Strength and deformability of compressed concrete elements with various types of non-metallic fiber and rods reinforcement under static loading

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Abstract. Adoption of modern building materials based on non-metallic fibers and their application in concrete structures represent one of the important issues in construction industry. This paper presents results of investigation of several types of raw materials selected: basalt fiber, carbon fiber and composite fiber rods based on glass and carbon. Preliminary testing has shown the possibility of raw materials to be effectively used in compressed concrete elements. Experimental program to define strength and deformability of compressed concrete elements with non-metallic fiber reinforcement and rod composite reinforcement included design, manufacture and testing of several types of concrete samples with different types of fiber and longitudinal rod reinforcement. The samples were tested under compressive static load. The results demonstrated that fiber reinforcement of concrete allows increasing carrying capacity of compressed concrete elements and reducing their deformability. Using composite longitudinal reinforcement instead of steel longitudinal reinforcement in compressed concrete elements insignificantly influences bearing capacity. Combined use of composite rod reinforcement and fiber reinforcement in compressed concrete elements enables to achieve maximum strength and minimum deformability.

1. Introduction

Development of construction industry involves introduction of new technologies and modern materials in design of new-built buildings and structures of various purposes. Studying possibility of integration of modern high-strength materials in structures is one of the important issues to improve design solutions. Non-metallic materials based on fibers are of particular interest as their use is already proved in the military, aerospace engineering and in the manufacture of aircrafts, ships, cars and other industrial products. The advantages of such materials include high strength properties and low weight, corrosion resistance, chemical and magnetic inertia.

Several types of raw building materials are produced based on fibers: fiber, obtained by cutting the filament used as the fiber (dispersed) reinforcement for the manufacture of fiber-reinforced concrete; composite rebar, which is non-metallic rods of continuous filament, bonded by polymer adhesive composition, which may be used as a concrete rod reinforcement; fibrous webs, which are used for enhancing various concrete structures. The production volume of such materials is increasing in different countries while scientists conduct studies to gather new data on the materials properties [1]. Research [2] has shown areas of their effective applicability in construction.
However, there are still many open issues in the field of application of these materials in manufacture of building structures on the basis of concrete [3].

2. Materials

For experimental research the following raw materials, based on non-metallic fibers were selected: basalt and carbon fiber for manufacture of fiber-reinforced concrete and composite rebar based on glass and carbon fibers used as rod reinforcement.

Preliminary testing of composite reinforcement under axial compression demonstrated that its compressive strength may reach values up to 650 MPa. Moreover, different types of composite reinforcement have high relative strain, higher values of deformations than of the steel reinforcement. Composite rebar has relatively low modulus of elasticity under compression compared with steel reinforcement. Fracture behavior of composite rebar based on carbon fibers is “bulging” of external fibers from the central compressive load and the scheme of destruction of composite reinforcement based on glass fibers has a shape of the shear.

Preliminary tests of fiber-reinforced concrete on basis of non-metallic fibers under axial compression showed that fiber non-metallic reinforcement of concrete increases its compressive strength and reduces deformability. After adding basalt or carbon fiber into concrete compressive strength increased up to 51%. This result was obtained using the developed technology of producing fiber-reinforced concrete [4,5].

3. Experimental procedure

The stress-strain state of compressed concrete elements with various types of non-metallic rod and fiber reinforcement has been studied experimentally. Program of experimental research included design, manufacture and compression testing of five concrete samples under static loading. For fiber reinforcement two types of non-metallic fibers were used: basalt and carbon. Composite reinforcement on the basis of glass and carbon fibers was used as non-metallic rod reinforcement. Experimental samples are concrete and fiber reinforced concrete elements with geometric dimensions of 100*100*1000 mm, reinforced with four longitudinal rods of metal or non-metallic reinforcing:

1) Concrete sample with metal longitudinal rod reinforcement, diameter of rods 10 mm Class A400 (standard compressive strength of 400 MPa) [6];

2) Concrete sample with non-metallic longitudinal reinforcement with rods of composite fiberglass reinforcement (GFRP) brand MONSTEROD (production of holding company "Composite", Moscow) nominal diameter of 9,4 mm;

3) Concrete sample with non-metallic longitudinal reinforcement with rods of composite carbon fiber reinforcement (CFRP) brand FibARMRebar (production of holding company "Composite", Moscow) nominal diameter of 9,6 mm;

4) Basalt fiber-reinforced concrete (BFRC) sample with non-metallic longitudinal reinforcement with bars of the CFRP brand FibARMRebar nominal diameter of 9,6 mm;

5) Carbon fiber-reinforced concrete (CFRC) sample with non-metallic longitudinal reinforcement with bars of the CFRP brand FibARMRebar nominal diameter of 9,6 mm.

Reinforcement of experimental samples in the transverse direction was made of rebar class Bp500 [4], diameter of 3 mm, located in pace of 75 mm. In abutting areas there were grids of confinement reinforcement arranged at a pitch of 20 mm to the height size of the sample bearing surface area. Fine grained concrete was used. The marking of the experimental samples was done in accordance with their design as shown in Table 1. Test program is shown in Figure 1.
Table 1. Marking of the experimental samples.

| Identifier of the sample | Number of samples, units | Quantity, type and nominal diameter of the longitudinal bars | Percentage of cross-sectional reinforcement, % | Type of fiber, which used for fiber-reinforcement of concrete | The percentage of fiber reinforcement (by weight of binder in concrete), % |
|--------------------------|--------------------------|-------------------------------------------------------------|-----------------------------------------------|-------------------------------------------------|-------------------------------------------------|
| CS-1                     | 1                        | 4xØ10 mm A-400                                             | 3.14                                          | -                                               | -                                               |
| CS-2                     | 1                        | 4xØ9.4 mm GFRP                                             | 2.89                                          | -                                               | -                                               |
| CS-3                     | 1                        | 4xØ9.6 mm CFRP                                             | 2.77                                          | -                                               | -                                               |
| CS-4                     | 1                        | 4xØ9.6 mm CFRP                                             | 2.77                                          | Basalt fiber                                    | 0.5                                             |
| CS-5                     | 1                        | 4xØ9.6 mm CFRP                                             | 2.77                                          | Carbon fiber                                    | 0.2                                             |

Figure 1. Design of experimental research.

Experimental samples were tested in accordance with the requirements of National State Standard GOST 8829-94 by static compressive load up to a limiting condition. Tests were carried out on an automated press PMM-250, equipped with advanced displacement sensors and electronic data recording. The loading was performed by the stages of 20 kN. After application of the load each stage was followed by a pause of 8 ... 10 minutes, during this pause redistribution of the internal stresses in the samples occurred. At this time the sample was examined, the formation and development of cracks was recorded. After holding the structure under the load the readings of devices were taken. The compressed samples were destroyed, while the value of the maximum efforts was recorded. General view of testing samples of compressed elements is given in Figure 2.
The following measurements were taken during tests. Longitudinal strain of reinforcement was recorded by resistance-strain gauge mounted at the stage of preparing samples on each of the four longitudinal bars in the middle of their length. Longitudinal and transverse deformations of concrete and fiber-reinforced concrete were also recorded by resistance-strain gauges mounted on the body of each of the sample pairs in mutually perpendicular directions along two adjacent sides in the middle of them. General longitudinal deformations of the samples were recorded by inductive displacement sensors mounted on two opposite sides of each of the samples.

The testimonies of electronic sensors were read through the measuring and computing complexes MIC-400D and MIC-300M. Force at each stage was recorded by an electronic display of the pressure machine.

4. Results

As a result of the tests performed schemes of crack formation and destruction of samples under static loading were obtained (Figure 3). The destruction of the samples was accompanied by crushing of concrete in all tests. Breaking load for samples were respectively: for CS-1 (A400) 360 kN, for CS-2 (GFRP) 339 kN, for CS-3 (CFRP) 347 kN, for CS-4 (BFRC, CFRP) 413 kN for CS-5 (CFRC, CFRP) 428 kN. Also, as a result of statistical treatment of readings of devices for each of the sample, the graph of longitudinal deformation of concrete was obtained (Figure 4).

The experimental data analysis showed that the bearing strength at the compression of concrete samples with longitudinal reinforcement with composite fiber reinforced glass and carbon rods (CS-2 and CS-3) is smaller than the bearing capacity of the sample reinforced with steel reinforcement rods class A400 (CS-1) by 5.8% and 3.6% respectively. The bearing capacity of samples of the basalt fiber-reinforced concrete (CS-4) and carbon fiber-reinforced concrete (CS-5) with a longitudinal reinforcement of composite carbon rods is more than load-carrying capacity of the sample of concrete (CS-3) and the remaining samples (CS-1 and CS-2).
Using basalt fiber for disperse reinforcement of compressed elements with carbon rod longitudinal reinforcement allowed to increase the carrying capacity by 19%, and with the use of carbon fiber it allowed to increase the carrying capacity by 23%. The reinforced-concrete sample of compressed element with composite rod reinforcement showed higher deformability: for sample with fiberglass reinforcement with longitudinal rod 142%, for the sample with carbon fiber-reinforced with longitudinal rod 133%.

Figure 3. Schemes of destruction and crack formation of compressed concrete elements.

Figure 4. Graph of longitudinal deformation of the compressed concrete elements.

Disperse reinforcement of concrete by basalt and carbon fiber contributed to reduction of deformability of the compressed concrete elements as a whole. It was also noted that the composite rebar and concrete (fiber-reinforced concrete) operate under strain compatibility.
5. Conclusion
According to the research, it was found that the fiber reinforcement of concrete enables increase in the carrying capacity of the compressed concrete elements and reduces their deformability. Despite the high rate of tensile strength of composite reinforcement its strength properties under compression are not realized completely due to the high marginal relative deformations in compression. In this regard, the composite rod reinforcement of compressed elements is advisable to use together with the dispersed fiber-reinforcement.

Further scientific research is required to study the possibility of joint application of rod composite reinforcement and fiber dispersed reinforcement in production of building structures.

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References
[1] Almerich Chulia A, Martin Concepcion P, Molines Cano J M and Rovira Soler J 2012 New GFRP bars as internal reinforcement in concrete Structures Proc. 15th European Conf. on Composite Materials (Venice)
[2] De Luca A, Matta F and Nanni A 2010 Behavior of full-scale glass fiber-reinforced polymer reinforced concrete columns under axial load ACI Structural Journal 107 589-596
[3] Степанова В Ф, Степанов А Ю и Жирков Е П 2013 Арматура композитная полимерная (Москва: АСВ) 200
[4] Кудяков К Л, Невский А В и Ушакова А С 2013 Влияние дисперсного армирования базальтовым волокном на прочностные свойства бетона Труды X Международной конференции студентов и молодых учёных Перспективы развития фундаментальных наук (Томск: ТПУ) 708-710
[5] Кудяков К Л, Невский А В и Ушакова А С 2014 Влияние дисперсного армирования углеродными волокнами на прочностные свойства бетона Труды XI Международной конференции студентов и молодых учёных Перспективы развития фундаментальных наук (Томск: ТПУ) 799-802
[6] СП 63.13330.2012 Бетонные и железобетонные конструкции. Основные положения Актуализированная редакция СНиП 52-01 (Москва: НИИЖБ)