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DOI: 10.31643/2023/6445.26
Engineering and Technology

Fine-grained fiber concrete using polypropylene and basalt fibers

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Received: *11 July 2022*
Peer-reviewed: *27 August 2022*
Accepted: *23 november 2022*

ABSTRACT
The purpose of the study is to evaluate the effect of fibers on the bending strength of fine-grained concrete samples. The results of experimental studies of polypropylene and basalt fibers for dispersion reinforcement of concrete are considered. The strength characteristics of fiber concrete of different compositions have been determined. The regularities of the influence of fiber type and concentration on the strength characteristics of fiber concrete are revealed. The results of determining the bending strength of fine-grained fiber concrete without adding fiber (control composition) and with the addition of polypropylene fiber 0.1, 0.5, 1.5, 2.5% of the weight of cement and basalt 0.05, 0.1, 0.2, 0.5% of the weight of cement are presented. It is shown that the optimal limits of the introduction of polypropylene fiber in the mixture of fine-grained concrete can be considered 0.5 % by weight of cement. The introduction of basalt fiber in the mixture of fine-grained concrete in an amount of 0.1 % of the weight of cement can increase the bending tensile strength.

Keywords: fiber concrete, polypropylene fiber, basalt fiber, strength.

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Introduction

One of the promising ways to increase the performance characteristics of concrete and mortars is considered the introduction of microfiber in their formulation [[1], [2]]. The use of this material makes it possible to increase the strength of the cement stone, which provides higher compressive and bending tensile strength, as well as increases other characteristics of cement-based construction materials.

It is recommended to use polypropylene fiber in the technology of fiber concrete, plaster, masonry and installation mortars, hydraulic and cellular concrete to reduce the delamination of mixtures, increasing water resistance, frost resistance, corrosion resistance, impact strength, abrasion resistance [[3], [4], [5]].

To produce fiber concrete with the best characteristics it is necessary to achieve technological compatibility of concrete-matrix and fiber, maximum anchorage of fiber in concrete. It is categorically not allowed to get lumps of fiber, it must be very carefully mixed [6].

The undoubted advantages of fiber concrete include its high performance characteristics. Concrete with fiber in its composition is much superior to conventional concrete in quality, strength and durability. Products made of it become resistant to abrasion and chemical attack, are not deformed during operation and have high tensile and breaking strength. The use of fiber as a reinforcing material can significantly reduce the labor intensity of concrete products. Such structures do not require additional reinforcement by means of metal frames and meshes. This factor significantly speeds up the construction process and eliminates labor-intensive costs [[7], [8]].

Among the most promising types of polymer fibers are polypropylene fibers. Polypropylene fibers belong to the class of fibers of organic origin. This type of fibers is characterized by low cost, low elastic modulus, high elongation coefficient and corrosion resistance [[9], [10], [11], [12]]. High corrosion resistance allows the use of fibers under the influence of acids and alkalis, which is especially important for concrete, hardening of which is activated by alkaline solutions [13]. Polypropylene fibers are produced by continuous method from pure polypropylene pellets by extrusion as well as by drawing when heated. When the fibers reach a certain temperature, an oiling compound is applied to their surface. It is this composition that promotes surface adhesion and dispersion of polypropylene fibers in concrete mortar. Fibers have the form of thin white polypropylene fibers of different sizes, which is an inert substance, resistant to alkalis and various chemicals [[14], [15], [16]].

The use of basalt fiber leads to the creation of the simplest aggregate formations, while viscoplastic properties are changed, as evidenced by the increase in the plastic strength of the system. The fibers improve the microstructure, reduce internal stresses and shrinkage of the cement stone [[17], [18]]. The spindle-shaped structure of basalt fiber chemisorptionally interacts with the cement system, creating conditions for the growth of newly formed low-base calcium hydrosilicates in the contact zone. The structure is strengthened due to adhesion, or fusion of fiber fibers with new formations of the curing material.

Basalt fiber is produced from basalt rock melts. The advantages of basalt fiber for disperse reinforcement are that along with high strength it does not pull under load, has chemical, corrosion and thermal resistance to the environment, temperature fluctuations and intense alternating loads, and also has a low cost. Basalt fiber (chopped basalt thread) is pieces of basalt fiber and is an effective reinforcing additive for various types of concrete [[19], [20]]. Basalt rock fibers have high natural initial strength, resistance to corrosive medium, durability, electrical insulation properties, and are produced from natural, environmentally friendly raw materials [21]. Therefore, basalt fibers have prospects of application in industry, construction, power engineering.

Purpose of the study: evaluation of the effect of fiber on the strength of standard concrete specimens.

To achieve the goal the following tasks were solved:

1. Preparation of samples;
2. Strength at bending;
3. Strength in compression;
4. Analysis of the results.

Experimental technique

For the experimental work as a binder used Portland cement PC 400 D0 without additive, true density - 3100kg/m^3, bulk density - 1100-1600 kg/m^3.

As a fine fraction of the aggregate used natural quartz sand with a fineness modulus of 2.23, which meets the requirements of GOST 8736-2014 «Sand for construction works».

Polypropylene and basalt fibers were selected for testing the mechanical properties depending on the degree of reinforcement of fine-grained fiber concrete.

The quantitative ratio of fibers in the composition of the samples was selected on the basis of their density ratios:

$$\frac{P\ pol.}{P\ baz.} = x \qquad (1)$$

$$a_1 \ldots a_n\, ,\ b_1 \ldots b_n$$

$$a_1 / b_1 = x \ldots\ldots\ldots\ldots\ a_n / b_n = x$$

Thus we obtain the necessary amount of each type of fiber by weight, corresponding to their equal volume in the sample. The variability of the concrete mixture with the addition of polypropylene fibers is characterized by the following variables: $a_1 \ldots a_n$ - the limits of adding polypropylene fibers to the concrete mixture. Accordingly, for the concrete mixture with the addition of basalt fiber, the variability of the composition is characterized by the variables $b_1 \ldots b_n$.

Polypropylene fiber was introduced into dry mixture for fine-grained concrete in the amount of 0.1, 0.5, 1.5, 2.5% of the mass of cement, followed by thorough mixing and mixing with water. From equation (1) you can find ratio for basalt fiber: 0.05, 0.1, 0.2, 0.5% of cement mass. The chosen range of fiber dosage corresponds to the requirements of regulatory documents and manufacturer's recommendations. The physical and mechanical characteristics of the fibers are given in Table 1.

Table 1 - Characteristics of fibers

Properties	***Polypropylene***	***Basalt***
Density (kg/m^3)	620	3100
Length (mm)	10	12
Dia. (mkm)	22	18
Tensile strength (MPa)	170 – 260	3000-4840
Elongation to break, %	150 – 250	3.1-6.0

Tap water as mixing water for concrete mix that meets the requirements of GOST 23732-2011 «Water for concretes and mortars».

Tensile bending strength of concrete were determined on specimens of bars 40x40x160 mm in size at the age of 3, 7 and 28 days of normal curing. The procedure of testing the bending strength of concrete bars was carried out in accordance with GOST 310.4-81 «Cements. Methods for Determining the Flexural and Compressive Strength».

Consumption of raw materials of cement-sand mortar samples is presented in Table 2.

Table 2 - Cement mortar composition

Type of sample	**Cement, g**	**Quartz Sand, g**	**Fiber, g**	**Water, g**
Type 1 Reference sample	450	1350	-	180
Polypropylene				
Type 2	450	1350	0.45	180.18
Type 3	450	1350	2.25	180.9
Type 4	450	1350	6.75	182.7
Type 5	450	1350	11.25	184.5
Bazalt				
Type 6	450	1350	0.225	180.09
Type 7	450	1350	0.45	180.18
Type 8	450	1350	0.9	180.36
Type 9	450	1350	2.25	180.9

The effect of micro-reinforcing fibers on the properties of fine-grained concrete with a cement to aggregate ratio of 1:3 and a water-cement ratio of 0.4 was investigated.

Mixtures were prepared manually in a mixing bowl in accordance with GOST 310.3-76. Preliminary prepared mixture of cement and sand was mixed with water for 2 minutes, after which fibers were evenly introduced into it for 4 minutes under constant stirring. After preparation of the mixture its consistency was determined by its melt on the shaking table in accordance with the method of GOST 310.4-81. There were investigated compositions with the consumption of polypropylene fiber 0.1, 0.5, 1.5, 2.5% and basalt fiber 0.05, 0.1, 0.2, 0.5% of cement mass, as well as control composition without additions, which were curing for 28 days in air-humid conditions.

Tap water as mixing water for concrete mix that meets the requirements of GOST 23732-2011 «Water for concretes and mortars».

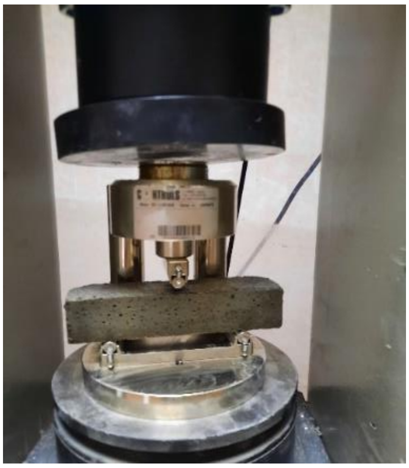
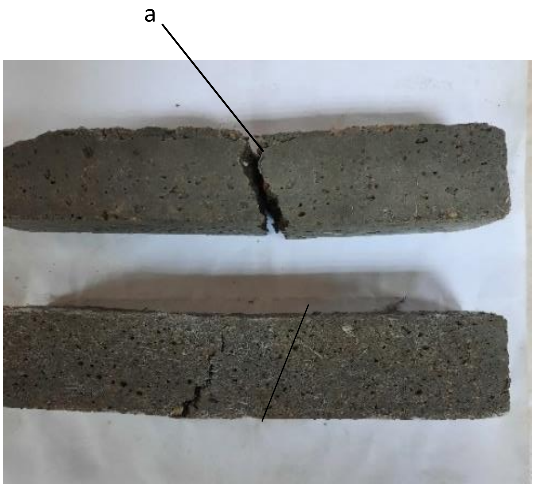


Figure 1 – Before the start of the test

Figure 2 – After completing the test

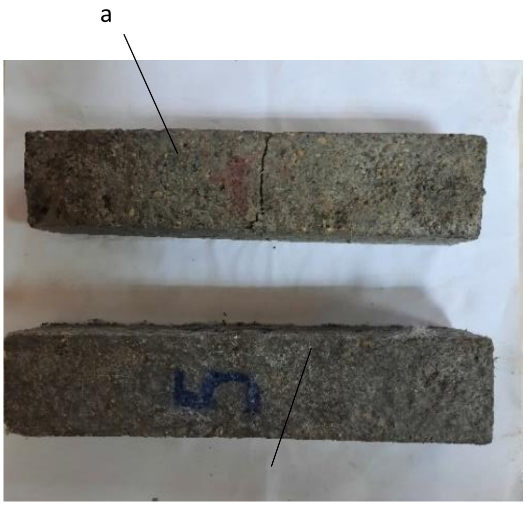
Tests were conducted at 3, 7 and 28 days of normal curing on an Automatic Pilot 500kN press (Figure 1-2).

After testing by destructive method, samples were inspected to visually assess the uniformity of the distribution of fiber concrete along the shear fracture of the beam (Figure 3-4).



b

Figure 3 – Samples, after completion of the test. Side view.
a – reference sample; b - reinforced with fiber.



b

Figure 4 – Samples, after completion of the test. Top view.
a - reference sample; b - reinforced with fiber.

Results and Discussion

Figure 5 shows the results of the reference sample (without the addition of fiber) in bending at the age of 3, 7 and 28 days of normal curing.

Figures 6-9 show the results of determining the bending strength of fine-grained fiber concrete with the addition of polypropylene fiber 0.1, 0.5, 1.5, 2.5% of the weight of the cement.

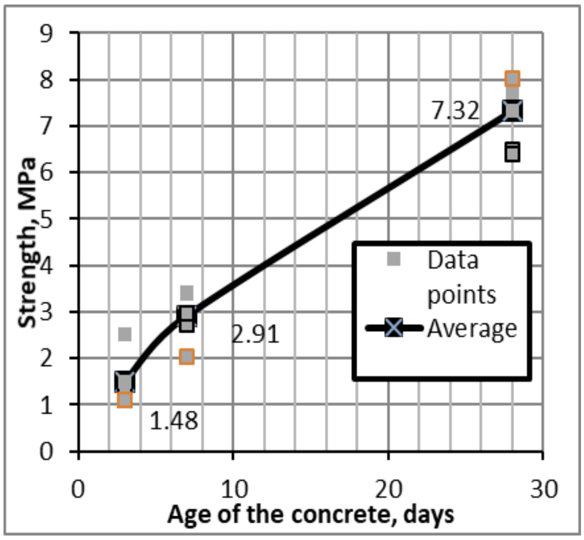


Figure 5 – Reference sample, Fiber content 0%

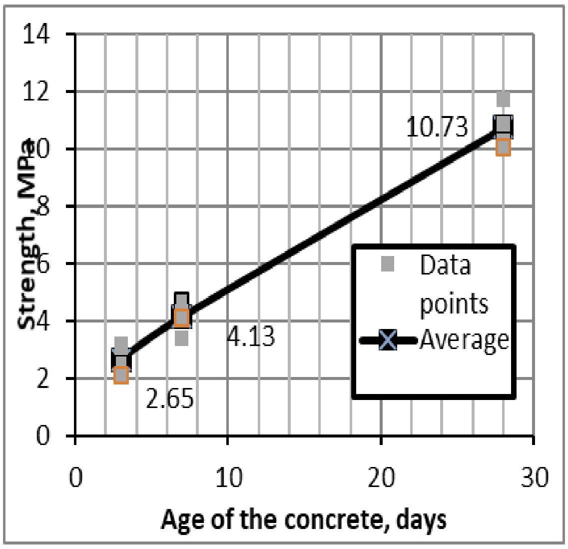


Figure 6 – Polypropylene Fiber content 0.1%

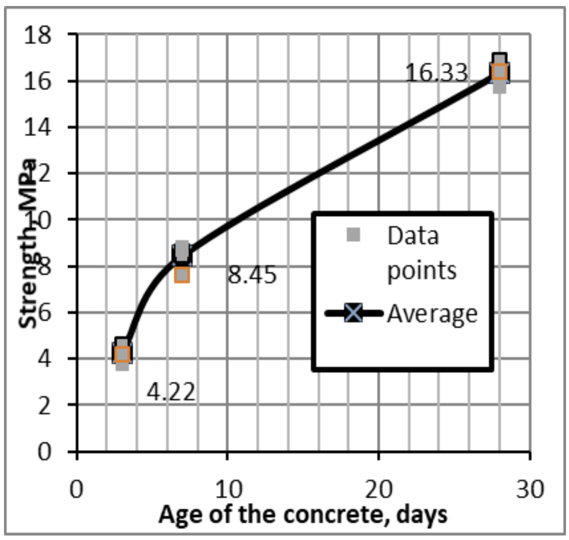


Figure 7 – Polypropylene Fiber content 0.5%

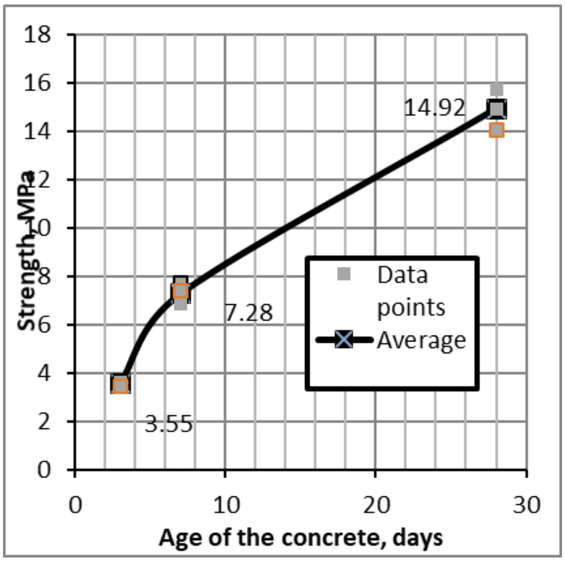


Figure 8 – Polypropylene Fiber content 1.5%

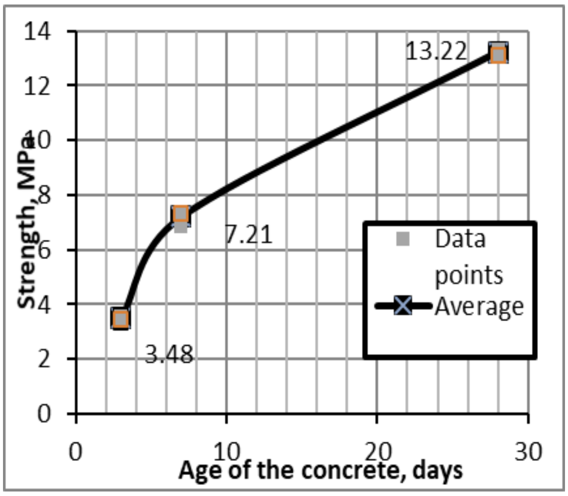


Figure 9 – Polypropylene Fiber content 2.5%

The test results show a positive trend in the dependence of the bending strength on the dosage of polypropylene fiber. According to Figure 6, an increase of 46.5 % in bending strength on 28 days is already observed with the addition of 0.1 % fiber volume compared to the reference sample (Figure 5).

Analysis of the data shows that with the introduction of 0.5% (Figure 7) polypropylene fibers, the ultimate tensile strength of concrete at flexure is in the range 16.33 MPa, and for the reference type 7.32 MPa, that is, this index is 2 times higher than for the reference sample (Figure 5).

A further increase in polypropylene fiber content of 1.5 and 2.5% in fine-grained fiber concrete leads to a gradual decrease in bending strength (Figure 8-9).

Figures 10-13 show the diagram of changes in bending strength with the addition of basalt fiber 0.05, 0.1, 0.2, 0.5% of the weight of cement as a function of curing time.

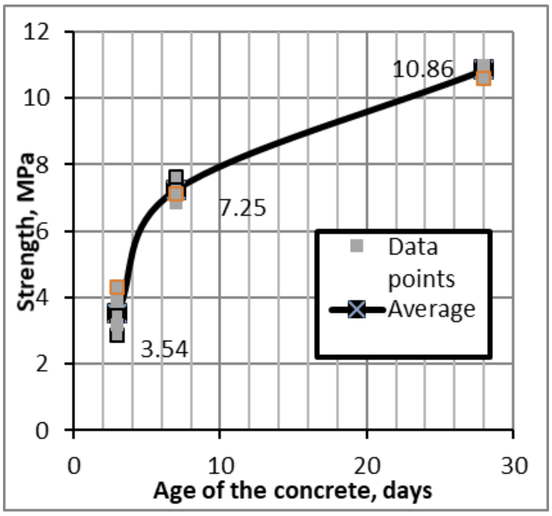


Figure 10 – Basalt Fiber content 0.05%

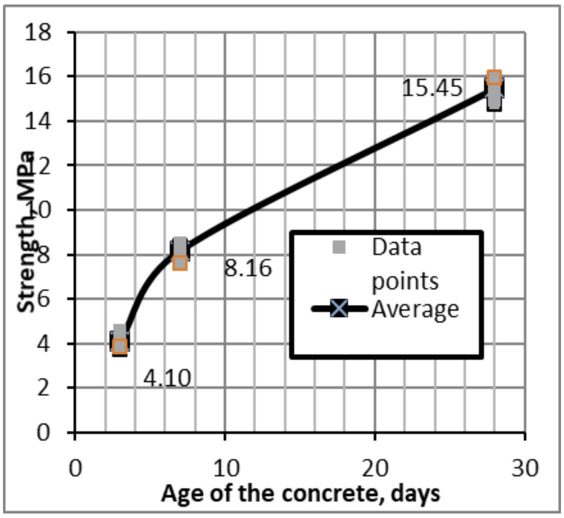


Figure 11 – Basalt Fiber content 0.1%

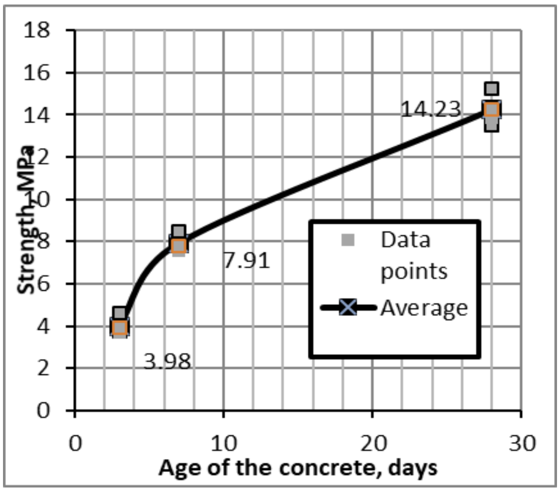


Figure 12 – Basalt Fiber content 0.2%

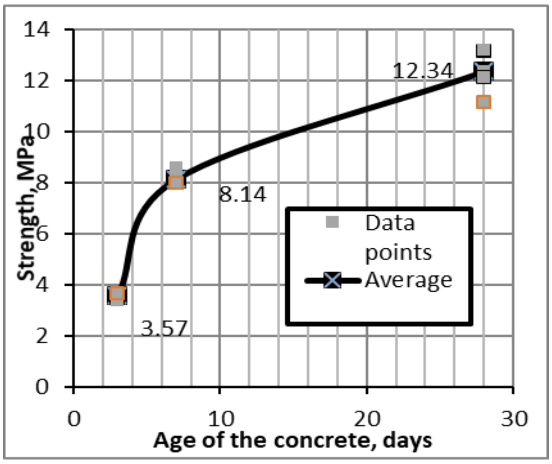


Figure 13 – Basalt Fiber content 0.5%

The introduction of basalt fiber in the concrete mix contributes to an increase in the compressive strength, tensile strength at bending by 5-14%, 24-39% respectively [[22], [23], [24]].

Figure 9 shows that the addition of basalt fiber in an amount of 0.05% bending strength of concrete increases slightly compared to the reference composition.

The most significant increase was observed with the introduction of basalt fiber in an amount of 0.1% (Figure 11) of the bending strength of concrete - an increase of almost 2 times compared with the reference composition.

The 0.2% content of basalt fiber in the concrete also increases the bending strength, but compared with the addition of basalt fiber at 0.1% there is a slight decrease of about 3% (Figure 12).

Figure 14 shows comparative bending tensile results with and without the addition of fibers.

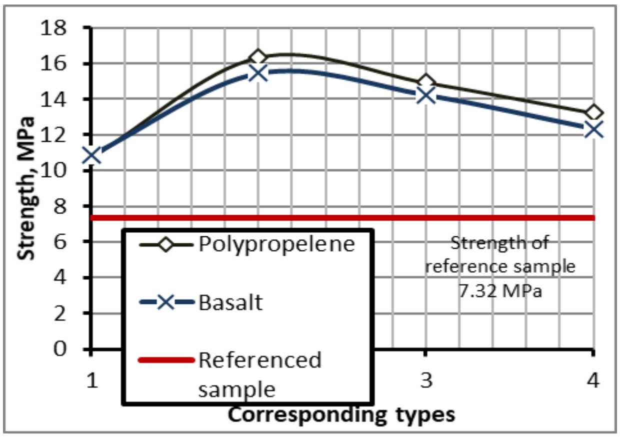


Figure 14 – Comparison of the results of the reference sample with the addition of polypropylene and basalt fiber

The introduction of basalt fiber in the amount of 0.5% also increases the bending strength of concrete, but there is a decline of 28% compared with the addition of fiber 0.1% of the weight of cement (Figure 13).

Figure 14 shows that the bending tensile strength with the addition of various fibers is a slightly higher than that without the addition. The addition of fibers in optimal amounts (polypropylene fibers 0.5% and basalt fibers 0.1%) has the most effective effect to increase the bending tensile strength of concrete.

With the addition of polypropylene and basalt fibers the crack resistance of concrete can be increased. Based on studies, the introduction of fiber in the mixture of fine-grained concrete reduces water separation, as well as increases resistance to cracking and impact [25].

If you visually compare two samples (a - reference sample, b - sample reinforced with fibers) on Figure 4-5, you can see that the reference sample, without fibers, after the load broke into two separate parts, the sample with polypropylene fibers on its surface has no cracks, on the side there are minor cracks. This means that the addition of fibers not only increases the strength of concrete samples, but also increases crack resistance. In general, visual inspection of the samples, after their destruction showed that the distribution of fibers is quite homogeneous. Throughout the cut (fracture) area, elements of fibers were observed.

Conclusions

Accordingly, the addition of polypropylene fiber in an amount of 0.5% of the weight of cement in the concrete mixture of fine-grained concrete allows increasing the flexural strength by 2 times more as compared with the reference composition. This consumption is optimal for the bending tensile strength, as a further increase in the consumption of polypropylene fiber leads to a decrease in the bending tensile strength.

The content of basalt fiber in the concrete mixture of fine-grained concrete in an amount of 0.1% of the weight of cement can increase the bending tensile strength by an average of 40%.

Conflict of interest

On behalf of all the authors, the correspondent author states that there is no conflict of interest.

Cite this article as: Nurbayeva MN, Aruova LB, Lukpanov RE, Vainberger SA, Gunasekaran M. Fine-grained fiber concrete using polypropylene and basalt fibers. Kompleksnoe Ispolzovanie Mineralnogo Syra = Complex Use of Mineral Resources. 2023;326(3):32-40. https://doi.org/10.31643/2023/6445.26

Полипропилен және базальт талшықтары қолданылған ұсақ түйіршікті фибробетон

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Мақала келді: *11 шілде 2022*
Сараптамадан өтті: *27 тамыз 2022*
Қабылданды: *23 қараша 2022*

ТҮЙІНДЕМЕ

Фибробетон үлгілері әртүрлі талшық түрлерімен сыналды. Бетондарды дисперсті армирлеуге арналған полипропилен және базальт талшықтарын эксперименттік зерттеулердің нәтижелері қарастырылады. Фибробетонның беріктік сипаттамаларына талшықтың түрі мен концентрациясының әсер ету заңдылықтары анықталды. Талшықты қоспай (бақылау үлгісі) және цемент массасының 0,1, 0,5, 1,5, 2,5% құрайтын полипропилен талшығын және цемент массасының 0,05, 0,1, 0,2, 0,5% құрайтын базальт талшығын қоса отырып, ұсақ түйіршікті фибробетонның иілу кезіндегі созылу беріктігін анықтау нәтижелері ұсынылған. Полипропилен талшығын ұсақ түйіршікті бетон қоспасына қосудың оңтайлы шегі цемент массасының 0,5% деп санауға болатындығы көрсетілген. Цемент массасының 0,1% мөлшерінде ұсақ түйіршікті базальт талшықты бетон қоспасына қосу иілу кезінде созылу беріктігін арттыруға мүмкіндік береді.

Түйін сөздер: фибробетон, полипропилен талшығы, базальт талшығы, беріктік.

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Мелкозернистый фибробетон с использованием полипропиленовых и базальтовых волокон

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Поступила: *11 июля 2022*
Рецензирование: *27 августа 2022*
Принята в печать: *23 ноября 2022*

АННОТАЦИЯ

Проведены испытания образцов фибробетона с различными типами фибры. Рассмотрены результаты экспериментальных исследований полипропиленовой и базальтовой фибры для дисперсного армирования бетонов. Определены прочностные характеристики фибробетонов различных составов. Выявлены закономерности влияния типа и концентрации фибры на прочностные характеристики фибробетона. Представлены результаты определения предела прочности на растяжение при изгибе мелкозернистого фибробетона без добавления фибры (контрольный состав) и с добавлением полипропиленовой фибры 0,1, 0,5, 1,5, 2,5% от массы цемента и базальтовой 0,05, 0,1, 0,2, 0,5% от массы цемента. Показано, что оптимальными пределами введения полипропиленовой фибры в смесь мелкозернистого бетона могут считаться 0.5 % от массы цемента. Введение в бетонную смесь мелкозернистого бетона базальтовой фибры в количестве 0,1-0,2% от массы цемента позволяет повысить прочность на растяжение при изгибе.

Ключевые слова: фибробетон, полипропиленовая фибра, базальтовая фибра, прочность.

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