TEXTILE REINFORCED CONCRETE - APPLICATION IN THIN-WALLED STRUCTURES

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Abstract

Textile reinforced concrete (TRC) is a special type of material, which has a major advantage – the reinforcement is evenly distributed and placed in a position most advantageous from the structural point of view. The research reported in this paper was focused on optimization of method of concreting of TRC specimens, verification of material properties and evaluation of modes of failure. Several slabs with basalt fabric reinforcement were made from C 40/50 concrete and high performance concrete (HPC) for this purpose. The first set of specimens was concreted in horizontal moulds, vertical moulds were used for the second one. Flexural and buckling tests were performed, the effect of production method used (vertical/horizontal concreting) was evaluated. Finally, numerical simulation of the tests in ATENA FEM software was conducted. The tests proved high load-bearing capacity of TRC specimens, optimal method for concreting was found.

Keywords: textile reinforced concrete, thin-walled structures, basalt fabric, high performance concrete

1. Introduction

In recent years, demands for efficiency and aesthetic quality of structures have increased and new technological options have been searched for this purpose. High architectural demands lead to design of more subtle structures. The research nowadays is focused on increasing of load-bearing capacity, finding of new production methods and life cycle costs reduction of these structures.

Besides improving the strength and durability characteristics of concrete, application of unconventional methods of reinforcement seems to be the promising way. Fibre reinforced concrete (FRC) with various types of fibres is used increasingly. FRC enables creation of structural elements of complex shape (e.g. organic shapes). By increasing ductility of the material, the fibres improve resistance to propagation of cracks caused by shrinkage and loading of the structure. Instead of a macrocrack, a set of hairline cracks is created, therefore the influence of aggressive environment on concrete is minimized. [1]

Textile reinforced concrete (TRC) is a progressively developing special type of FRC. TRC has a major advantage – the fibres are evenly distributed in the material and placed in a position most advantageous from the structural point of view. The thickness of the elements is minimized thanks to reduced concrete cover depth required. TRC is a way to

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produce thin and elegant concrete elements with an extremely high load-bearing capacity. [2]

To ensure the sufficient cohesion, it is appropriate to use textile fibre mesh together with fine-grained concrete matrix. The most commonly used fabrics are made of basalt, glass and carbon fibres, they are usually combined with high performance concrete (HPC) in structures. Fresh concrete is placed into the mould, in which the fabric is fixed in the desired position. By this approach, high architectural quality of concrete surfaces is secured. Shotcreting can be also used to produce complexly shaped TRC elements. Surface quality can be improved by further surface treatment, e.g. by grinding.

The research reported in this paper was focused on optimization of method of concreting of TRC specimens, verification of material properties and evaluation of modes of failure. Flexural and buckling tests were performed, the effect of production method used (vertical/horizontal concreting) was evaluated. Finally, numerical simulation of the tests in ATENA FEM software was conducted.

2. Experimental program

For this purpose, thin slab-shaped specimens with dimensions 400/600/20 mm were prepared. Several slabs with basalt fabric reinforcement on one or both sides were made of the concrete C 40/50 and HPC. Figure 1 describes the geometry. Several plain concrete slabs of the same dimensions were made for comparison. Further, several plain concrete test beam with dimensions 100/100/400 mm were made in order to determine the strength of hardened concrete. They have been tested for flexural and compressive strength.

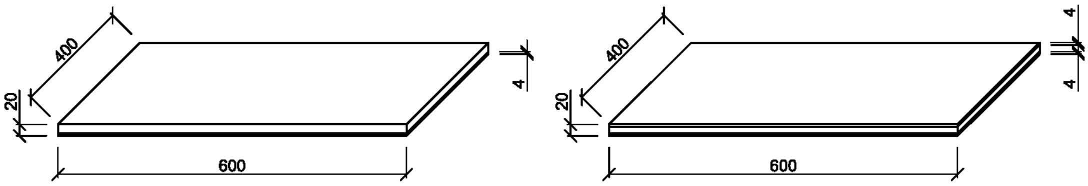

Figure 1: Position of fabric in specimens.

All specimens were produced in The Experimental Centre of CTU at the Faculty of Civil Engineering. Basalt fabric used to reinforce of slabs was sent by Basaltex, a.s. The fresh concrete was first placed into special horizontally oriented wooden moulds. In the next phase, the concrete was casted into the vertical wooden form. The specimens were tested for flexural strength and buckling. Test results were then compared.

2.1 Horizontally casted specimens

Special horizontally oriented wooden moulds of internal dimensions 400/600/20 mm were made. The photograph is on the figure 2. Mixing of concrete was performed in the laboratory. During the setting process, the slabs and beams were covered by foil in order to avoid undesirable evaporation of water. After two days, the specimens were striped and placed in a water bath for another 26 days. [3]

The basalt fabric in the specimens reinforced on one side were placed 4 mm from the lower surface of form into the fresh concrete. A displacement of the fabric out of the designed position below the surface has occurred during insertion of the remaining concrete mixture. The cause of displacement was insufficient fixation combined with low fabric weight. [3]

The fabric in the specimens reinforced on both sides have been first inserted on the lower surface of the form. Then the fresh concrete mixture was added on the fabric and was twice shortly vibrated. The vibration has achieved the displacement of fabric from the lower surface upward. Then the second fabric was inserted and the remaining concrete mixture was placed into the form. The slabs were not vibrated anymore to avoid a displacement of the fabric. [3]

Figure 2: A horizontal form.

2.2 Vertically casted specimens

Secondly, the concrete was casted in vertically oriented mould, while the fabric was stretched, to prevent fabric replacement. The special moulds with the same dimension as the first specimens were made to fix fabric in the required position. Just before casting the fabric was stretched in the form. The vertical form is on the figure 3. No vibration was used, only a light tapping with a rubber hammer was applied on the sides of the mould. The precautions during producing have proved effective.

Only specimens of HPC reinforced on both sides have been produced by this way. The curing of concrete was the same as in the horizontally concreting slabs.

Figure 3: A vertical form.

2.3 Testing of slab specimens

A tests of specimens was performed in The Experimental Centre of CTU at the Faculty of Civil Engineering. The testing procedure was controlled by deformation of the specimen.

The rate of increase in deformation for all slabs was fixed at a standard rate of 0.2 mm/min.

2.2.1 Three-point bending test

The horizontally casted specimens reinforced on one side and both sides were subjected to three-point bending test. Tests were finished after reaching deflection of specimen 3-5 mm. A force and deflection have been measured during testing. Support were placed at a distance of 550 mm and a load was linearly transmitted to the centre of the slab span (figure 4). The tests of unilaterally reinforced slabs of HPC have demonstrated significant benefits of fabrics; the maximum force has achieved 2.35 kN and maximum increase in strength compared to non-reinforced slabs has been about 35%. [3]

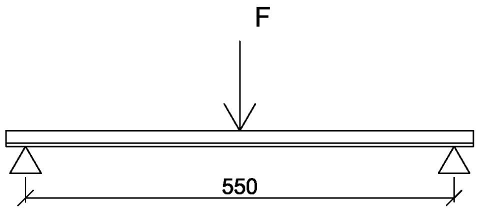

Figure 4: A three-point bending test.

Then the vertically casted slabs of HPC with stretched fabric were tested. The test was conducted under the same conditions as the previous tests. During the flexural tensile strength test, there was an increase of tensile strength. The maximum force reached 2.63 kN, which corresponds to approximately 51% increase in strength compared to non-reinforced slabs of C 40/50.

There are a three-point bending test results in the table 1 and a comparison of test results for vertically casted reinforced slab of HPC, horizontally casted reinforced slab of HPC and horizontally casted non-reinforced slab of C 40/50 in the three-point bending test on the figure 5.

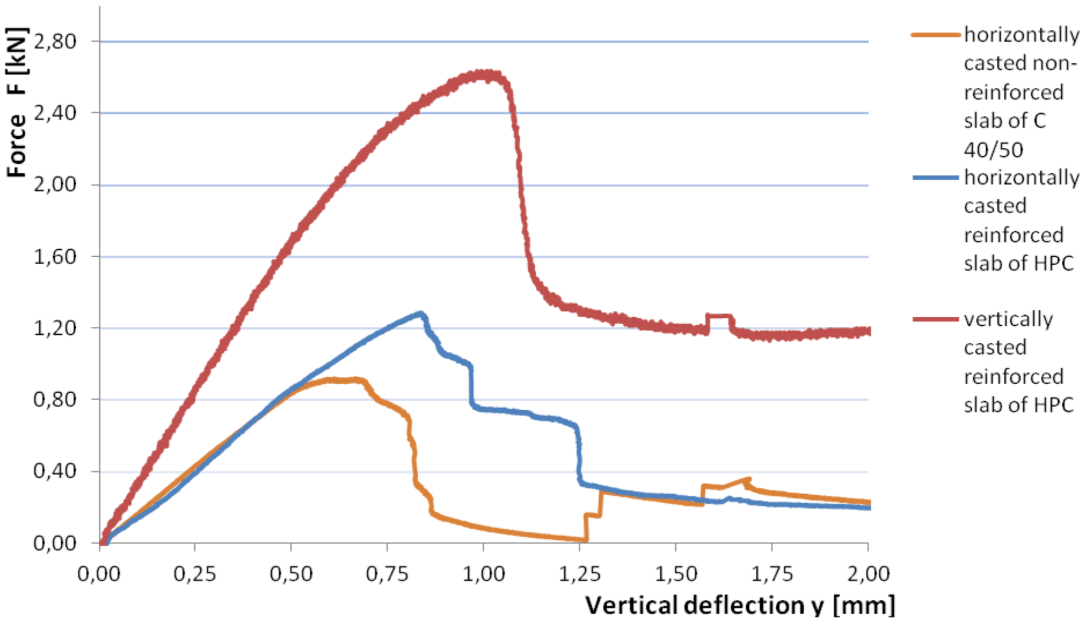

Figure 5: The comparison of the average results in the three-point bending test.

2.2.2 Compression buckling test

The specimens reinforced on both sides have been tested for compression buckling on the longest dimension (figure 6). The testing procedure was again controlled by deformation of the specimen. A force and lateral deflection have been measured during the horizontally casted concrete testing. The slabs have been tested on a machine E 40, which can measure forces up to 400 kN.

At first, there have been breaches in few places and then the slabs collapsed explosively. Cracks appeared on the slabs were longitudinal. The crack expanded along the fabric. The textile reinforcement minimized the damage of concrete and prevented premature spalling.

The horizontally casted slabs of HPC have been tested at first. Upon reaching force of 300 kN, a further increase in forces was manually carried out. The failure occurred at maximum force of 400 kN, which exceeded expectations obtained by calculations. The horizontally casted slabs of C40/50 have been tested at second. The maximum forces were from 280 to 400 kN. Although there was a displacement of the fabric out of the designed position below the surface during insertion of the fresh concrete, the results were very positive. [3]

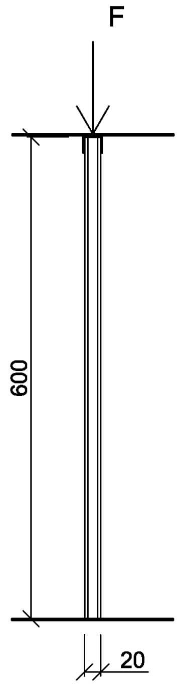

Figure 6: A compression buckling test.

Than the vertically casted slabs of HPC with stretched fabric were tested. The test was conducted under the same conditions as the previous tests, but after exceeding a maximum measurable force 400 kN the test had to be completed on machine VEB, which has measured vertical displacement due to the different location of the sensor.

The maximum force of 535 kN was reached during buckling test. This corresponds even to a 34% increase in strength compared to previous tests of slabs reinforced on both sides. A comparison of the average test results in the compression buckling test is on the figure 7.

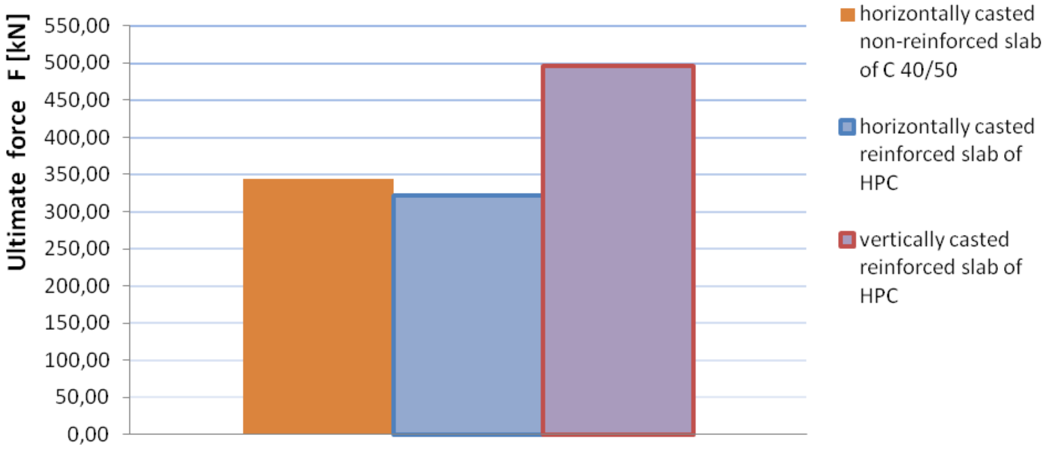

Figure 7: The comparison of the average results in the compression buckling test.

3. Mathematical simulation in ATENA program

Finding of suitable mathematical simulation have followed the experimental part of the research. For this purpose, a computer model of the carried out tests was created in 2D ATENA to simulate both types of performed tests. This program can simulate real behaviour of concrete and reinforced concrete structures including concrete cracking, crushing and reinforcement yielding. ATENA is able to check and verify their structures. [4]

During searching an appropriate realistic model, it was necessary to bring the influence of the initial imperfections and to adjust the input value of the materials from the ideal values measured during testing materials themselves. The realistic models are the result - the test process corresponding to values measured for both type of tests.

3.1 Three-point bending test in ATENA program

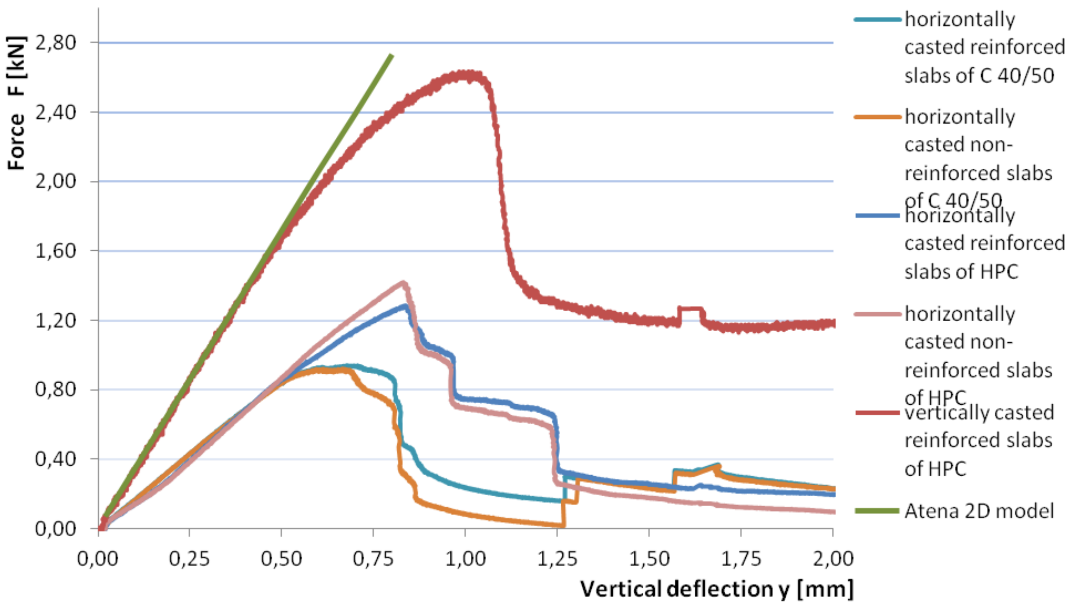

Figure 8: The comparison of average test results and model in ATENA 2D program.

For this type of thin-walled structures, the model deals with only rising part of the graph because the moment of crack formation is concurrently the moment of serviceability limit states (SLS) reaching. On the figure 8, there is the comparison of the average results in the three-point bending test and model in 2D ATENA program.

There are two graphic outputs of the model in 2D ATENA program on the figure 9 and 10.

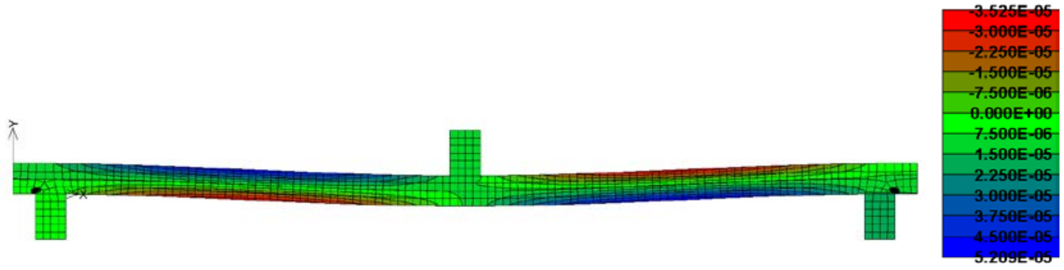

Figure 9: A displacement of the bending test model in ATENA program.

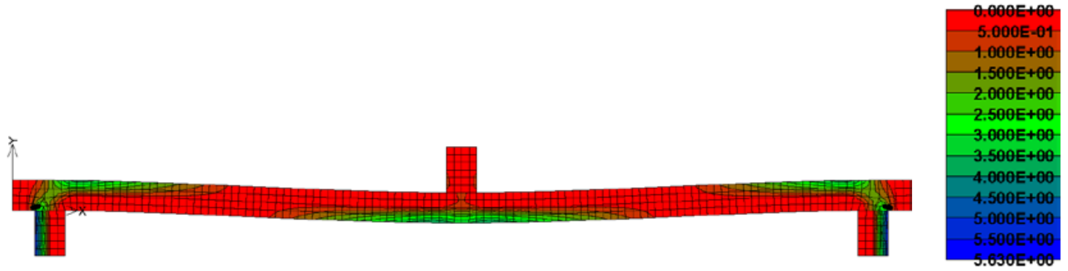

Figure 10: A principal stress of the bending test model in ATENA program.

3.2 Compression buckling test in ATENA program

There was brought initial geometric imperfections in the buckling test model in ATENA program by introduced eccentric. The model corresponds to the real course of the test and subsequent failure mode by a sudden collapse of the structure (figure 11).

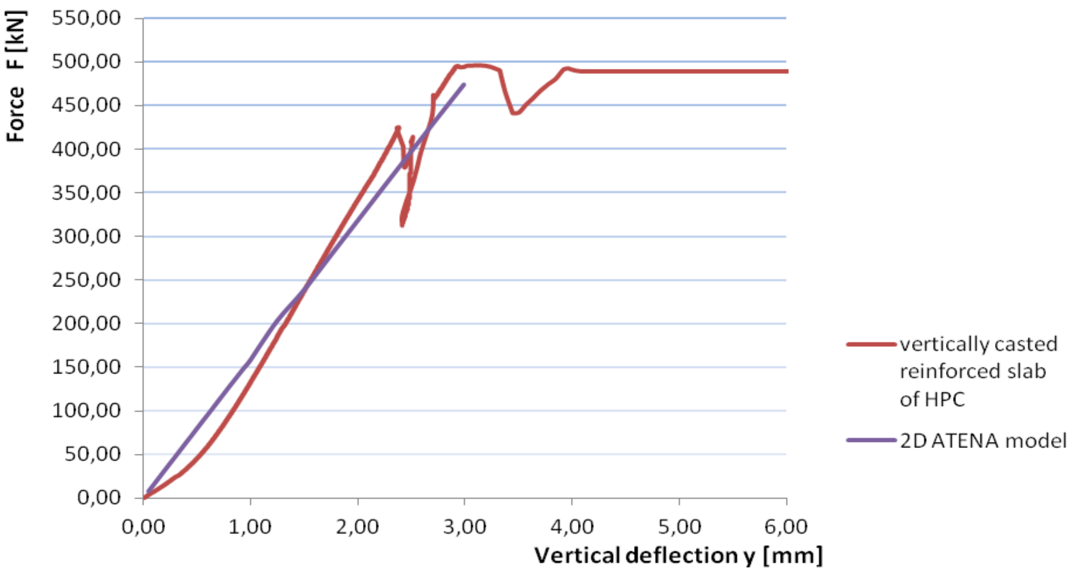

Figure 11: The comparison of the test results and model in ATENA program.

There are two graphic outputs of the model in 2D ATENA program on the figure 12.

4. Conclusion

TRC is a way to produce thin and elegant concrete elements with an extremely high load capacity. Several thin-walled slabs reinforced with basalt fabric were made by two methods of concreting. Flexural tensile strength and compression buckling tests have demonstrated higher strength in the second case. The paper has showed a simulation of the carried out tests. The next step will be possibility verification of using glass and carbon fabrics, including detection of material characteristics and production of concrete specimens sprayed onto the shaped fabric. After application to simple specimens, the production of organically shaped specimens will follow. The improving production technology of TRC and the unifying the method of calculation even complicated mouldable elements are the aim. A mathematical simulations of selected shaped elements for architectural using are and always will be the basis for the design.

Acknowledgements

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