The compressive strength of steel fibre reinforced concrete obtained by testing cubes and cylinders

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Abstract. There are two most popular approaches to determining the compressive strength of concrete: testing cubes, testing cylinders. The use of different samples gives different results, which are intended to characterize one parameter of the material - compressive strength. The article discusses a general approach to determining the compressive strength of cylinders and cubes. The analysis of the factors influencing the transition coefficients when testing the cylinder samples with the ratio of height to diameter is less than 2. The results of testing cubes and cylinders for compression made of fiber-reinforced concrete are presented.

1 Introduction

Concrete is a brittle material. In order to increase the fracture toughness, fiber is added to concrete by mixing. The resulting material - fiber-reinforced concrete, has a number of advantages in comparison with ordinary concrete: it increases the concrete bending strength; the vibration resistance of concrete increases; does not prevent the formation of microcracks, but well keeps cracks from expanding and growing microcracks into macrocracks, etc. The physical and mechanical properties of fiber-reinforced concrete depend on a number of parameters of fiber reinforcement, production technology and structure of the concrete matrix.

Compressive strength is one of the main quality indicators of building materials such as concrete and fiber-reinforced concrete. This parameter is obtained simply - the fracture stress related to the cross-sectional area of the test specimen. The size and shape of the test specimens are two of the most important parameters affecting the compressive strength index. There are basically three shapes of specimens used: cube, cylinder and prism. The aspect ratio significantly affects the results of compression tests of brittle materials such as concrete, fiber-reinforced concrete, foam concrete. It was found experimentally [12] that the ultimate load increases as the aspect ratio decreases, and attempts to bring it to the standard ratio become more complicated when the material strength level changes.

According to the recommendations of the International Organization of Testing Laboratories, compression tests are preferably performed on cylindrical specimens that give more uniform results. Here, smaller dependences can be traced: the destruction of the sample - on the stress at its ends, and the strength - on the properties of the coarse aggregate. The distribution of deforming stress along the horizontal planes of the cylinder is more uniform than in specimens with a square cross section [1, 2].

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The test strengths of cubes and cylinders made of the same concrete vary. The pulling action of the plates of the testing machine extends over the entire height of the cube, but leaves the part of the tested cylinder unaffected [3].

A number of scientific studies [4-15] have established that the effect of the aspect ratio on the nominal strength of quasi-brittle materials that break down after stable growth of large cracks is mainly caused by the release of energy. Studies of the influence of changing the aspect ratio due to the increase in the length of the sample [8, 9], confirm the great influence of the ratio h / d on the value of the compressive strength of the concrete sample. The angle of inclination shown in Fig. 1, is assumed to be approximately equal to 45 °, since at a different value of the angle the limiting effect of the friction force would be insignificant. In the diagrams shown in Fig. 1 shows how the aspect ratio of the cylinder specimens affects the fracture mode.

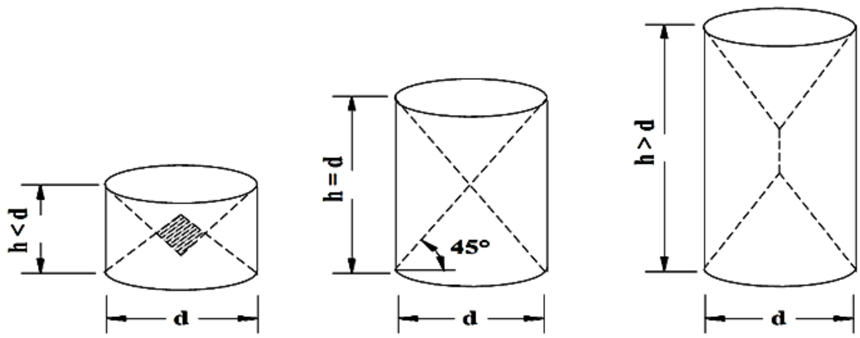


Fig. 1. Influence of the size and shape of the sample on the destruction mode [6]

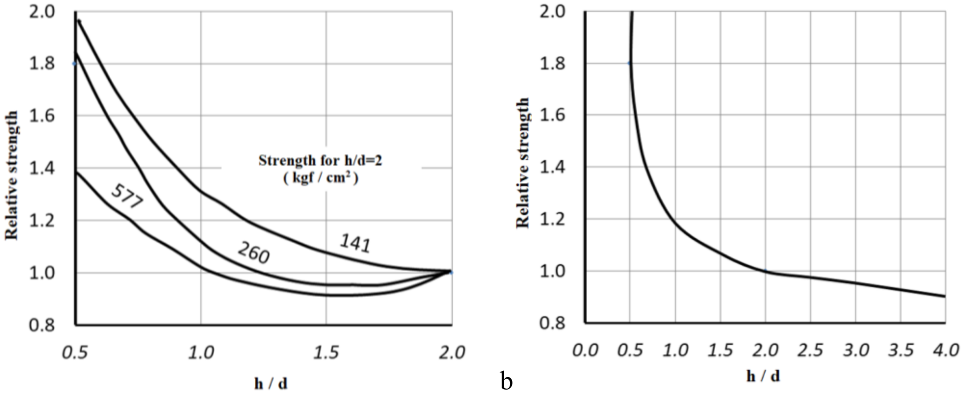
In this article, we make an attempt to assess the change in the compressive strength of fiber-reinforced concrete for sample cubes 100x100x100 mm and sample cylinders 150x150 mm. The aspect ratio of the test specimens is 1.

In the standards (GOST 28570, GOST 10180), the nominal dimensions of the diameters of the samples-cylinders when tested for compression are given: 70, 100, 150, 200, 250, 300 mm, similar to the dimensions of cubes. In this case, the height must be greater than or equal to the diameter. In GOST 10180 it is indicated that "it is allowed to use samples of other shapes and sizes, if they are provided for in the current regulatory or technical documents", thus tests can be carried out on samples of different sizes. Scale factors are given only for samples with a diameter of 100, 150, 200, 250, 300 mm and $h = 2d$ (Table 1).

Table 1. The generally accepted conversion factors [1, 2, 8]

Scale factor				Correction factor				
hxd, mm	GOST 10180	h=d, mm	K	h/d	GOST 28570	h/d	ASTM 42-90	BS 1881
100x200	1,16	200	-	1,95 -2,05	1,20	2,00	1,00	1,00
150x300	1,20	150	1,05	1,75-1,84	1,18	1,75	0,98	0,97
200x400	1,24	100	1,02	1,55-1,64	1,14	1,50	0,96	0,92
250x500	1,26	70	0,91	1,25-1,34	1,10	1,25	0,93	0,87
300x600	1,28	50	0,81	1,05-1,14	1,04	1,00	0,87	0,80
-	-	-	-	0,95-1,04	1,00	-	-	-

If h/d> 2, the sample can be shortened by sawing off part of its length to the standard ratio $h/d = 2$. With a short sample-cylinder h/d <2, it is necessary by calculation to bring the strength of concrete to an equivalent value at $h/d = 2$. The correction factor depends on the size of the sample and the strength of the concrete (Fig. 2, a). It is known that for low-strength concretes h/d has a greater effect than for high-strength concretes [2].



a b

Fig. 2. a - the effect of *h/d* on the strength of the cylinder for different levels of concrete strength; b - the effect of *h/d* on the strength of the cylinder [4]

The graph in Fig. 2 shows that the dimensions of the sample have a greater effect on the strength when the ratio *h/d* <2. For *h/d* <1.5, the measured strength increases rapidly due to the constraint of the plates on the testing machine. The increase in strength at equal values of the height and diameter of the sample is 15–20% of the strength of the sample with *h/d* = 2 [9, 16-17].

2 Method

In 2018, in the laboratory complex of RUE "Belenergostroy", at the construction site of the Belarusian NPP, the authors of this article carried out experimental work. For testing, fiber-concrete samples-cylinders 150x150 mm and samples-cubes 100x100x100 mm were made. Three types of fibers were used as dispersed reinforcement (Fig. 3):

- fiber from sheet steel of wave profile ФЛВ-0.9-50 - steel strip resembling a volumetric zigzag curve with corrugation (1% by volume of the mixture);
- anchor wire fiber ФАП-1.0-50 - steel wire with anchor ends (1% by volume of the mixture);
- polymer fiber of wave profile ФПВ-0.95-40 - rigid polymer monofilament with a profiled surface, made of polypropylene (0.4% by volume of the mixture).

a b c

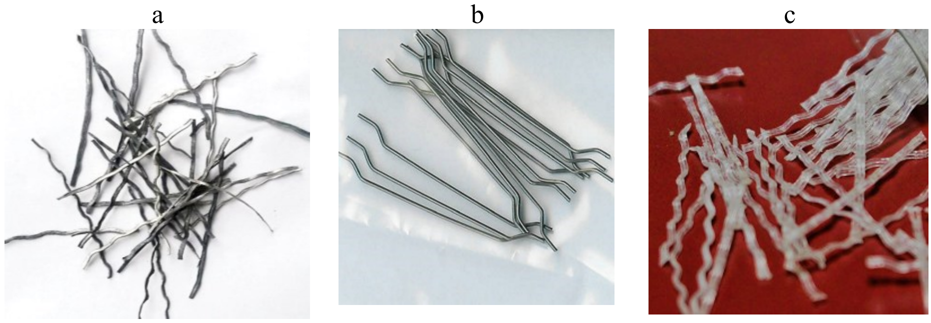


Fig. 3. Fiber fibers: a - sheet steel with a wave profile; b - anchor wire; c - polymer wave profile (Hereinafter - drawings by the author Sadovskaya E.A.)

Four types (A, B, C, D) of heavy concrete mixtures were used as a concrete matrix: A - cement, 400 kg, crushed stone 1020 kg, sand, 800 kg; B - cement, 445 kg, crushed stone 1035 kg, sand, 820 kg; B - cement 425 kg, crushed stone 875 kg, sand 950 kg, sulfoaluminate additive, 40 kg; G - cement 485 kg, crushed stone 825 kg, sand 800 kg, sulfoaluminate additive 40 kg, silica fume 45 kg. A modifier based on carbon nanostructured materials was introduced into each composition in an amount of 0.4–1.0% of the binder weight. The samples obtained were tested for compression in a hydraulic press Testing 2.1005 in a production laboratory at the construction site of the BelNPP. Compressive strength was calculated by the formula

$$R = \alpha \cdot \frac{F}{A} \ , \qquad (1)$$

where for cubes: α = 0.95; A = 100x100 mm; for cylinders: α = 1; A=π 75^2 mm.

The test results are shown in Fig. 4.

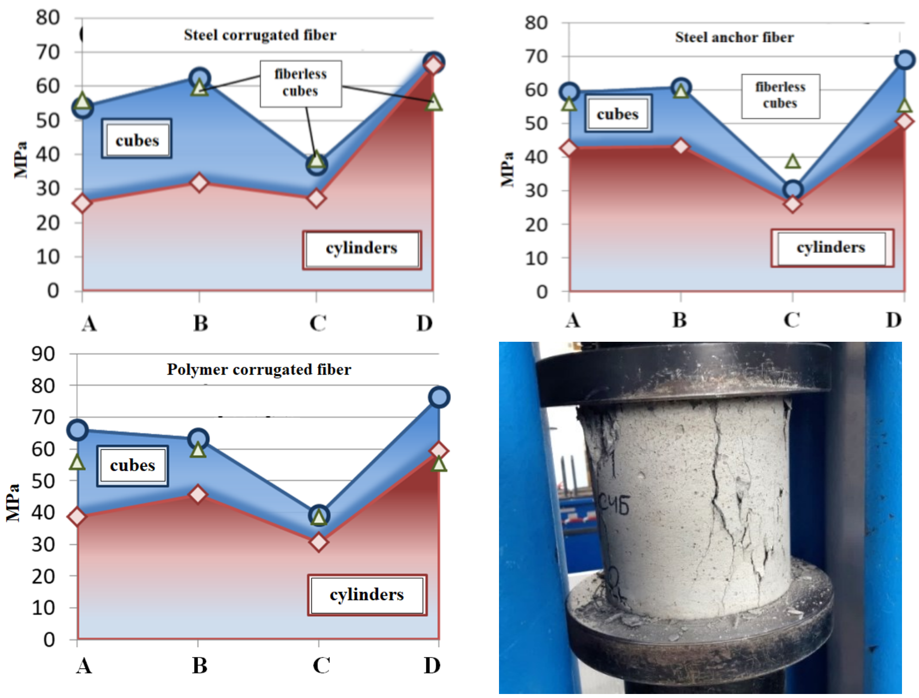


Fig. 4. Results of compression tests of fiber-reinforced concrete cubes and cylinders

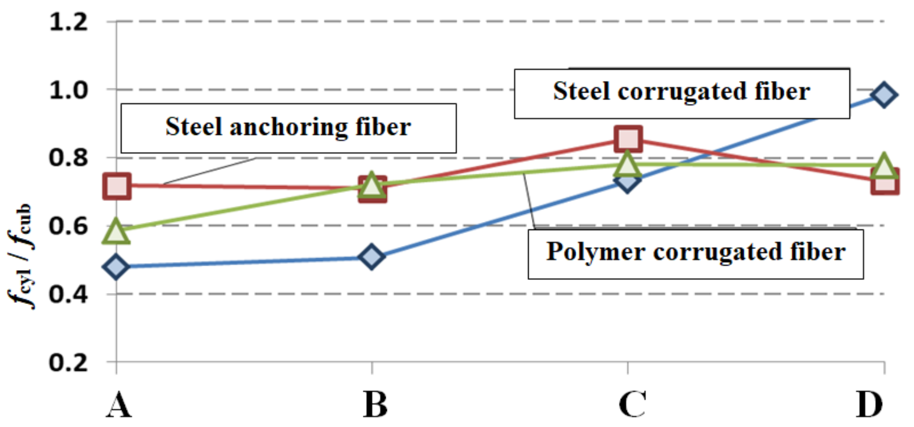


Fig. 5. Change in the ratio of compressive strength of cylinders to cubic strength

3 Results and Discussion

The data obtained indicate an insignificant effect (or its absence) of fiber reinforcement on the compressive strength of cubic specimens. Cubic specimens are tested perpendicularly, and cylindrical specimens are tested parallel to the stacking layers. This fact can have an impact when testing concrete specimens with dispersed fiber reinforcement. From this point of view, fiber-reinforced concrete specimens-cylinders simulate the work of the material under a compressive load that is closest to real conditions. It is known that with a homogeneous mixture without delamination, the compression of cubes parallel and perpendicular to the stacking layers does not differ.

4 Conclusions

The analysis of the results obtained allowed us to draw the following conclusions.

- The relationship between the strengths of the cylinder and the cube depends not only on the strength of the material.

- The transition coefficient from the compressive strength of a cube to the compressive strength of a cylinder is influenced by the strength of fiber-reinforced concrete, the ratio of the height of the sample-cylinder to its diameter, and the type of coarse aggregate.

- A height to diameter ratio of 2 gives the best results.

- The closest values of the compressive strength of different samples were obtained in composition B, which refers to fiber-reinforced concrete of medium strength.

- Fiber reinforcement at the dosage used has no effect on the compressive strength of the cubes and only slightly affects the compressive strength of the cylinders at the same height to diameter ratios.

- Fiber reinforcement has little effect on the compressive strength of the cubes.

- When testing the compression of fiber-reinforced concrete specimens, the homogeneity of the fiber-concrete mixture should be taken into account, especially when combinations of movable concrete matrices with metal fiber fibers, which tend to settle.

In the future, it is planned to conduct a study of the orientation of fiber fibers in samples with different aspect ratios.

5 Practical significance

The standard compression test for cylindrical specimens involves the use of specimens with a height h equal to two diameters d. But there are cases when samples with a different aspect ratio are used, for example, when using cores drilled from concrete of a structure or using samples made for other tests (for example, physical tests), but suitable for mechanical tests. The use of the same samples in different tests makes it possible to establish more reliable dependences, since the error caused by the inhomogeneity of the material is eliminated.

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