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Reducing alkaline corrosion of basalt fiber in concrete

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Abstract. The article presents the results of studies on the development of fiber-reinforced concrete using composite binders and basalt fibers obtained in an experimental plasma reactor. To reduce the negative impact of Portland cement on the mineral fiber, composite binders based on Portland cement and fly ash were used in the study. To reduce the normal density in the composition of the binder, a polycarboxylate type superplasticizer was used in the work. The microstructure of cement stone was studied using SEM and IR-spectroscopy. The compressive strength was tested on cubes with an edge of 100 mm according to EN 12390-6, flexural strength – on prisms with a size of 100×100×500 mm according to EN 12390-3. The optimum content of fly ash (30 %) in the composite binder is evaluated, which allows to obtain high mechanical properties. It was revealed that the combined use of composite binder and fiber leads to an increase in compressive and flexural strength of fiber concrete. With the addition of fly ash, both hardening of the structure of the cement stone and a decrease in the alkaline effect of the basalt fiber binding on the surface are observed. Infrared spectroscopy of cement systems showed a change in the phase composition and a decrease in the basicity of the resulting calcium hydrosilicates upon addition of fly ash into the composition binder.

1. Introduction

Despite the proven effectiveness of fiber-reinforced concrete in comparison with traditional reinforced concrete [1–5], their use is quite rare in construction practice. This is due, inter alia, to the fact that for some types of fiber there is insufficient information about the possibility of its use in certain conditions. In particular, the study of mineral fibers remains relevant, due to the high mechanical properties of individual fibers and a lower density of these fibers compared to steel fibers [6–9]. However, Rybin [10] and Monaldo [11] report that mineral fibers corrode upon contact with the alkaline environment of Portland cement.

Alkaline solutions, which cause corrosion, affect basalt fiber, as well as glass fiber, which in turn leads to fiber destruction [12]. The resulting loss of strength causes the destruction of the composite under load during operation. Wei et al [13] proved that the alkali resistance of basalt fiber is higher than that of E-class fiber glass. There are differences in corrosion resistance of basalt fiber and fiberglass from E-class components, although the main components, SiO_2 and Al_2O_3, are the same for the two types of fibers. E-glass fiber has a much larger contribution from CaO and B_2O_3, while Fe_2O_3 and FeO are found only in basalt fiber [14].

Analyzing various approaches to solving the problem of preserving mineral fiber from the action of an alkaline medium, it can distinguished the main areas: the use of alkaline-free binders [15–18] and low-alkaline binders [19–22], the use of additives that reduce the alkalinity of the binder [23, 24], modification of fiber surface [25, 26], modification of fiber microstructure [27–30]. According to this classification, the objects of influence can be either individual fibers or fiber-reinforced concrete, and the feasibility of applying a specific method of protection from an alkaline environment is determined by the feasibility study. To protect the mineral fiber from the negative effects of the environment of Portland cement, the study decided to use fly ash to obtain

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a composite binder (CB), the effectiveness of which was previously proven, for example, for resistance of glass fiber [31, 32].

The scientific novelty lies in the use for dispersed reinforcement of concrete the mineral fiber obtained by the electrothermal method in a plasma-arc reactor and different from the known types of mineral fibers (basalt roving, thin staple fiber) with lower energy consumption during production.

The purpose of the article is to develop basalt fiber concrete and study their mechanical properties and corrosion resistance of fibers obtained by the electrothermal method.

2. Materials and Methods

The studies used follow materials: Portland cement (OPC) CEM I 32.5 N (Spasskcement, Russia), fiber based on basalts of the Selendum deposit (Russia) and fly ash.

Composite binders were obtained by joint grinding of fly ash (0–50 % by weight of the OPC) with Portland cement to a specific surface area of 430–450 m^2/kg. To reduce the water-binding ratio and increase the physicomechanical parameters of CB, Sika Viscocrete 5 New (Switzerland) in the amount of 0.6 % by weight of the binder was added into its composition with mixing water.

Fly ash obtained by burning coal at the Gusinoozersk thermal power plant (Russia). The results of determining the main characteristics of fly ash show that it can be used without restrictions for the production of building materials and products (Table 1).

Table 1. The main characteristics of fly ash.

Characteristics	ASTM C618 – 19 requirements	Value obtained
Free calcium oxide content, wt. %	≤10	0.05
Magnesium oxide content, wt. %	≤5	1.9
Total content oxides of silicon, aluminum and iron, wt. %	≥70	84.97
Sulfur and sulfate compounds content, wt. %	≤3	0.34
Alkaline oxides content, wt. %	≤3	2.7
Specific surface area, m^2/kg	≥300	350

Fiber production was carried out in the experimental reactor, the design features of which made it possible to obtain a pure melt, free of occluded gases and reduced metals, which makes it possible to produce better products. Thus, it was possible to organize the smelting mode in one stage, consisting of combined heating of raw materials. At start-up, plasma-electric arc heating and melting of the raw material occur, and subsequently, as the melt is melted and a conductive cup is formed, the raw materials are added and current flows through the molten aluminosilicate mass, with its simultaneous electromagnetic stirring and homogenization using electromagnets connected in series, which is significantly reduces the time required to reach the operating mode and reduces the energy intensity of production. The required power required to obtain a melt with a bulk weight of up to 150 kg/h is 1.1–1.3 kW/kg (for comparison, the consumed power of working induction furnaces is 6 kW/kg) [33, 34]. The obtained mineral fibers have the following characteristics: average fiber diameter – 10 μm, tensile strength – 1350 MPa, heat resistance – 600 °C.

The microstructure of fiber cement compositions was determined using a Jeol JSM 6510 LV scanning electron microscope (Japan) with a magnification of x1000. The phase composition in the entire chamber was studied by IR analysis using an IR-Fourier spectrometer IRAffinity-1 (Shimadzu, Japan).

Concrete cubes of dimensions 100×100×100 mm were prepared for compressive strength test at the age of 2, 7 and 28 days for all mixes. The concrete specimens were unmolded after 24 hours of casting and then immersed in curing tank at room temperature and relative humidity at 65 ± 5 % until the age of testing. This test was carried out using a Shimadzu (Kyoto, Japan) tester machine with a capacity of 200 kN according to EN 12390-3. Flexural strength of the prisms with an edge length of 100×100×500 mm specimens was tested according to EN 12390-6.

3. Results and Discussion

The test results showed that the use of fly ash in the composition of composite binders leads to a change in normal density, setting time and physicomechanical parameters (Table 2, Figure 1).

Table 2. Physico-mechanical characteristics of composite binders with a water-binder ratio of 0.4.

Parameter	CBs with the SP at ash content, wt. %			Control specimen (OPC)
	10	30	50	
Standard consistence, %	27	25	24	28
Initial setting, min	140	150	160	90
Final setting, min	300	320	330	245

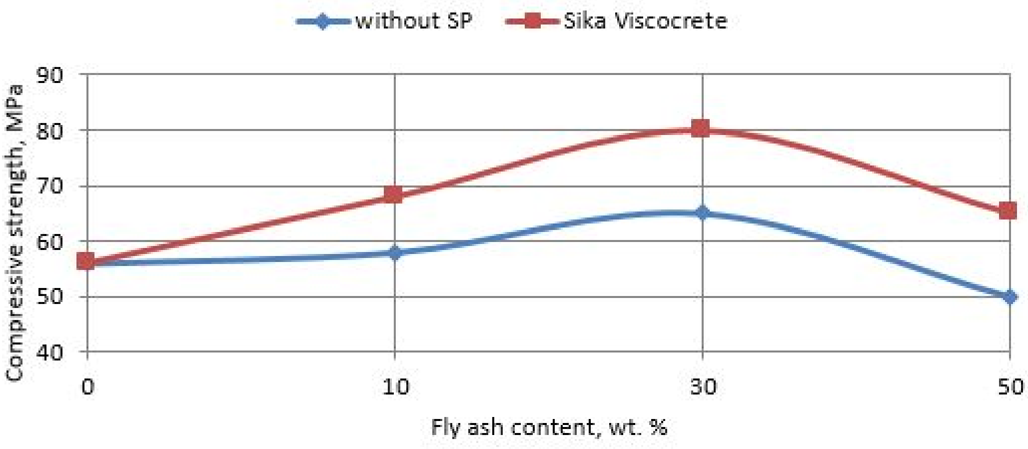


Figure 1. Compressive strength of composite binders at the age of 28 days.

The high content of SiO_2 in the fly ash (57 wt. %), when grinding with Portland cement leads to the activation of a composite binder. Fly ash acts as an active mineral additive, participating in the structure formation of cement stone. However, due to the fact that ash increases water demand, this effect is compensated by the addition of superplasticizer. Moreover, as can be seen from Figure 1, the addition of superplasticizer leads to an increase in compressive strength of composite binders by 10–15 %. In addition to the water-reducing effect, which helps to increase the mechanical characteristics of cement stone, superplasticizer significantly affects the processes occurring in the cement system through various effects, which was described by the authors earlier [28, 29]. In particular, the molecules of surfactants, adsorbed on the surface of the particles, reduce surface energy, while there is a partial saturation of free chemical bonds on the surface of the solid phase, preventing adhesion.

The change in the mechanical properties of fiber concrete occurs due to the directed formation of the structure and increase the corrosion resistance of the fiber by reducing the alkalinity of the binder. SEM results showed a change in the microstructure of Portland cement and a composite binder with basalt fiber in an amount of 4 wt. % at the age of 28 days (Figure 2).

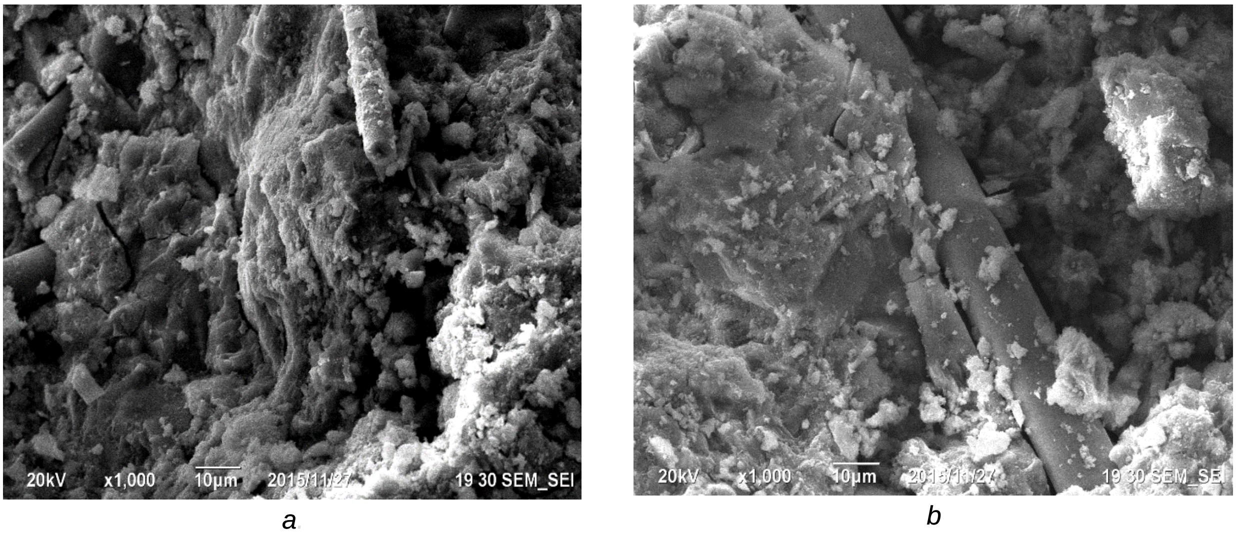
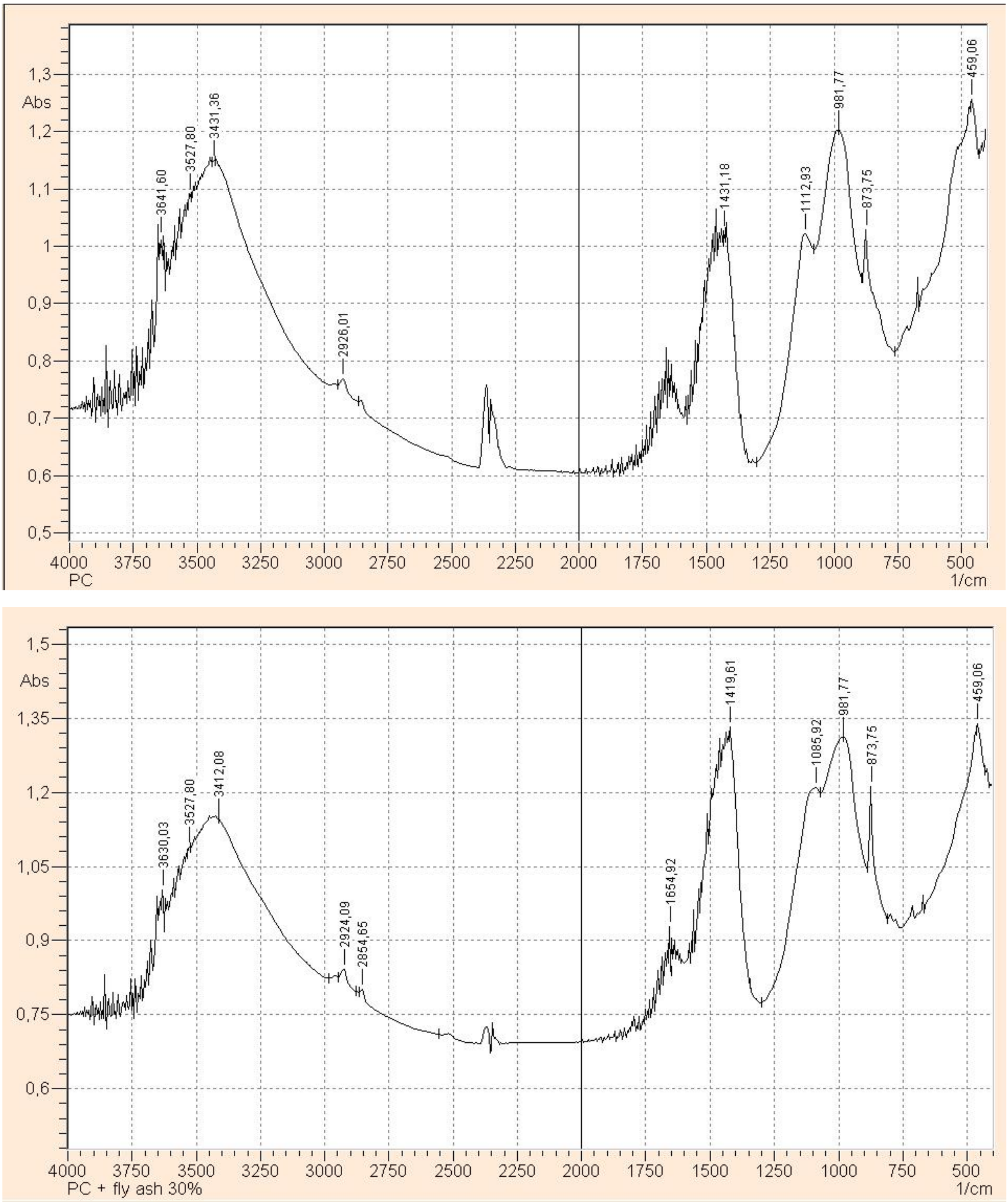


Figure 2. SEM images (x1000) of the surface of Portland cement with basalt fiber (a) and the composite binder with basalt fiber (b) at the age of 28 days.

Analysis of the microstructure allows us to conclude that the fiber surface in the sample with conventional Portland cement contains inclusions indicating the interaction of the fiber and Portland cement. This leads to a decrease in the reinforcing effect, in comparison with the composition of fiber concrete with a composite binder. The addition of fly ash contributes to the directional formation of a high-strength stone structure from low-basic calcium hydrosilicates and a decrease in the content of calcium hydroxide. Reducing the content of calcium hydroxide helps to maintain the surface strength of the mineral fiber and high mechanical properties. The change in the phase composition of the cement stone is confirmed by IR spectral analysis (Figure 3).

An analysis of the IR spectra showed that with the addition of fly ash there is a change in the intensity of the absorption band in the frequency range 1000–1100 cm^{-1}, which correspond to vibrations of Si-O bonds, which is associated with the formation of calcium hydrosilicates. This indicates a change in the process of hydration of Portland cement with the addition of fly ash and the formation of an additional amount of calcium hydrosilicates. The shift in the frequencies of the absorption bands corresponding to calcium hydrosilicates also suggests that the resulting structures with the use of the CBs differ from the traditional ones in the direction of increasing the number of low-basic hydrosilicates.



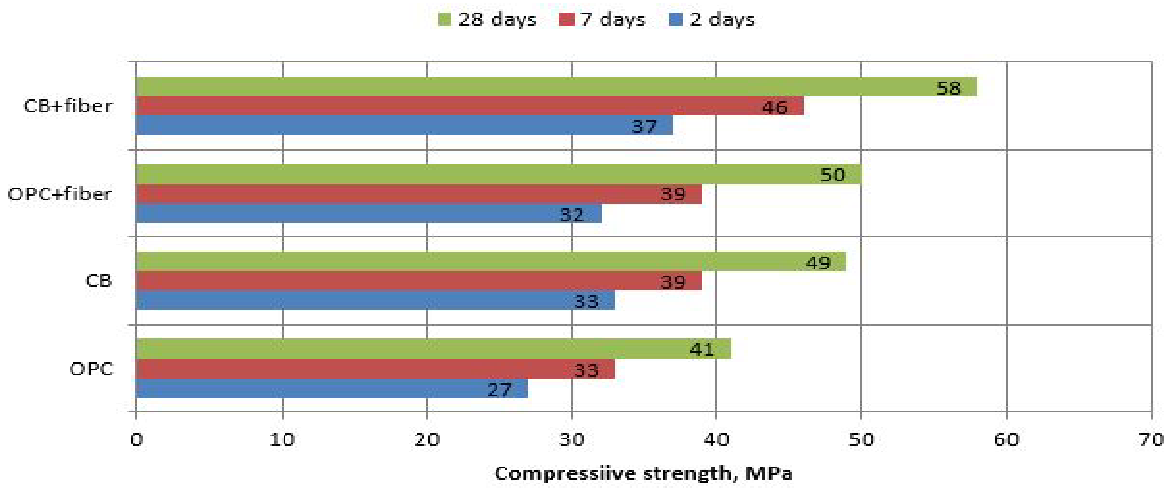
a.

b.

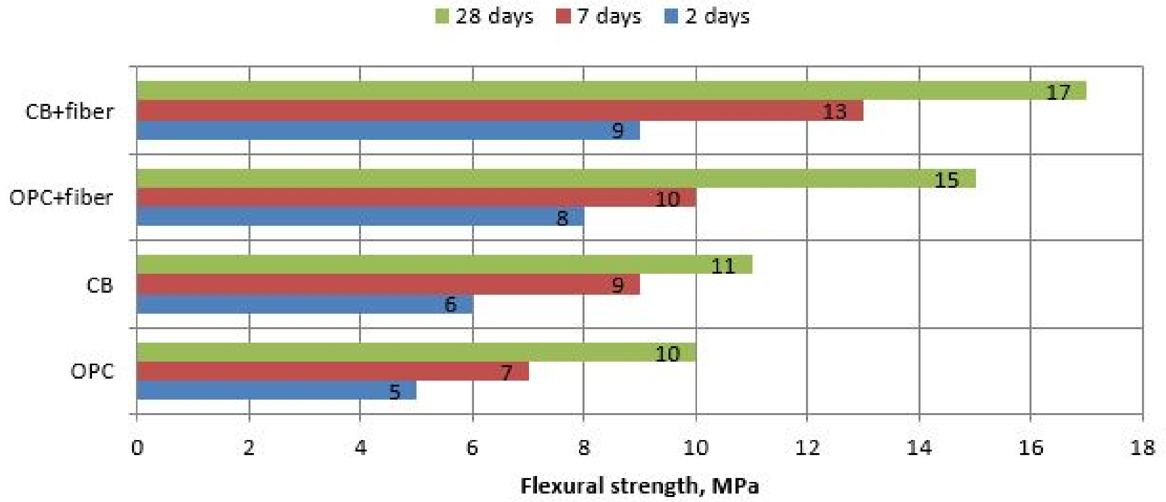
Figure 3. IR spectra of cement stones: on Portland cement (a) and on the CB (fly ash – 30 %) (b).

Development of fiber-reinforced concrete using the composite binder with an ash content of 30 wt. % and basalt fiber in an amount of 4 wt. % led to an increase both in compressive and flexural strength by 10–15 % (Figure 4).

The high mechanical properties of fiber-reinforced concrete are due to the reinforcing effect of basalt fibers, which is manifested to a greater extent in compositions with a composite binder.



a.



b.

Figure 4. Effect of basalt fiber on compressive strength (a) and flexural strength (b) of fiber-reinforced concrete.

4. Conclusion

Based on the results obtained, the following conclusions can be drawn:

– the effectiveness of the use of basalt fiber obtained by the innovative electrothermal method (provided that the alkaline environment of the cement stone is reduced) has been proved;

– the reduction of the negative effect of alkaline medium on the mineral fiber was shown by the composition of fiber concrete using fly ash, in addition, showing higher both compressive and flexural strength due to the binding of additional $Ca(OH)_2$;

– the study of the cement stone microstructure and IR spectroscopy allow us to conclude that the addition of fly ash contributes to the directional formation of a high-strength stone structure from low-basic calcium hydrosilicates and a decrease in the content of calcium hydroxide;

– the use of fly ash in the binder helps to increase the corrosion resistance of the mineral fiber and maintain the reinforcing effect of its addition.

Given the low energy intensity of the equipment for producing basalt fiber using the electrothermal method (proved earlier in [35]), this technology can be competitive. After additional calculations, fiber production can be implemented in industrial volumes.

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Снижение щелочной коррозии базальтовой фибры в бетоне

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Ключевые слова: фиброармированные материалы, фибробетон, цементы, цементные композиты, вяжущие, бетоны, механоактивация

Аннотация. В статье представлены результаты исследований по получению фибробетона с использованием композиционных вяжущих и базальтовых волокон, полученных в экспериментальном плазменном реакторе. Для снижения негативного воздействия среды портландцемента на минеральное волокно в исследовании были использованы композиционные вяжущие вещества на основе портландцемента и золы уноса. Для снижения нормальной густоты в составе вяжущего в работе использован суперпластификатор поликарбоксилатного типа. Исследована микроструктура цементного камня с помощью СЭМ и ИК-спектроскопии. Прочность на сжатие исследовалась на кубах с ребром 100 мм согласно EN 12390-6, прочность на растяжение – на призмах размером 100×100×500 мм согласно EN 12390-3. Установлено оптимальное содержание золы уноса (30 %) в составе композиционного вяжущего, позволяющего получить высокие механические показатели. Выявлено, что совместное использование композиционного вяжущего и фибры приводит к повышению прочности при сжатии и изгибе фибробетона. При введении золы уноса наблюдается как упрочнение структуры цементного камня, так и снижение щелочного воздействия вяжущего на поверхность базальтового волокна. Инфракрасная спектроскопия цементных систем показала изменение фазового состава и снижение основности образующихся гидросиликатов кальция при введении в состав вяжущего золы-уноса.

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