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Optimization of Formula and Technological Parameters of Fiber-Reinforced Concrete Manufacturing

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Abstract. The development of modern construction technologies requires the development of efficient building materials with a unique property set and the improvement of existing ones. Fiber-reinforced concrete is one of the types of effective composites that meets the specified requirements, ensuring the structures operation reliability. The difficulty of achieving its maximum physical and mechanical characteristics is due to the complexity of the fiber equal distribution in the concrete matrix. Studies aimed at the optimization of the formulation and technological manufacture parameters of fiber-reinforced fine concrete, have revealed that from the perspective of obtaining products with optimal physical and mechanical characteristics, it is most feasible to introduce the agglutinant sand (cement + sand) of pre-prepared suspension from fibers, water of mixing and naphthalene formaldehyde plasticizer. Optimal dosages of input products were also revealed (basalt fiber, cement, plasticizer), which made it possible to create mixes of fine concrete and products based on it with class B25-B60 for compressive strength and Btb2,8-Btb6,0 for bending, frost resistance not less than F300.

Introduction

As is well known, building industry is not static, modern innovative construction technologies require the development of new design decisions and building materials with a unique set of properties. At the moment the most significant trends in construction development area include the use of light prefabricated structures; development of 3D printing technologies [1–5]; the consumption growth of energy-saving structures that contributes to increase the number of productions of highly efficient thermal insulating materials [6–9 and others]; increased percentage of materials produced using production wastes and secondary raw materials [10–12]; the development of highly efficient materials with desired properties for operation in extreme conditions [13–15], as well as the production of certain types of materials, such as various fiber types reinforced concrete - fiber-reinforced concrete [16–25].

Fiber-reinforced concrete products are highly resistant to cyclic and fatigue loads, as well as impact, tensile and twisting loads, which provoke uncontrolled cracking and destruction of the cement matrix, as well as unevenly distributed loads on the reinforcing elements. Fiber introduction in the concrete mix allows to avoid the concrete brittle fracture and at the same time to control cracking.

The main problem faced by fiber-reinforced concrete product manufactures is the difficulty of ensuring the equal fiber distribution in the concrete matrix, which is a determining factor necessary for achieving the maximum physical and mechanical characteristics of the final products. This problem can be solved using various techniques, in particular, the choice of the best way of fiber distribution in the system, but this is not always a sufficient condition.

In this regard, the aim of this paper is a consideration of the possibility of effectiveness increasing of micro-reinforced fine concrete by optimizing the formula and technological parameters of its manufacture, such as a fiber introduction and content method, type and quantity of plasticizer.

Goal, Tasks, Methods of Study

According to the analysis, at the moment it is possible to distinguish a dry method of fiber introduction in the system and hydro-pilling. The choice of the best way to introduce fiber is carried out experimentally by preparation the samples using specified methods of fiber introduction and output parameters comparison.

Mixing of mortars according to the first method is carried out by mixing dry components into mixers, followed by the addition water of mixing. It should be noted that the negative consequence of this method use is the mechanical damage of the micro-reinforcing component and as a result the reduction of the technical and operational fiber characteristics and final products.

The application of the hydro-pilling method, which essence is the preliminary fibers mixing in water with the subsequent introduction of cement and sand, allows to achieve a better distribution of the reinforcing element in the concrete volume. As a disadvantage of this method, it is necessary to distinguish the adhesion of individual fibers into bundles ("hedgehogs").

Due to the fact that not one of the considered method, since the presence of shortcomings does not allow the maximum use of the fibers potential, a mixed method was proposed and the possibility of obtaining the cement concrete in three ways was investigated:

I - mixing the components of the concrete mix when they are simultaneously loaded into a concrete mixer;

II - introduction to the agglutinant sand (cement + sand) of a previously prepared suspension of fibers, water of mixing and plasticizer;

III - introduction to the agglutinant sand (cement + sand + plasticizer) pre-pilled fibers in water.

Ensuring a given mobility of the concrete mixture was carried out using the superplasticizers of various nature:

- Sika VescoCrete 125 Powder (manufacturer Sika) based on polycarboxylic ethers;
- SP-1 (manufacturer Polyplast) - naphthalene formaldehydes.

Selection of the optimal dosage was carried out according to the standard procedure GOST 24211–2008.

The minimum dosage of the superplasticizer at which the specified mobility of the concrete mixture was achieved was taken to be optimal. For Sika Viscocrete 125 Powder the optimal concentration was 0.28 %, for SP-1 – 0.8 %.

Experimental Part

In order to determine the influence of the fiber introduction methods and the type of superplasticizer on the strength characteristics of the final products, samples were made, which were tested for 28 days after hardening in normal conditions (fig. 1).

Analysis of the results showed that, regardless of the used superplasticizer type, the highest indicators of ultimate compressive and bending strength are the samples obtained using the II method of fibers introducing.

If we consider the influence of the superplasticizer nature, then from the presented results it can be seen that the use of SP-1 is the most appropriate, which, together with method II of fibers introducing increased the compressive strength (fig. 1, a-2) by 46%, and bending (fig. 1, b-2) by 42.9%, compared with similar mixtures obtained using the I method and, accordingly, by 22.3% and 14.8% in comparison with the mixtures obtained by the III method. This can be explained by hydrophilization of basalt fiber by adsorption the superplasticizer on its surface, which contributes to the formation of solvation spheres and ensures the fibers uniform distribution, first in water and then in the mortar mixture.

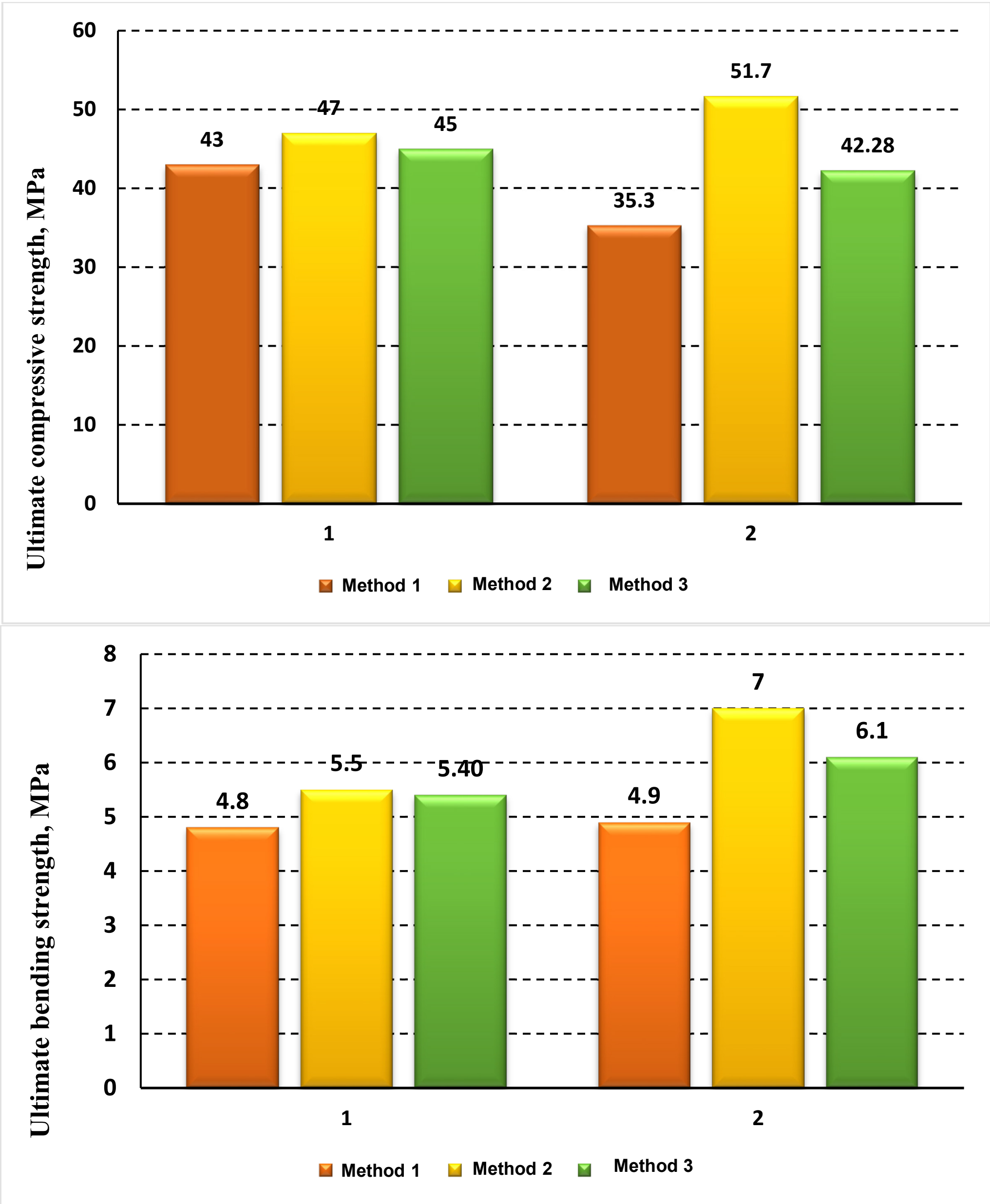

Fig. 1. Ultimate compressive strength (a) and bending strength (b) depending on the superplasticizer type (1 - Sika Vesco Crete 125 Powder; 2 - SP-1) and the method of basalt fiber introduction

At the same time, the use of Sika ViscoCrete 125 Powder superplasticizer on a polycarbaxilate basis (fig. 1, a-1, b-1) does not give such results and the increase in compressive strength using II is 9.3% and 4.4% in comparison with I and III method respectively; for bending strength, these figures were 14.6% and 1.9%.

The results obtained can be explained by the chemical nature of the additive, the plasticizing effect of which is manifested to a greater extent in an alkaline medium. While naphthalene formaldehyde additives are universal and their plasticizing effect does not depend on the pH of the aquatic environment.

In this regard, II method of obtaining material was adopted in further experiments. The plasticizer SP-1 was used as a plasticizer.

Selection of the optimal mixture of fine concrete was carried out using the method of mathematical planning of the experiment. The amount of cement, additives and basalt fibers were chosen as variation factors. The amount of additive and fiber was assigned to the cement weight and varied as a percentage of its quantity.

The planning conditions of the experiment performed and the planning matrix are presented in table1.

The output parameters for the selection of rational technological parameters were the ultimate compressive and bending strengths. Fine concrete that does not contain fiber was used as a control.

Table 1. Conditions of experiment planning

Factors		Variation levels			Variation interval
Natural state	Coded state	–1	0	1	
Cement quantity, [kg/m^3]	X_1	402.5	480.3	540.2	77.8
Additive quantity, [%]	X_2	0.5	0.8	1.1	0.3
Basalt fiber quantity, [%]	X_3	5	7	9	2

After statistical processing of the results (table 2), regression equations were obtained, which made it possible to analyze the influence of variable factors on the output parameters.

Table 2. Planning matrix

№	X_1	X_2	X_3	Ultimate bending strength R_{bend}, [MPa]	Ultimate compressive strength $R_{compress}$, [MPa]
1	1	1	1	3.77	42.11
2	1	1	–1	3.91	61.3
3	1	–1	1	7.1	57.46
4	1	–1	–1	6.55	62.81
5	–1	1	1	3.8	42.1
6	–1	1	–1	4.1	38.9
7	–1	–1	1	3.9	42.1
8	–1	–1	–1	4.2	30.3
9	1	0	0	8.2	60.29
10	–1	0	0	5.09	47.3
11	0	1	0	5.21	56.5
12	0	–1	0	4.22	50.9
13	0	0	1	5.98	54.8
14	0	0	–1	5.53	50.9
15	0	0	0	6.2	56.31
16	0	0	0	6.12	55.8
17	0	0	0	6.23	57.02

- *ultimate compressive strength, MPa*

$$R_{cs} = 56.56 + 8.33X_1 - 2.78X_1^2 - 2.88X_2^2 - 3.73X_3^2 - 3.18X_1X_2 - 4.94X_1X_3 - 2.8X_1X_2X_3$$

- *ultimate bending strength, MPa*

$$R_{bend} = 6.22 + 0.84X_1 + 0.42X_1^2 - 1.51X_2^2 - 0.47X_3^2 - 0.72X_1X_2 - 4.94X_1X_3 - 2.8X_1X_2X_3$$

A cement content of 480 kg / m^3 is recommended for all mixtures. In this case, the developed materials are characterized by the necessary compressive strength and bending strength without overspending of the binding component.

Table 3. The composition and properties of fine cement concrete

№ composition No.	Materials consumption kg/m3		Additive quantity, %	water/cement ratio	Basalt fiber quantity, %	Cone slump, cm	Ultimate compressive strength, MPa	Ultimate bending strength, MPa	Compressive strength grade of concrete	Bending strength grade of concrete	Freeze-thaw resistance grade
	Cement	Sand									
1	402.5	847	0.8	0.42	7	17	47.3	5.09	B35	$B_{tb}4.0$	F300
2	480.3	847	0.8	0.4	7	17	56.31	6.2	B40	$B_{tb}4.4$	F300
3	402.5	847	–	0.49	–	17	42.11	3.77	B30	$B_{tb}3.2$	F300
4	480.3	847	–	0.47	–	17	45.81	4.3	B35	$B_{tb}3.6$	F300

The revealed optimal dosages of raw materials (basalt fiber, cement, plasticizer) made it possible to develop compositions of fine concrete, allowing to obtain materials with class B25 – B60 for compressive strength and Btb2.8 – Btb6.0 for bending strength, areeze-thaw resistance not less than F300.

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