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Prospects for using amorphous ferromagnetic alloy microwire for reinforcement of cement mortar

Ivan Grachev[1], *Polina* Polyakova[1], *Elvina* Rakhmatullina[1], *Alina* Gasanova[1], *Lolita* Cherkasova[1] and *Aleksandr* Inozemtcev[1*]

[1] Moscow State University of Civil Engineering, 26, Yaroslavskoye shosse, Moscow, 129337, Russia

Abstract. Traditionally, fibers for fiber-reinforced concrete are made of metal, polypropylene, basalt or glass. На сегодняшний день для строительства актуально использование волокон с уникальными электрофизическими свойствами. The possibilities of using a microwire made of an amorphous ferromagnetic alloy based on cobalt with a shell of borosilicate glass in concrete technologies are studied in this paper. The influence of the content of fibers of different sizes (length 7 and 15 mm) on the rheological and physico-mechanical properties of the solution was established. The deterioration of the workability of mixtures and the average density of the composite with the introduction of the studied fiber is shown. It has been established that the spread diameter of the mortar mixture with a fiber content of 0.5...3.0 % by weight of Portland cement is reduced by 9.8...26.1% compared to the control composition. It is shown that the short fiber (7 mm) at the maximum content (3 %) leads to a more significant decrease in the average density (up to 9.6 %) compared to the long fiber (15 mm) of the same concentration (reduction is no more than 4 %). A positive effect on the flexural strength and crack resistance of the solution was established. The increment of flexural and compressive strength ranges from 1.11 to 1.54 and from 0.99 to 0.78 respectively with increasing fiber concentration. The presence of fiber in the composition of the solution allows you to increase the crack resistance from 0.098 to 0.164. The increase in the crack resistance coefficient for compositions with a fiber 7 mm long is 51...68 % and compositions with a fiber 15 mm long is 22...37 %. The possibility of using such microwire based on a ferromagnetic alloy for dispersed reinforcement of cement solutions opens up prospects for the creation of "smart" materials.

1 Introduction

The use of modern building materials is determined by the need to create structures with a complex set of properties. One of the well-known directions for improving the properties of materials is the use of dispersed reinforcement. The introduction of various fibers allows to control the physical, mechanical and deformative properties of concrete. One of the main

* Corresponding author: InozemcevAS@mgsu.ru

advantages of fiber-reinforced concrete is increased crack resistance, bending and impact strength, as well as abrasion resistance and frost resistance [1, 2]. However, the achievement of these positive qualities of fiber-reinforced concrete is typical for homogeneous systems [3]. A frequent problem in dispersed reinforcement of concrete is the uniform distribution of reinforcing fibers in the volume.

Currently, there are many types of fiber, differing both in the type of material and in geometric dimensions and shape. The most common are basalt, metal, polypropylene and glass fiber [2-7].

The use of steel (metal) fibers is very limited due to high cost and low corrosion resistance. Steel fiber has high mechanical properties, therefore, it allows to increase crack resistance, tensile and bending strength, as well as resistance of concrete to aggressive environment [3]. As a rule, such fibers are used to increase impact strength and reduce shrinkage deformations, which is in demand in the manufacture of reinforced concrete slabs, road surfaces or floor screeds [2]. Basalt fiber has been widely used in construction since the nature of the substance is similar to concrete. This provides high adhesion, allowing you to increase the strength, chemical resistance, and frost resistance [8, 9]. In [10] shows that the addition of basalt fiber in an amount of not more than 1.5% by weight of the binder increases the compressive strength by 4.5%. Due to their qualities, basalt-fiber-reinforced concretes are used in hydraulic structures, in construction in seismically hazardous regions, in road construction of roads, bridges and the construction of nuclear power plants and radioactive waste storage facilities [11]. Polypropylene fiber is characterized by the ability to control properties, which allows to optimize the effectiveness of concrete reinforcement [6, 7]. Such fibers, along with basalt fiber, are effective in protecting concrete from brittle fracture. The advantage of polypropylene fiber is a high modulus of elasticity and elongation factor, but the limitation is the relatively low melting point. In the process of mixing mixtures with an excess of polypropylene fiber, clumping also occurs. This leads to an increase in air entrainment. To prevent this effect, fiber is often pre-mixed with moistened fine aggregate [12]. Materials with the addition of glass fiber fibers have high flexibility and elasticity. The disadvantage of glass fiber is its low resistance to corrosion in alkaline environments.

The experience of different countries [2, 6, 10] shows the technical and economic efficiency of the use of steel fiber reinforced concrete in various types of building structures. However, in [11, 13-14] conflicting data are presented on the effect of fibers from various materials on the compressive strength of concrete. So, in one case (the use of basalt fibers), a decrease in this indicator by 4% is observed, and in the other case (the use of polypropylene fibers), an increase is established within the same limits. Such changes are correlated with the experimental error limits. At the same time, for concrete with basalt fiber, a positive effect is noted [11, 15-18]. The compressive strength of concrete increases by 6.5 %. The effective fiber concentration for concrete modification does not exceed 3.0 %.

Thus, the effectiveness of the use of fiber in concrete is related to many factors, such as the material, its size and shape, method of introduction, etc. The introduction of fibers often increases impact strength, flexural strength, and crack resistance. At the same time, the control of these factors makes it possible to improve various properties of the material: flexural and compressive strength, wear, water and frost resistance, hardness, etc. However, the effective use of fibers is possible only with a uniform distribution of fibers in the volume of concrete.

Traditionally, reinforcing fibers for fiber-reinforced concrete are made from a material with a homogeneous structure (metal, polypropylene, basalt, etc.). However, adding fibers to concrete can result in unique properties such as radio absorption or radio transparency. This is possible when using a material with specified electrophysical properties as a fiber.

One such material that has unique magnetic, mechanical and magnetoelastic properties is a cobalt-based amorphous ferromagnetic alloy [19]. It is made in the form of a microwire, covered with a sheath of borosilicate glass. The possibility of using such a microwire in concrete technology opens up prospects for the creation of "smart" materials [20]. For example, this can be used to monitor structures during operation or initiate (activate) self-healing processes by exposure to a magnetic field. At the same time, the possibility of using such a microwire in cement composites as reinforcing fibers is an important issue.

2 Methods

In this paper, the study of the effect of fibers from an amorphous ferromagnetic alloy on the properties of cement mortars based on Portland cement CEM I 42.5 N (PC), quartz sand (S) fr. 0.16-0.63 mm (C/S = 1/3), microsilica MS-85 (MS = 15% by weight of binder), water (W) at W/C = 0.5 and polycarboxylate plasticizer (P = 1.0% by weight of binder). Alkali-resistant microfiber with a metal core made of an amorphous alloy based on cobalt in a glass borosilicate sheath was used as reinforcing fibers (content of SiO_2 – 80 %, B_2O_3 – 12...13 %, Na_2O – 3...4 % and Al_2O_3 – 1...2 %). Fiber density is 7300…7800 kg/m^3; modulus of elasticity is 120…170 GPa, elongation coefficient 2.5…4.0 %.

Two types of fiber were studied:

- series 1: bundles of fibers with a length of 7 mm (diameter d = 12 μm) glued with a water-soluble varnish (Fig. 1a);
- series 2: separated fibers with a length 15 mm (diameter d = 30 μm) (Fig. 1b).

a) b)

Fig. 1. Fiber from an amorphous ferromagnetic alloy in a glass borosilicate sheath in a glued (a) and separated (b) form.

The content of fiber in the solution varied in the range of 0.5...3.0 % of the mass of Portland cement. The fibers were introduced into the pre-mixed mortar mixture.

The preparation of the mortar mixture was carried out using an automatic mortar mixer according to GOST 30744. As the estimated indicators, the following were chosen: mobility according to the spread diameter on the Hegerman table after shaking (D_{sp}, mm), average density (ρ_m, kg/m^3), flexural (R_b, MPa) and compressive (R_{com}, MPa) strength according to GOST 31376. The resistance to crack development was evaluated by the coefficient of crack resistance as the ratio of flexural strength to compressive strength.

The value of the standard deviation for the diameter of the spread and the average density was less than 2 %, for the flexural and compressive strength was less than 10 %.

3 Results

As a result of the studies carried out to assess the possibility of using a microwire made of an amorphous ferromagnetic alloy in a borosilicate glass sheath as reinforcing fibers for cement compositions, the dependences of rheological (Fig. 2a) and physico-mechanical (Fig. 2b, 3 and Table 1) properties were obtained.

a) b)

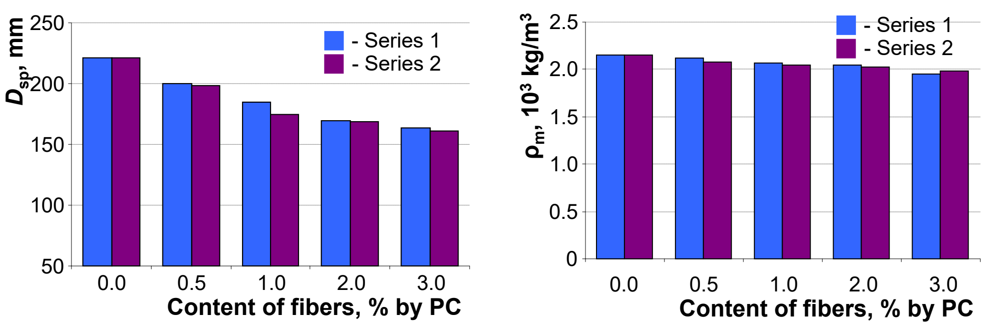

Fig. 2. Dependence of the spread diameter of the mortar mixture (a) and the average density of the solution (b) on the content of fibers from an amorphous ferromagnetic alloy.

It has been established that the introduction of reinforcing fibers into the composition of cement mortars leads to thickening of the mixtures. Thus, the spread diameter D_{sp} of the mortar mixture is reduced by 9.8...26.1 % compared to the control composition with a fiber content of 0.5...3.0 % by weight of Portland cement. Such a dependence is typical for each type of fiber under study (series 1 and series 2).

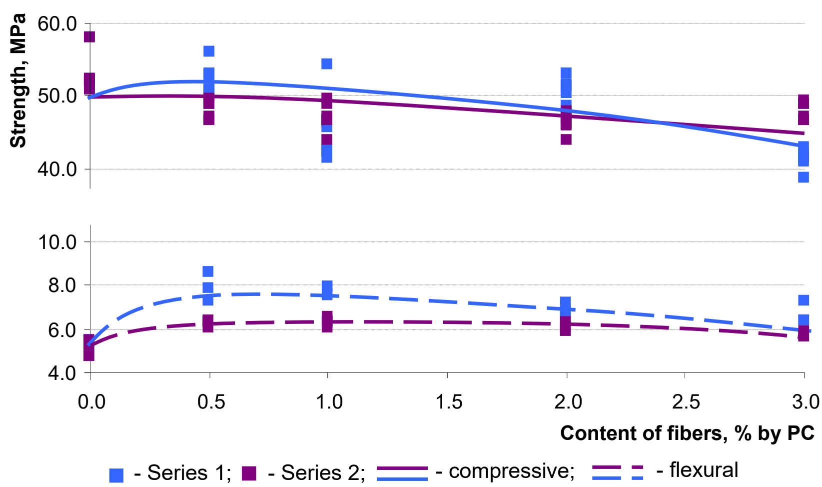

Fig. 3. Dependence of flexural and compressive strength of solutions on the content of fibers from an amorphous ferromagnetic alloy.

Figure 3 shows that the introduction of fiber from an amorphous ferromagnetic alloy leads to an ambiguous effect on strength. There is a positive effect on flexural strength and a negative effect on compressive strength. The increment of flexural strength R_b is from 1.11 to 1.54, and increment of compressive strength R_{com} is from 0.99 to 0.78 (table 1). Those, the introduction of fibers makes it possible to increase the resistance of the system under study to flexural loads by at least 10 %, but leads to a decrease in compressive strength by 22 %. In this case, the maximum flexural strength is 7.92 MPa (for the control composition R_{com} = 5.15 MPa).

Table 1. Strength increment of solutions with fiber from an amorphous ferromagnetic alloy.

Properties	Fiber	Fiber content, % by weight of Portland cement				
		0	**0.5**	**1.0**	**2.0**	**3.0**
Flexural strength increment	Series 1	1.00	1.54	1.50	1.35	1.29
	Series 2		1.22	1.21	1.18	1.11
Compressive strength increment	Series 1		0.99	0.89	0.90	0.78
	Series 2		0.92	0.89	0.87	0.87

A complex parameter that takes into account the change in the mechanical properties of the material is the coefficient of crack resistance. It allows to evaluate the impact on fracture resistance due to the formation of defects (crack propagation). The ratio of flexural strength to compressive strength is used to calculate this coefficient (Fig. 4).

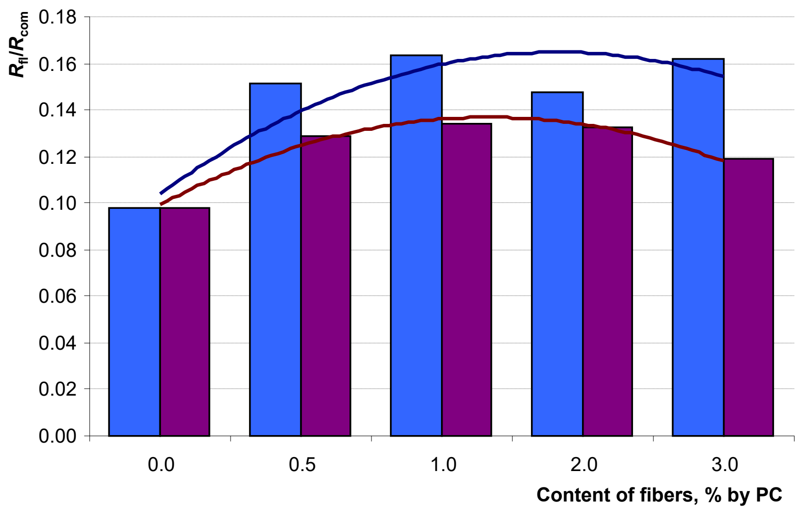

Fig. 4. Dependence of the crack resistance coefficient on the content of fibers from an amorphous ferromagnetic alloy.

Fig. 4 shows an extreme dependence on the concentration of fibers, which is associated with the manifestation of multidirectional changes in the strength characteristics of solutions with fiber from an amorphous ferromagnetic alloy. This pattern is typical for each series, regardless of the type of fiber. At the same time, the introduction of fiber into the solution makes it possible to increase the crack resistance from 0.098 (for the control composition) to 0.164 (at a fiber concentration of 1.0% (series 1)). For compositions with a fiber 7 mm long (series 1), the increase in the crack resistance coefficient is 51…68 %, and for compositions with fiber 15 mm long (series 2) is 22…37%.

4 Discussion

Fig. 2a shows that the introduction of fiber leads to a regular decrease in the spread diameter of the mortar mixture. This is due to the structuring of the mixture due to the violation of the uniformity of the components in shape. Those, fibers have a disproportionate ratio of geometric dimensions compared to the mineral component of the mixture. The intensity of the decrease in mobility is proportional to the increase in the concentration of fibers in the composition. An excess of fibers in the volume leads to their poorer distribution at a constant mixing mode.

Despite the introduction of a component with a higher density (fibers from an amorphous ferromagnetic alloy) into the composition of the studied systems, the average density of solution samples is decreased with increasing fiber concentration (Fig. 2b). This is due to a decrease in the fluidity of the mortar mixture, which leads to air entrainment and a deterioration in workability. Note that a shorter fiber (7 mm - series 1) at the maximum concentration (3 %) leads to a more significant decrease in average density (up to 9.6 %) compared to 15 mm fiber of the same concentration (reduction is no more than 4 %). This is due to the initial state, which is the fibers glued with acrylate varnish. That is, for the homogenization of such fibers, additional technological methods should be performed. For example, preliminary dissolution of varnish in water, longer mixing or a change in the stages of fiber introduction. The standard mixing mode used is not sufficient to distribute the fibers.

It is obvious that the change in mobility, which leads to a decrease in the density of the solution, is reflected in the mechanical properties (Fig. 3). The results obtained indicate the ambiguous effect of the studied fiber on the strength of the solution. Thus, an increase in bending strength may indicate satisfactory adhesion at the interface between the cement stone and the glass shell. However, the investigated range of concentrations is rather excessive for increasing the compressive strength, since it leads to a violation of the homogeneous structure of the solution due to clumping of the fibers and air entrainment.

Increasing the fiber concentration leads to a decrease in the positive effect on flexural strength and an increase in the negative effect on compressive strength. The established regularities indicate that a fiber with a smaller fiber size (L = 7 mm) has a less negative impact. At the same time, the concentration of the reinforcing additive, not more than 0.5% by weight of cement, can be considered as having no effect on the compressive strength (the increment is 0.99). Taking into account the indicators of mobility and average density, the indicated concentration can be considered the limit of the effective use of fibers from an amorphous ferromagnetic alloy.

The complex crack resistance parameter (Fig. 4) also indicates the need to limit the fiber content in the studied compositions. In this case, the boundary concentration for each of the series is 1.0%, since a further increase in the amount of fiber leads to a decrease in R_{fl}/R_{com}.

5 Conclusions

Thus, the performed studies of fibers from an amorphous ferromagnetic alloy in a glass borosilicate shell allow us to formulate the following conclusions:

- The use of a microwire made of an amorphous ferromagnetic alloy based on cobalt in a borosilicate glass shell can be promising for dispersed reinforcement of cement compositions;
- The introduction of the studied fibers into the cement mortar makes it possible to increase the bending strength by 50%; In this case, the effective concentration is the content of 0.5% by weight of the binder; A study of lower fiber concentrations is required to evaluate the positive effect on compressive strength;

– Research is required to establish the possibility of changing the injection technology or fiber geometry to improve efficiency, taking into account the additional qualities (electro-physical properties) acquired by the composite in the presence of ferromagnetic components in the composition.

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