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Sand Bazalt-Fiber Concrete

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Abstract: In modern construction sand concrete is increasingly used because of the widespread availability of raw materials. However, due to high specific surface area of the filler its strength characteristics are lower than those of conventional heavy concrete. To improve the physical and mechanical characteristics the authors of the article suggest using sand fractionation and basalt fiber. The composition of sand concrete must necessarily include superplasticizing supplements to reduce the water-cement ratio. The most effective are superplasticizers based on polycarboxylate. As fiber it is necessary to use fiber from cut roving as its corrosion in alkaline medium is less than that of the staple fiber. The use of basalt fiber in the sand concrete increases the tensile strength at bending and splitting. This is due not only to reinforcement of the cement matrix with fiber, but also to high cohesion of cement stone and basalt fiber, which is a positive change from other types of fibers.

Key words: Sand concrete · Basalt fiber · Fiber resistance · Bending strength · Graded sand · Superplasticizers

INTRODUCTION

Sand concrete lately has been increasingly used because of the widespread availability of raw materials. Distinctive features of sand concrete are possible creation of high-quality homogeneous structure without large inclusions and high technological effectiveness - the possibility to form structures and products with various methods [1].

The properties of sand concrete are determined by the same factors as those of the conventional concrete. However, cement-sand concrete has some features conditioned by the structure, which is characterized by higher uniformity and fineness, high cement content, lack of hard stone lattice, increased porosity and specific surface area of the solid phase [2]. For the same input of cement the sand concrete compared to conventional heavy concrete has a lower compressive strength due to significant void, specific surface area and water requirement of the filler. The increase in cement consumption leads to an increase in shrinkage and creep deformation, so it is necessary to choose other ways to increase the strength considering the characteristics of sand concrete.

Application of superplasticizing supplements is technologically the easiest way to modify the sand concrete [3, 4]. The choice of such additives in concrete technology is based on their effectiveness depending on the type of fillers and cement [5]. With modern superplasticizers based on polycarboxylate we achieve significant decrease of water-cement ratio, which increases not only the strength but also the durability of concrete [6, 7, 8].

One of the current trends of sand concrete modification is using fibers of different origin [9]. The problem of fiber distribution in the medium of cement paste and concrete is one of the most important in the manufacture of fiber-reinforced concrete [10]. The maximum fiber distribution solves several problems at once, such as mixture caking, formation of pores and voids, increased water requirement and as a result insufficient strength of the resulting material. Possibility to use basalt fiber in cement systems largely depends on fibers resistance to the products of cement hydration. Earlier research of S.F. Kanaev [11] showed that the resistance of basalt fiber and basalt plastic reinforcement is higher than that of fiberglass analogues.

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Research of mineral fibers durability in the solution of $Ca(OH)_2$ performed by a group of scientists led by F.N. Rabinovich proves rather high degree of destruction of the mineral fibers in a corrosive medium. For example, alumina-borsilicate monofilament aged for 12 months in a saturated solution of lime lost 72% of its original strength according to their data. However, researchers have noted a relatively high resistance of basalt fiber, which strength after exposure in the same conditions decreased only by 26-32% [12]. The authors also noted the tendency to attenuation of the reaction of basalt fibers with CaO in time. The most intense leaching processes are observed during the first three months.

A group of authors led by A.A. Paschenko in their research of the mineral fibers strength mention a higher resistance of basalt fibers in corrosive media of cement stone and saturated solution of lime. So for example, after three years of testing of basalt fiber strength, its strength decreased only by 12-15 % [13].

Thus, to obtain high-quality sand concrete it is necessary not only to obtain high values of strength, but also to maintain these characteristics during its operation, which is quite problematic in the use of fibers. In this regard, the purpose of this study was to obtain sand bazalt fiber concrete with high physical and mechanical characteristics and the study of basalt fiber resistance in the alkaline medium.

MATERIALS AND METHODS

To assess the properties of concrete we used the standard GOST 10180-90 techniques for determining the compressive strength and tension at bending and splitting. Evaluation of sand properties was carried out according to GOST 8735-88. Evaluation of chemical resistance of basalt fiber was carried out at its storage for three years in a saturated solution $Ca(OH)^2$, as well as at boiling in this solution for 4 hours.

Activeness of basalt fibers with respect to CaO was determined in the saturated solution. Fiber was tempered with a saturated solution of CaO. After two days after mixing 50 ml of solution was taken from the solution with additive and titrated. As titre 0.05H solution of hydrochloric acid was used. Then, once a day the flask with the solution was shaken and after every two days titrated. After each titration 50 ml of a saturated lime solution was added in the flask. Thus the solution is titrated 15 times for 30 days. The total amount of CaO absorbed by 1 g of mineral supplement is determined by summing up all 15 measurements.

Preparation of concrete mix was carried out in the laboratory paddle blade-type mixer. To prepare the concrete we used Portland cement CEM I 42.5B and as additives - superplasticizers based on naphthalene formaldehyde C-3 and polycarboxylate Melflux 2651. The used filler was sand for construction works from Kama deposit.

Key Part: In the easily workable mix the compaction method practically does not affect the strength properties of the concrete. To increase the strength it is necessary to properly choose the composition of fillers, in particular sand and plasticizing additive. In order to optimize the grain composition of sand the combination of three fractions was used: 5-1.25 mm, 1.235-0.315 mm and 0.315-0.14 mm. The correlation of fractions was selected experimentally depending on the bulk density and specific surface area [14]. As a result the optimum is the content of fraction 5-1.25 mm - 60%, fraction 1.25-0.315 mm - 20% and fraction 0.315-0.14 mm - 20%. This correlation of fractions provides a minimum void coefficient of sand at low specific surface.

To improve the physical and mechanical properties of sand concrete it is necessary to use effective superplasticizing additives. So at optimization of grain content of sand and use of effective superplasticizers the strength of sand concrete can reach 100 MPa or more (Table 1). It is also necessary to take into account the air entrainment in sand concrete and to find a superplasticizer, reducing air entrainment of concrete mix [14].

As it is seen from Table 1, the largest strength is specific for sand concrete with admixture Melflux 2651, as at 1 day of normal hardening the compressive strength was 45.6 MPa and in 28 days - 111.8 MPa. The increase in strength is bound with a significant reduction in water-cement ratio.

The next step in the increase of sand concrete strength was the use of basalt fibers. This will significantly increase the tensile strength at sand concrete bending. However, it is necessary to choose the fiber, which is less corroded in alkaline medium concrete.

In this regard we have tested stability of bazalt staple and continuous basalt fibers in a saturated solution of $Ca(OH)^2$ - the main component of the liquid phase of hydratable cement in terms of CaO absorption [15]. Evaluation of chemical resistance of basalt fiber at its three-year storage in a saturated solution of $Ca (OH)^2$, as well as at boiling in this solution for 4 hours [13].

Table 1: Composition and properties of sand concretes from easily workable mixtures

	Material consumption, kg						Compressive strength of sand concrete, MPa (bending/compression) in the age of	
No.	Cement	Sand	MC	Water	Admixture	W/C	1 day	28 days
1	550	1550	55	191	C-3. 4.5	0.35	6.5 / 42.9	9.0 / 91.3
2	550	1550	55	172	Melflux. 2.75	0.32	6.1 / 45.6	10.1/ 111.8
3	500	1600	50	161	Melflux 2.75	0.32	5.8 / 40.8	9.2 / 96.7

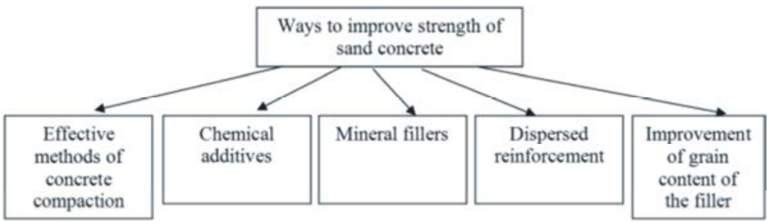

Fig. 1: Variants of ways

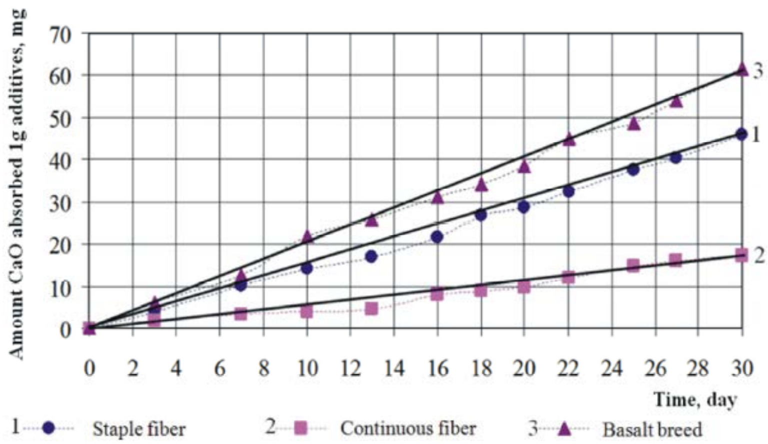

Fig. 2: Activity of basalt fiber towards CaO

Results of the study on CaO absorption are shown in Fig. 2. As it can be seen from Fig. 1, the largest activity with respect to CaO is specific for basalt rock, despite the fact that the specific surface of powder obtained from basalt rock is Ssp = 2500 cm^2/g. This suggests a greater reactivity of basalt with respect to CaO compared to quartz sand. This is proved at recalculation of CaO absorption on $100m^2$ of the additive surface. The largest activity here is specific for staple fiber (0.31 kg/m^2). This is explained by the largest developed surface, the presence of defects on the surface of staple fiber produced by blowing from melt, in contrast to the smooth texture of continuous basalt fiber produced by extrusion of the melt through the die hole.

Absorption of CaO from saturated sodium lime solution by continuous basalt fiber is 0.18 kg/m2, which proves its chemical interaction with the products of Portland cement hydration.

The effect of these two types of fibers on flexural strength of cement stone, as it is seen from the histogram in Fig. 2, leads to the conclusion about the unsuitability of staple fibers for disperse reinforcement of cement concrete.

Therefore, all further studies were carried out with the fiber from cut roving (continuous fiber) and length of 9 mm, although this fiber also enters into a chemical reaction of hydrated lime of cement matrix with the formation of calcium hydrosilicates. In this regard, continuous basalt fiber resistance was tested by its storage in a saturated lime solution for 3 years and boiling for 4 hours in this solution, which according to Paschenko is equivalent to 10 years in cement concrete, Fig. 4.

With an optical microscope we have revealed the localized areas of new growths on the fiber surface, increasing its diameter and surface roughness that can promote better cohesion with the cement matrix. Fig. 3a shows that as a result of 3 years of basalt fiber storage in a saturated solution of Ca $(OH)^2$ on the fiber surface the length of sections of new growths relative to the total length of the fiber under consideration is about 12%.

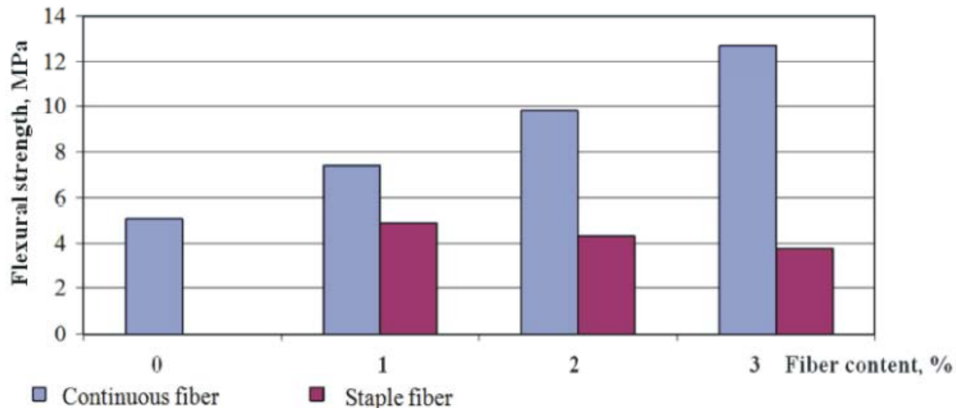

Fig. 3: Influence of fiber type on cement paste strength at bending (28 days)

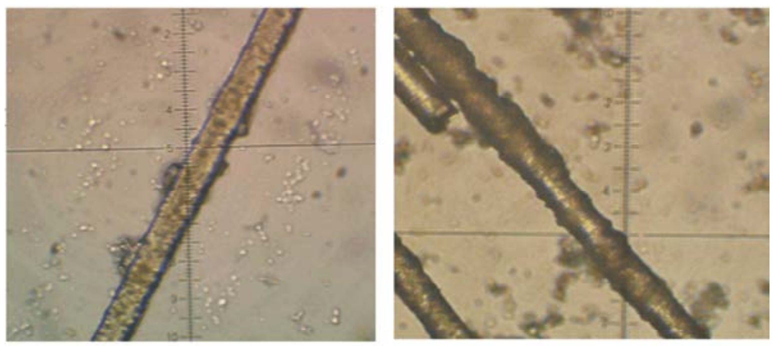

Fig. 4: Micrographs of basalt fibers (x1000): continuous fiber a) after 3-year storage in the saturated solution $Ca(OH)^2$; b) after 4-hour boiling in the saturated solution $Ca(OH)^2$

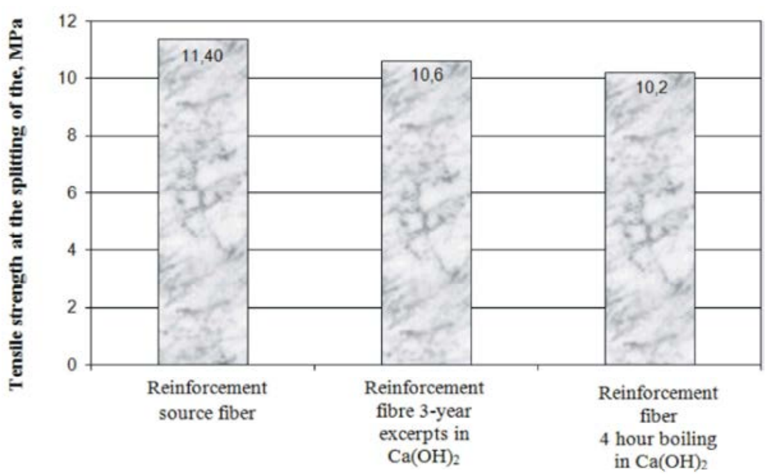

Fig. 5: The tensile strength of cement paste in the age of 28 days of normal humidity conditions of storage at splitting with fiber held in an alkaline medium

On the site of basalt fibers subjected to 4 hours of boiling in a saturated solution of $Ca(OH)^2$ (Fig. 3b), the length of new growths is approximately 15% of the total length of the considered fragment of fiber.

To assess the effect of fiber stored in an aggressive medium on the strength of cement paste we produced samples of a prism with the size of 20h 20h 80 mm. Compositions of cement paste contained 3% of fibers in

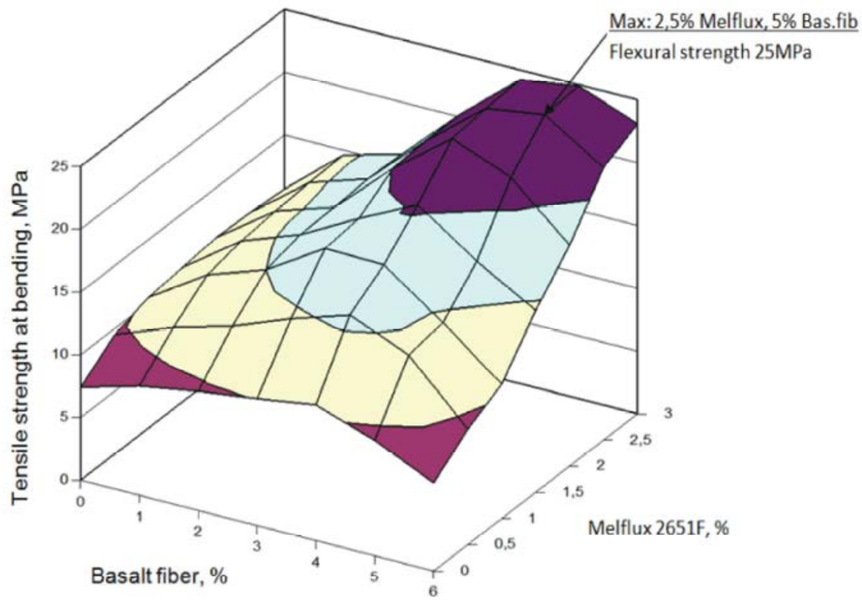

Fig. 6: Tensile strength at bending of the plasticized (Melflux 2651F) cement paste in the age of 28 days, reinforced with basalt fibers

their mass. All the compositions in addition contained 1% of superplasticizer C-3. Basalt fiber was introduced into the compositions by preliminary dry mixing with the cement powder. Superplasticizer was introduced with tempering water. All compounds were prepared with the same water-cement ratio equal to 26.5%. After remolding, the samples were stored in normal-humidity conditions until testing at a relative humidity of 100%. Tests of cement tensile strength at splitting on the 28th day of normal-humidity storage conditions are shown in Fig. 5.

All compounds of cement paste had the same content of basalt fiber - 3%. As it can be seen from Fig. 4, the tensile strength of cement paste at splitting with fiber stored for 3 years in a saturated solution of lime was 10.6 MPa. This is only a 6% lower than the control composition with the source fiber whose strength was 11.4 MPa after 28 days of storage at normal humidity conditions. The strength of the composition reinforced by basalt fiber boiled for 4 hours in a saturated solution of lime was 10.2 MPa, which is by 10% lower than the strength of the control sample with the fiber not subjected to prior exposure of the saturated solution of lime.

The obtained data on the resistance of basalt fiber are well correlated with the data of S.F. Kanaev [11]. His tests for long-term strength for the first 10 years showed a reduction in the strength of bazalt-fiber concrete for axial tension within 10-12%. The following 15 years resulted in the decline by extra 5-7%. In his opinion, the intensity of interaction of basalt fiber with cement matrix has damped because on the fiber surface a layer of insoluble hydrosilicates hindering the development of fiber corrosion is formed.

As it was shown earlier, the introduction of basalt fiber in the cement medium is the best at its simultaneous grinding with cement [16]. This serves to achieve the best possible distribution of the fiber. However, at co-grinding not only fiber is distributed but the cement particles are grinded as well, i.e. mechanical activation of cement occurs. At simultaneous grinding of cement and basalt fiber a plasticizer should be added to reduce the water requirement of the cement mixture reinforced with basalt fibers. As a result of this technology the strength of cement paste at bending significantly increases.

As it can be seen from Fig. 6, the strength of cement paste at the optimum ratio of plasticizer and basalt fiber has increased 3 times.

With the introduction of the binder in the composition of sand concrete with microsilica the strength increases by 20-50% (Table 2).

As it is seen from Table 2 the best results show the composition with 3% content of basalt fibers and superplasticizer Melflux 2651F. Increase of tensile strength at bending relative to the same composition without the basalt fiber was 74%. At that the increase in compressive strength was 31 % in relation to the control composition without the fiber.

Table 2: The strength of sand concrete, dispersedly reinforced by basalt fiber

No.	BF content, %	Type/ Plastisizer content, %	Compressive strength, MPa TBO	Compressive strength, MPa 28days	Tensile strength at bending, MPa TBO	Tensile strength at bending, MPa 28days
1	0	C-3 / 2	64	82	6.1	7.3
2	2		72	96	7.8	8.9
3	3		83	107	9.1	11.8
4	0	Melflux 2651 / 2	75	92	6.7	8.4
5	2		81	113	8.8	10.2
6	3		104	121	11.5	14.6

CONCLUSION

The modification of sand concrete with various types of additives can increase its physical and mechanical properties and result in a material, which properties are better than the ones of the conventional heavy coarse concrete. The use of basalt fiber in the composition of sand concrete increases the tensile strength at bending and splitting. This is due not only to the cement matrix reinforcement with fiber, but also with high cohesion of cement stone and basalt fiber, which is a positive change compared with other types of fibers. Therefore, the use of basalt fibers for reinforcement of concrete sand is an effective method of increasing its strength characteristics.

Findings: The performed research has shown that the most effective for sand concretes are superplasticizers based on polycarboxylates. With their use the sand concrete strength reaches 110 MPa.

Use of basalt fibers in the sand concrete increases the tensile strength at bending by 74%. The greatest effect of the fibers is achieved at the use of polycarboxylate superplasticizer.

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