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Influence of basalt fiber length on strength characteristics of fine-grained fiber concrete

[1]Nurbayeva M.N., [1]Lukpanov R.E., [1]Aruova L.B., [2]Gunasekaran M.

[1]L.N. Gumilyov Eurasian National University, Astana, Kazakhstan
[2]Uttaranchal University, Dehradun 248007, India

** Corresponding author email: marzhan_nurbaeva@mail.ru*

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ABSTRACT
The samples of fiber concrete with different lengths of basalt fiber have been tested. The characteristics of basalt fiber used for the manufacture of fiber concrete are given. The aim of the study is to identify the pattern of influence of fiber length on the strength characteristics of fiber concrete. The paper presents the results of determining the compressive and bending tensile strength of fine-grained fiber concrete with no fiber added (control composition) and with the addition of basalt fiber 0.2 % of the weight of cement with a fiber length of 40 mm, 20 mm, 10 mm and 5 mm. It is demonstrated that the optimal limits of basalt fiber introduction into the mixture of fine-grained concrete can be considered a length of 20 mm fibers, which leads to an increase in compressive strength up to 47.2 %, in bending tensile strength up to 2 times more in comparison with the control composition.

Keywords: Basalt fiber, reinforcement, compressive strength, bending.

Information about authors:

Nurbayeva Marzhan Nurbaykyzy — *Ph.D. Student, Department of Technology of Industrial and Civil Construction, L.N. Gumilyov Eurasian National University, 010000, Satbayeva Street 2, Astana, Kazakhstan. Email: marzhan_nurbaeva@mail.ru*

Lukpanov Rauan Ermagambetovich — *Ph.D., Professor of the Department of Technology of Industrial and Civil Construction, L.N. Gumilyov Eurasian National University, 010000, Satbayeva Street 2, Astana, Kazakhstan. Email: rauan_82@mail.ru*

Aruova Lyazat Boranbayevna — *Dr. tech. sc., Professor of the Department of Technology of Industrial and Civil Construction, L.N. Gumilyov Eurasian National University, 010000, Satbayeva Street 2, Astana, Kazakhstan. Email: ecoeducation@mail.ru*

Gunasekaran Murali — *Professor of the Division of Research & Innovation, Uttaranchal University, Dehradun 248007, India. Email: murali_220984@yahoo.co.in*

Introduction

In the last few years, high-strength concretes with various modifying additives and fillers have been gaining popularity due to the development of high-rise buildings. The consequence of this trend is an increase in the requirements imposed on the construction materials from which the building or structure is erected. Due to the addition of various components [1], engineers achieve an increase in important indicators of the material: strength, cracking resistance, wear resistance, durability, impact resistance, service life, etc.

Fibers of natural or artificial origin are used to increase the resistance of concrete [[2], [3]]. Its effect is aimed at several characteristics of concrete: resistance to cracks, water resistance, and frost resistance. After adding the material to the concrete, it is evenly distributed throughout the mixture and increases its strength many times over, and the fiber copes with this task much better than traditional mesh reinforcement [[4], [5]].

One of the popular modern fillers used today is basalt fiber, which has high adhesion. A special place among reinforcing additives in concrete is occupied by basalt fiber, the technology of its introduction, as well as its quantitative content in concrete compositions, its influence on the formation of the structure and properties of cement mortars and concretes are of interest [6].

Basalt fiber is a special material produced from sedimentary basalt rocks with further melting and transformation into fibers [[7], [8], [9], [10]]. The diameter of the particles ranges from 20 to 500 microns, with lengths from 1 to 150 mm. Basalt fiber has a high elastic modulus (75 GPa, which is higher compared with other types of fiber, except steel (190 GPa)), a low percentage of elongation at break

(3.2%, which is lower compared with all other types of fiber), and acceptable density (2600 kg/m^3) and melting temperature (1450 °C) [2]. Basalt fiber is used in the production of dry mortars, cellular concrete blocks, chemically resistant pipes, and concrete collectors, as well as in the construction of floor screeds and foundations.

According to the authors [4], a study of the effect of highly dispersed fibrous fillers on the mechanical properties of fiber concrete using basalt micro reinforcing fiber length of 12 mm and a diameter of 10 microns, leads to increased rates of compressive and flexural strength of samples that is explained by the cohesion of basalt fibers with the cement-sand matrix [[11], [12], [13], [14]].

Basalt-fiber concrete has high flexural and tensile strength with good technological properties. It allows you to reduce the percentage of reinforcement and metal mesh in the concrete elements. It is also worth noting that concrete with the addition of basalt fiber can tolerate more elastic deformations, as basalt fiber has a high modulus of elasticity and almost no plastic deformations [15]. Basalt fiber is not subject to corrosion and has 2-2.5 times higher strength compared with metal fiber. Dispersed reinforcement of the cement matrix with basalt fiber has significant advantages: no corrosion, significantly lower specific weight, radio transparency, better bonding with the matrix, increased plasticity of the mortar and prevention of cracking [[16], [17]]. This opens up opportunities for the wide application of basalt fiber for concrete reinforcement in earthquake, hydraulic, and road construction.

The superfine fiber reacts with the cement medium as an active mineral additive, followed by the formation of needle-like crystals, increasing the strength of the concrete. However, the strongly alkaline nature of the medium affects the strength of the fiber and, ultimately, the strength characteristics of the reinforced concrete [[18], [19], [20]].

The following problems were resolved:

1. Preparation of specimens under laboratory conditions;
2. Strength in the bending;
3. Compressive strength;
4. The analysis of the Results.

Comparisons of the results of laboratory tests were carried out for five types of concrete:

Type 1: control of the composition of concrete without fiber;

Type 2: composition of concrete with basalt fiber of 40 mm length;

Type 3: concrete composition with basalt fiber with a length of 20 mm;

Type 4: Concrete composition with basalt fiber with a length of 10 mm;

Type 5: concrete composition with basalt fiber with a fiber length of 5 mm.

Purpose of the study: evaluation of the influence of the length of basalt fiber on the strength of standard concrete specimens.

Experimental technique

For the experiments as a binding used portland cement PC 400 D0 with no addition, the real density was 3100 kg/m^3, bulk density was 1100-1600 kg/m^3.

A small fraction of the sand filler used natural quartz sand with a particle size modulus of 2.23, meeting the requirements of GOST 8736-2014 "Sand for construction works.

Basalt fibers with lengths of 40 mm, 20 mm, 10 mm, and 5 mm were selected for testing the mechanical properties of fine-grained fiber concrete depending on the length of the fibers (Fig. 1).

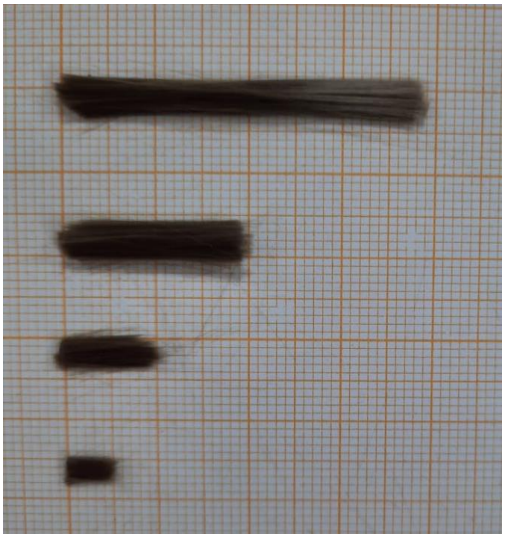

Figure 1 – Basalt fibers of various lengths

The physical and mechanical characteristics of basalt fiber are shown in Table 1.

Table 1 - Characteristics of basalt fiber

Properties	***Basalt***
Density (kg/m^3)	3100
Dia. (mkm)	18
Length (mm)	5; 10; 20; 40
Tensile strength (MPa)	3000-4840
Elongation to break, %	3.1-6.0

Water for concrete mix preparation that meets the requirements of GOST 23732-2011 «Water for concretes and mortars».

Raw material consumption of samples of cement-sand mortar is given in Table 2.

Table 2 - Cement mortar composition

Type of sample	*Cement, g*	*Quartz Sand, g*	*Bazalt Fiber, g*	*Water, g*
Type 1 Reference sample	450	1350	-	180
Type 2 Fiber length 40мм	450	1350	0.9	180.18
Type 3 Fiber length 20 мм	450	1350	0.9	180.9
Type 4 Fiber length 10мм	450	1350	0.9	182.7
Type 5 Fiber length 5мм	450	1350	0.9	184.5

The mixtures were ready by hand in a bowl for mixing in compliance with GOST 310.3-76. The previously prepared mixture of cement and sand was stirred with water for 2 minutes, after which the fibers were introduced into it for 4 minutes with continuous mixing evenly (Fig. 2).

Figure 2 – Sample preparation

The determination of the bending strength of the control and basalt cement-sand mixes was carried out on beam samples with dimensions of 40×40×160mm (Fig. 3). The test of bending strength of the concrete beams was performed following GOST 310.4-81 “Cement. Methods of Determination of Flexural and Compressive Strength”.

Figure 3 – Generated samples

To explore the fine fiber properties, samples were obtained from the mixture with different fiber lengths. The index of strength was measured as an arithmetic amount equal to 5 indexes for different curing periods (3, 7, 28 days).

Results and Discussion

Reactions on the "fiber-cement matrix" surface can also improve the properties of the composite as a consequence of increased adhesion of the matrix to the fiber, monolithic system, and improved conditions of compatibility of loading of the fibers in the composite.

Figure 4 shows a diagram of changes in the bending tensile strength of the samples as a function of curing time.

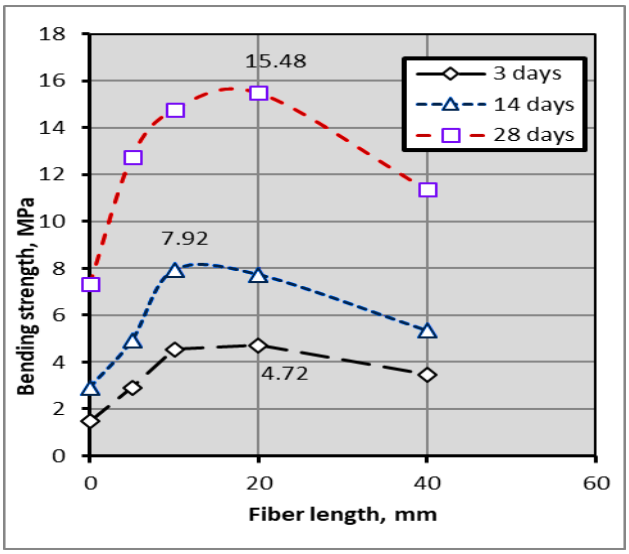

Figure 4 – Dependence of bending strength of fiber concrete on their fiber length and curing age

The analysis of the data presented in Figure 4 shows that a greater value of the strength of fiber

concrete at 28 days (15.48 MPa) is achieved with the introduction of a basalt fiber length of 20 mm compared to the control samples without the addition of fiber (7.32 MPa).

At 14 days, the addition of 20 mm fiber length compared to 10 mm fiber length showed an increase in bending strength of 2.6 % (7.92 and 7.73 MPa, respectively).

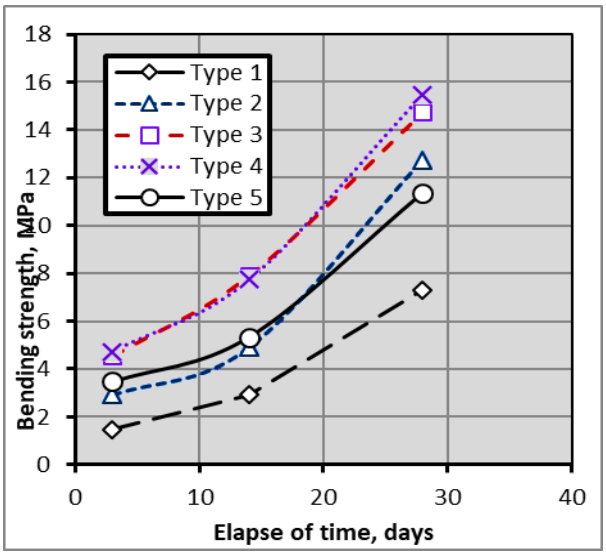

Figure 5 – Dependence of bending strength of fiber concrete on fiber length

According to the test results shown in Figure 5, the maximum average bending tensile strength of the control samples is 7.32 MPa (28 days), while the maximum average strength of samples using basalt fiber with a length of 20 mm is 15.48 MPa, that is, this figure is 2 times higher than for the control sample.

According to strength comparisons, presented in Fig. 5, for 10 mm fiber length specimens, on the 3rd and 14th day an increase in strength to 4.55 and 7.92 MPa is observed relative to specimens without fiber (type 1 - 1.48 MPa on the 3rd day and 2.91 MPa on the 14th day). On the 28th day, the tendency of increasing the strength remains. In any case, there is a positive effect of increasing the strength of samples with the addition of basalt fiber.

Analyzing the data obtained, it should be noted that the maximum effect of flexural tensile strength was achieved with the introduction of basalt fiber with a length of 20 mm, the strength of which was 15.48 MPa.

The results of determining the compressive strength of fiber concrete specimens are shown in Figure 6.

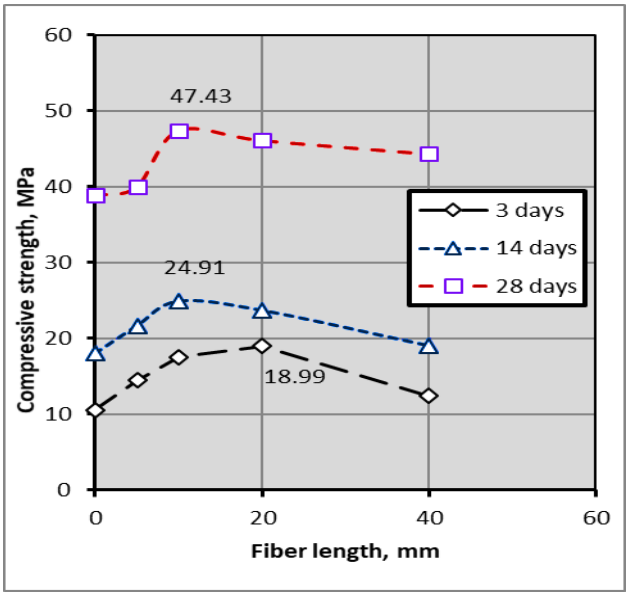

Figure 6 – Dependence of compressive strength of fiber concrete on fiber length and curing age

When comparing the index of the ultimate strength of the prepared sample, equal to 38.91 MPa, with this index for the concrete, prepared composition, which was between 40.4-47.43 MPa, we can assume that the fiber concrete is of higher quality.

As a result of the data obtained, it can be argued that the fiber concrete with basalt fiber in the first 3 days has a higher strength of 17.5-79.3%; on 14 days - 20 - 38% and 28 days - 13.9 - 21.9% in comparison with its analogs.

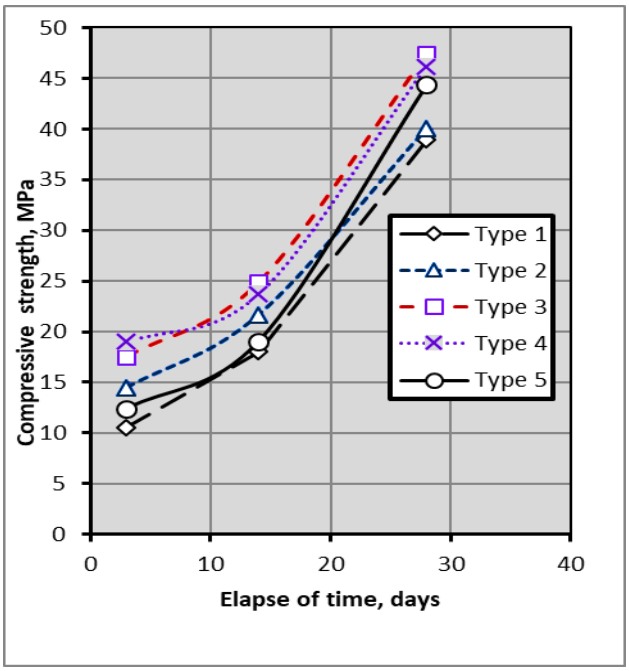

Figure 7 – Dependence of compressive strength of fiber concrete on fiber length

The reference specimens of type 1 (without the use of fiber) showed the lowest strength, a percentage less by 3.8 % compared to type 2, 21.9 % less than type 3, and 18.58 % less than type 4, 13.9 % less than type 5. The partial strength values range from 10.55 to 38.91 MPa (Fig. 7).

Type 2 specimens showed a 20.64% higher strength than Type 1 specimens, but less than Type 3 by 17.8%, Type 4 by 8.9%, and Type 5 by 9.7%. The partial strength values range from 14.48 to 40.4 MPa.

Type 3 specimens showed the highest strength, exceeding Type 1 by 42%, Type 2 by 17.8%, Type 4 by 5.32%, and Type 5 by 24.9%, Partial strength values range from 17.54 to 47.43 MPa.

Type 4 specimens showed a strength of 42.93% higher than Type 1 specimens and 2.14% higher than Type 2 specimens, but 2.77% lower than Type 4 specimens. Partial strength values ranged from 14.36 to 52.6 MPa.

Type 5 specimens showed a strength higher than Type 1 specimens by 12.2 % but lower than Type 2 specimens by 9.7 % at 28 days, Type 3 by 6.9 %, and Type 4 by 4.1 %. Particular strength values range from 12.4 to 44.35 MPa.

The reason for the increased performance is the good adhesion of basalt fiber with other concrete constituents (cement, sand).

The use of basalt fiber in the composition of the mixture helps to increase the strength of the components [[21], [22]].

Conclusions

It has been proved that the compressive strength of fine-grained fiber concrete samples depends on the length of the added fiber. At a length of 20 mm of fibers an increase in the compressive strength of concrete samples by 47.2 % is observed.

Basalt fiber reacts with the cement medium as an active mineral additive, with the subsequent formation of crystals of needle-like structure, resulting in an increase in the strength of concrete.

The bending tensile strength of the samples also depends on the length of the fibers. The highest strength is shown by the addition of 20 mm of fiber length. The increment of bending tensile strength in comparison with the control specimens is 21.9 %.

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

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Базальт талшығының ұзындығының ұсақ түйіршікті фибробетонның беріктік сипаттамаларына әсері

[1]Нұрбаева М.Н., [1]Лукпанов Р.Е., [1]Аруова Л.Б., [2]Gunasekaran M.

[1]Л.Н. Гумилев атындағы Еуразия ұлттық университеті, Астана, Қазақстан
[2]Уттаранчал университеті, Дехрадун 248007, Үндістан

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ТҮЙІНДЕМЕ

Базальт талшығының ұзындығы әртүрлі болатын фибробетон үлгілеріне сынақтар жүргізілді. Фибробетон дайындау үшін қолданылатын базальт талшығының сипаттамалары берілген. Зерттеудің мақсаты талшық ұзындығының фибробетонның беріктік сипаттамаларына әсер ету заңдылықтарын анықтау болып табылады. Талшықтарды қоспай (бақылау құрамы) және талшық ұзындығы 40 мм, 20 мм, 10 мм және 5 мм болатын цемент массасының 0,2% базальт талшығын қосқанда ұсақ түйіршікті талшықты темірбетонды иілу кезіндегі қысу және созылу беріктігін анықтау нәтижелері ұсынылған. Ұсақ түйіршікті бетон қоспасына базальт талшығын енгізудің оңтайлы шектері талшық ұзындығы 20 мм деп санауға болатыны көрсетілген, бұл қысу беріктігінің 47,2%-ға дейін артуына әкеледі, иілу кезінде созылу беріктігі - бақылау құрамымен салыстырғанда 2 есе көп болады.

Түйін сөздер: базальт талшығы, арматуралау, қысу беріктігі, иілу беріктігі.

Нұрбаева Маржан Нұрбайқызы	***Авторлар туралы ақпарат:*** *PhD докторанты, «Өнеркәсіптік және азаматтық құрылыс технологиясы» кафедрасы, Л.Н. Гумилев атындағы Еуразия ұлттық университеті, 010000, Сәтбаев көшесі 2, Астана, Қазақстан. Email: marzhan_nurbaeva@mail.ru*
Лукпанов Рауан Ермагамбетович	*PhD, «Өнеркәсіптік және азаматтық құрылыс технологиясы» кафедрасының профессоры, Л.Н. Гумилев атындағы ЕҰУ, 010000, Сәтбаев көшесі 2, Астана, Қазақстан. Email: rauan_82@mail.ru*
Аруова Лязат Боранбаевна	*Т.ғ.д., «Өнеркәсіптік және азаматтық құрылыс технологиясы» кафедрасының профессоры, Л.Н. Гумилев атындағы ЕҰУ, 010000, Сәтбаев көшесі 2, Астана, Қазақстан. Email: ecoeducation@mail.ru*
Gunasekaran Murali	*Зерттеу және инновация кафедрасының профессоры, Уттаранчал университеті, Дехрадун 248007, Үндістан. Email: murali_220984@yahoo.co.in*

Влияние длины базальтовой фибры на прочностные характеристики мелкозернистого фибробетона

[1]Нурбаева М.Н., [1]Лукпанов Р.Е., [1]Аруова Л.Б., [2]Gunasekaran M.

[1]Евразийский национальный университет им. Л.Н. Гумилева, Астана, Казахстан
[2]Уттаранчальский университет, Дехрадун 248007, Индия

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АННОТАЦИЯ

Проведены испытания образцов фибробетона с различной длиной базальтовой фибры. Даны характеристики базальтовой фибры, который используется для изготовления фибробетона. Целью исследования является выявление закономерности влияния длины фибры на прочностные характеристики фибробетона. Представлены результаты определения предела прочности при сжатии и на растяжение при изгибе мелкозернистого фибробетона без добавления фибры (контрольный состав) и с добавлением базальтовой фибры 0,2 % от массы цемента с длиной волокон 40мм, 20мм, 10 мм и 5 мм. Показано, что оптимальными пределами введения базальтовой фибры в смесь мелкозернистого бетона могут считаться длиной волокон 20 мм, что приводит к приросту прочности при сжатии до 47,2 %, на растяжение при изгибе в 2 раза больше по сравнению с контрольным составом.

Ключевые слова: базальтовая фибра, армирование, прочность при сжатии, изгиб.

Нурбаева Маржан Нурбайкызы	***Информация об авторах:*** *Докторант PhD, Кафедра «Технология промышленного и гражданского строительства», ЕНУ им. Л.Н.Гумилева, 010000, улица Сатбаева 2, Астана, Казахстан. Email: marzhan_nurbaeva@mail.ru*
Лукпанов Рауан Ермагамбетович	*PhD, Профессор кафедры «Технология промышленного и гражданского строительства», ЕНУ им. Л.Н.Гумилева, 010000, улица Сатбаева 2, Астана, Казахстан. Email: rauan_82@mail.ru*
Аруова Лязат Боранбаевна	*Д.т.н., профессор кафедры «Технология промышленного и гражданского строительства», ЕНУ им. Л.Н.Гумилева, 010000, улица Сатбаева 2, Астана, Казахстан. Email: ecoeducation@mail.ru*
Gunasekaran Murali	*Профессор отдела исследований и инноваций, Университет Уттаранчал, Дехрадун 248007, Индия. Email: murali_220984@yahoo.co.in*

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