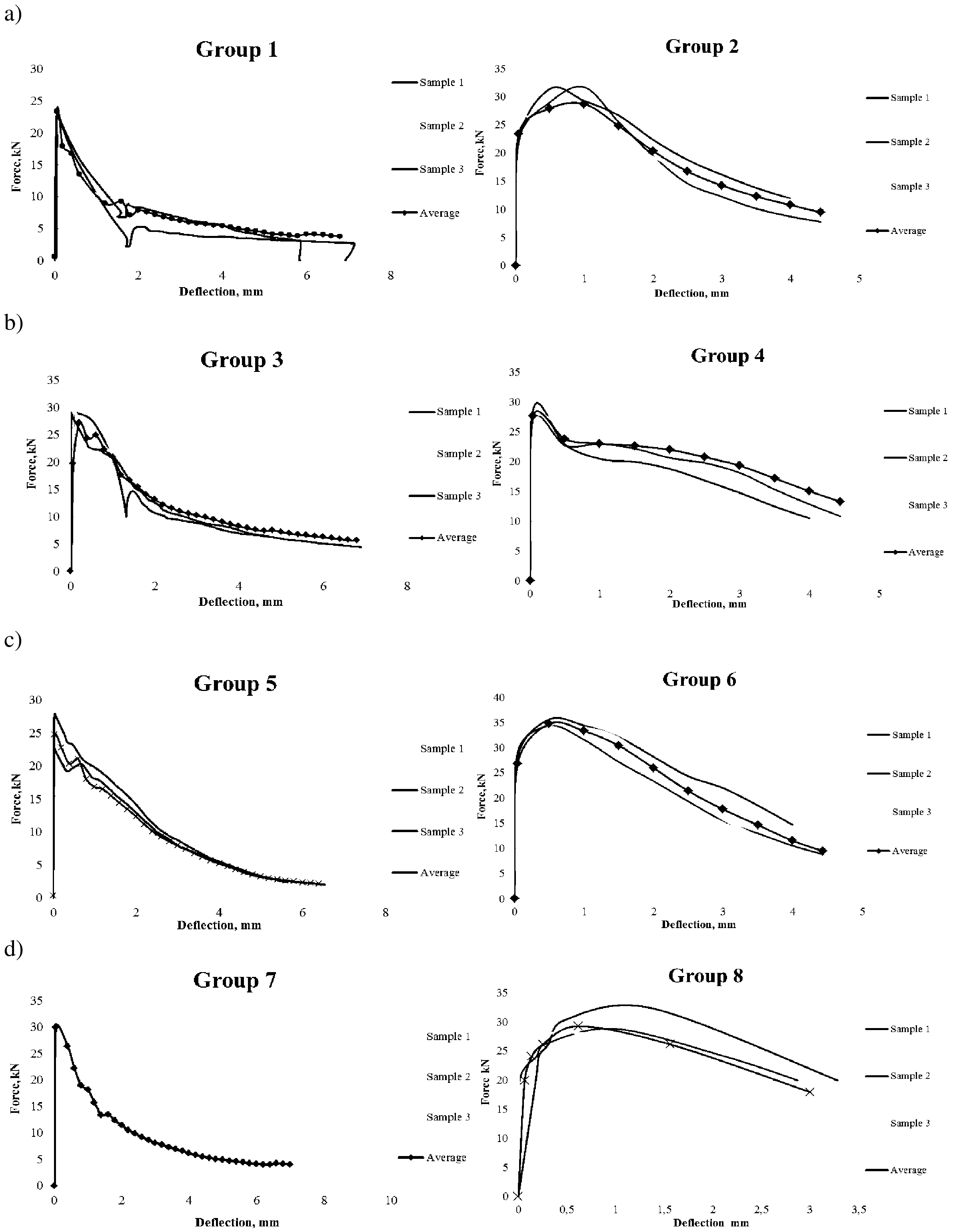

Fig. 2. **Load – vertical deflection graphs for specimens in Group No.1 and2 (a); Group No.3 and 4 (b); Group No.5 and 6 (c); Group No.7 and 8 (d)**

The experimental average curves for all eight groups are given in Fig. 3. As it can be observed, Group 3 and 4 reaches the highest load carrying capacity during the crack opening stage due to the highest concentration of fibers compared to other groups in the lower part of the prism which bears the maximum tensile load. As it results from the obtained graphs, Groups 1 and 2 (reference specimens) reach lower average load carrying capacity compared to the specimens with non-homogeneous distribution of fibers. Similar tendencies can be observed among the diagrams of the average results of the specimens – the maximal load carrying capacity is reached with deflection of prisms 0.75-1 mm, which correlates with the crack opening size.

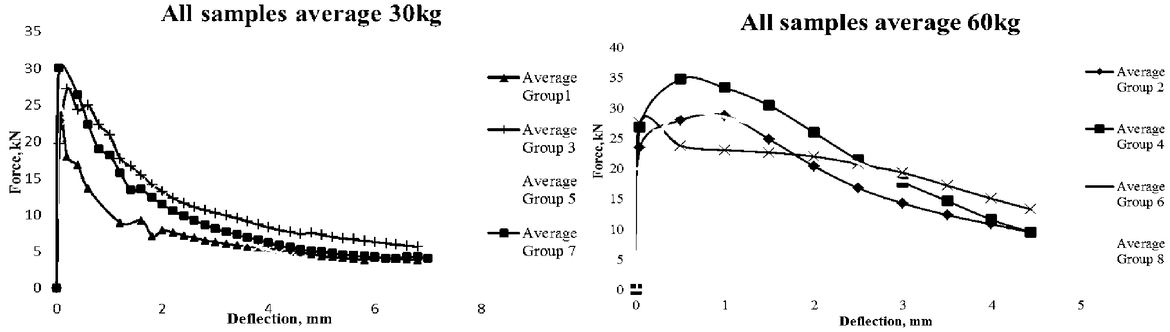

Fig. 3. **Average results of all sample groups**

Conclusion

According to the performed bending tests, the specimens with chaotic fiber distribution in the sample volume show lower average load carrying capacity during the crack forming and opening stage compared with the specimens which had non-homogeneous distribution of fibers.

Acknowledgments

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