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Fine-Grain Concrete Reinforced by Polypropylene Fiber

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Abstract: The study gives considerations over application of polypropylene fiber for fiber reinforcement of fine-grain concretes. There was performed experimental analysis of fiber-concrete samples produced with use of a composite binding agent. There was established a percentage of fine-grain concrete fiber reinforcement with polypropylene fiber which was equivalent to 4 kg/cub.m. This value can be explained by the fact that the further increase of fiber reinforcement ratio results in insignificant enhancement of service properties of concrete and in some cases even in impairment of the same due to reduction of concrete layer thickness to the extent when the material tends to segregation.

Key words: Fine-grain concrete, technogenic sand, fiber-reinforced concrete, segregation, binding

INTRODUCTION

Presently the sphere of reinforced concrete structures application in Russia is significantly expanded. Functional purpose of a lot of buildings and facilities is being changed. Use of composite materials could be a way to solve the mentioned problems (Brandt, 2009).

Use of fiber-reinforced cement compounds allows producing lightweight building structures characterized by enhanced bending and impact resistance. Selection of a definite type of fiber depends on the required properties of the resulting compound.

There are plenty of types of products made of fiber-reinforced concrete which are designed for various applications. Use of polypropylene fiber allows reduction of expenses thanking to section size reduction. Study of an opportunity to interchange other reinforcing fibers used in concrete by polypropylene fiber showed that the resulting firm and lightweight compound with high cracking resistance could be quite promising.

The scientists from Austria, Australia, Belgium, Germany, Holland, Spain, Canada, China, Poland, the USA, France, the Czech Republic, Switzerland, RSA, Japan and other countries made great contribution to development of the science dealing with steel fiber concrete, among them the following scientists are worth noting: J.P. Romualdi, B. Gordon, G.B. Batson, M. Jeffrey, I.A. Mandel, I.L. Carson, W.F. Chen, D.I. Hannant, B. Kelly, P.S. Mangat, A.E. Naaman, R.N. Swamy, D. Colin Johnston, D.R. Lankard, V. Ramakrishnan, G. Ruffert, K. Kordina, W.A. Marsden, J. Vodichka, etc. (Brandt, 2009; Beaudoin, 1990; Maidl, 1995; Piasta *et al*., 1985).

MAIN PART

In recent years, the situations when high-quality coarse aggregates can not be found in the area of construction are quite often. Transportation of crushed stone from other regions across significant distances becomes not cost-effective. In which case a question of feasibility of use of local materials inclusive of sands and wastes from mining and processing industry as concrete aggregates becomes actual.

At the present time non-metal mining, mining and other industries annually accumulate in disposal areas hundreds of millions of cubic meters of loose wastes with various composition and texture and with grain size up to 10 mm. Since, the classification of such wastes in not available and their properties as well as characteristics of concrete mixtures based on such wastes are not sufficiently examined the same are not widely used as fine concrete aggregates.

The properties of technogenic sands, concrete mixtures and concretes produced with use of such sands depend on various factors conditioned by characteristics of initial materials, ways of their grinding, methods of benefication of the resulting product, etc. The initial materials strength, structure and composition are the most important properties.

When the properties of natural and artificial sands are compared the basic, fundamental differences of these materials are taken into account. The natural sands mainly belong to quartz sands with round-shaped and smoothly-surfaced grains while the artificial sands have essential differences in composition and properties of the initial materials, grain form and roughness of

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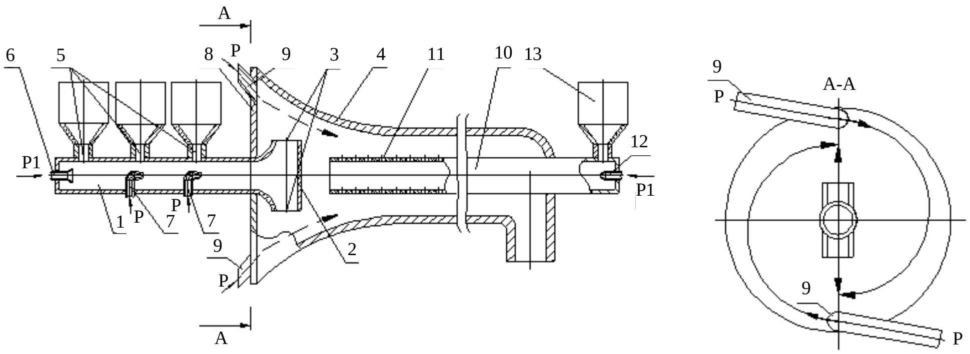

Fig. 1: Counterflow pneumatic mixer: 1: feed pipe; 2: closed end; 3: outlets; 4: case; 5: input nozzles; 6, 7, 12: air nozzles; 8: large end; 9: inclined air nozzles; 10: pipe branch; 11: radial holes

Table 1: Cement chemical composition

Cement grade	Chemical composition (percentage by weight)								
	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	R_2O	CaO_{free}	Loss on ignition
Cem I 42.5N	22.49±0.5	4.77±0.3	4.40±0.1	67.22±1.0	0.43±0.03	2.04±0.01	0.20±0.05	0.20±0.05	1.5±0.5

Table 2: Physical and mechanical properties of aggregate

Index description	Quartzitic sandstone screenings	Sand from Tavolzhanskoye deposit field
Fineness modulus	3.50	1.38
Loose weight density (kg/m^3)	1415	1448
True density (kg/m^3)	2710	2630
Void content (%)	47.8	44.9
Water demand (%)	5.5	7

grain surface. Artificial sands are characterized by freshly-exposed surface. Due to the above reasons the properties of artificial sands vary. Interaction between the surface of technogenic sands with cement grout and set cement has much more complicated nature than that of natural ones. The influence of granulometric composition, grain shape, surface roughness and other characteristics on the properties of mixtures and concretes can hardly be evaluated without due account of the above specified interaction (Klyuyev *et al*., 2012, 2013).

There were developed fine-grain concrete compositions containing screenings from quartzitic sandstone grinding in order to assess the possibility of technogenic sands use as a raw material for fiber-reinforced concrete production. For achievement of more dense packing of aggregate sand from Tavolzhanskoye deposit field was used.

The experimental investigations deal with study of behavior of concrete elements which were reinforced with polypropylene fibers under the conditions of compression and extension at time of bending.

For production of high-strength fine-grain concrete various methods of cement activity and concrete mixture quality increase are applied (cement regrinding and vibration activation, vibration mixing, use of superplasticizing agents).

Use of a composite binding agent obtained through joint grinding of high-grade cement and C-3 superplasticizing agent offers a challenge in getting high-strength concretes.

The composite binding agent was produced with use of finished cement Cem I 42.5 N of CJSC “Belgorodskiy cement” (Table 1) and C-3 superplasticizing agent.

In order to evaluate quality of the used aggregates their principal physical and mechanical properties were analyzed (Table 2).

Production practice showed that reinforcement of cement matrix with use of polypropylene fiber characterized by high chemical resistance to alkaline medium. Polypropylene fibers are included in concrete samples in order to enhance compression strength of concrete from 10-60% and bending strength from 10-200%.

Preparation of a dry fiber-reinforced mixture is one of the important phases of production. The specialists of the mechanical equipment chair of BSTU named after V.G. Shukhov have developed a pneumatic mixer for blending dry mixture components in order to ensure the mixture quality (Fig. 1).

The experimental investigations showed high production efficiency of the mixer and guaranteed “pilling” of fiber lumps.

Dried sand, screenings from quartzitic sand grinding, composite binding agent and polypropylene fiber were

Table 3: Physical and mechanical properties of fine-grain concrete depending on the length of polypropylene fiber

Item No.	Concrete composition	Without fiber	Polypropylene fiber with the length of 3 mm	Polypropylene fiber with the length of 6 mm	Polypropylene fiber with the length of 12 mm
1	CEM I 42.5 N (kg)	400.0	400.0	400.0	400.0
2	Sand (kg)	520.0	520.0	520.0	520.0
3	Quartzitic sandstone screenings (kg)	1240.0	1229.0	1229.0	1229.0
4	Water (kg)	220.0	223.0	225.0	226.0
5	Polypropylene fiber (kg)	-	4.0	4.0	4.0
6	Compression strength (kg)	36.2	43.5	45.4	40.3
7	Bending strength	4.3	6.2	6.5	5.8

mixed up to obtaining a homogenous composition. Water was added afterwards for getting a uniform mass. After molding and packing the samples were stored under the temperature of 15°C or higher within the period of 24 h. After removing the molds the concrete samples were transported to a dry place (hardening chamber with the temperature of 20°C and the humidity over 90% which corresponds to GOST requirements).

Testing of the samples for determining compression strength (cubes of 100×100×100 mm) and bending strength (prisms of 100×100×400 mm) was performed with use of a multi-purpose testing machine according to a standard procedure. The experiment results are shown in Table 2.

For the purposes of enhancement of fine-grain concrete service properties it was offered to use a composite binding agent and polypropylene fiber reinforcement since it is alkali-resistant.

At present polypropylene round-shaped fibers with the diameter of 20-30 μ and the length of 3, 6, 12 and 18 mm are the most widely used (Fig. 2).

Service properties and durability of polypropylene fiber depend on its diameter. Use of polypropylene fiber with lesser diameter ensures high indices of bending strength and impact resistance. The results of the performed investigations showed that with the bigger fiber diameter its reinforcing capability was maintained for a longer time (Beaudoin, 1990; Maidl, 1995; Piasta *et al*., 1985).

The influence of the size of polypropylene fiber on strength properties of concrete was examined in order to find out an optimum size of fiber for fine-grain concrete. There was selected the percentage of reinforcement equivalent to 4 kg/m^3. The results of the investigations are shown in Table 3.

The analysis of the carried out investigations allows coming to a conclusion that the highest increase of strength properties can be observed when concrete is reinforced with polypropylene fiber with the length of 6 mm. So, this length will be taken for the following investigations.

In order to optimize the structure of fine-grain fiber concrete we'll use VNV-100 (binding agent with low water demand) as a binding agent and will establish the

Table 4: Concrete compositions

Item No.	Concrete composition	1 Contr.	2	3	4
1	VNV-100 (kg)	400	400	400	400
2	Sand (kg)	520	520	520	520
3	Quartzitic sandstone screenings (kg)	1240	1229	1224	1221
4	Water (L)	220	225	227	229
5	Polypropylene fiber, length of 6 mm (kg)	3	4	5	

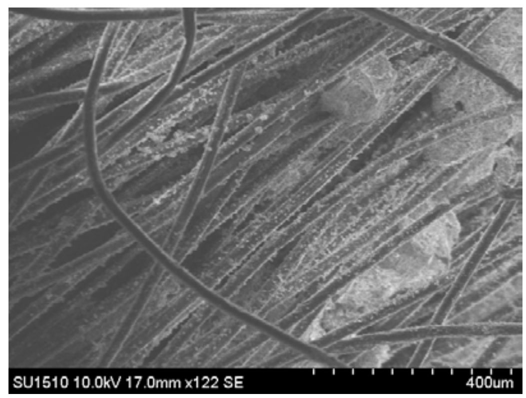

Fig. 2: Microstructure of a bunch of polypropylene fibers

optimum percentage of polypropylene fiber reinforcement. The compositions of fiber reinforced fine-grain concreted are given in Table 4.

The results of experimental investigations over the influence of reinforcement material on the strength properties of fine-grain concrete are presented on Fig. 3.

The carried out investigations showed the efficiency of fiber reinforcement of fine-grain concrete produced with use of technogenic raw materials and composite binding agent since the compression strength increased by 32% and the bending strength by 64%. Therefore, there was determined the optimum content of polypropylene fiber in fine-grain concrete designed for highway roads pavement equal to 4 kg/m^3.

On the basis of the experimental investigations, there was proved the possibility to use a counterflow pneumatic mixer for production of fiber-reinforced mixtures for it ensures "pilling" of polypropylene fibers and allows to avoid forming of "bunches" or "lumps" which results in as much as 5 fold increase of

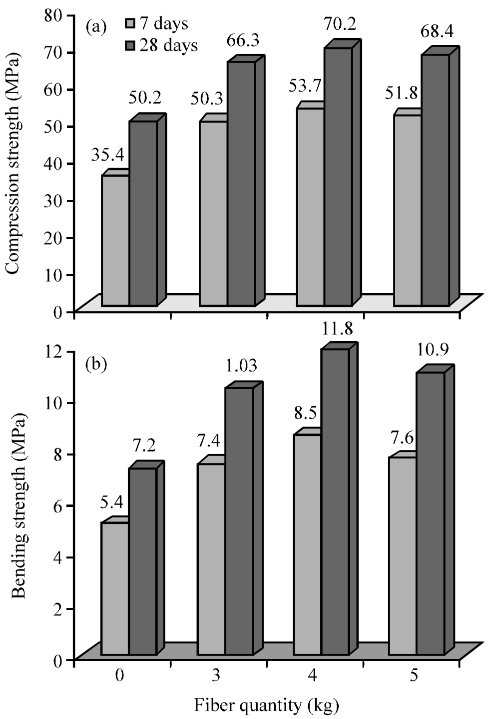

Fig. 3: Results of experimental investigations of fine-grain fiber-reinforced concrete: a) compression strength and b) bending strength

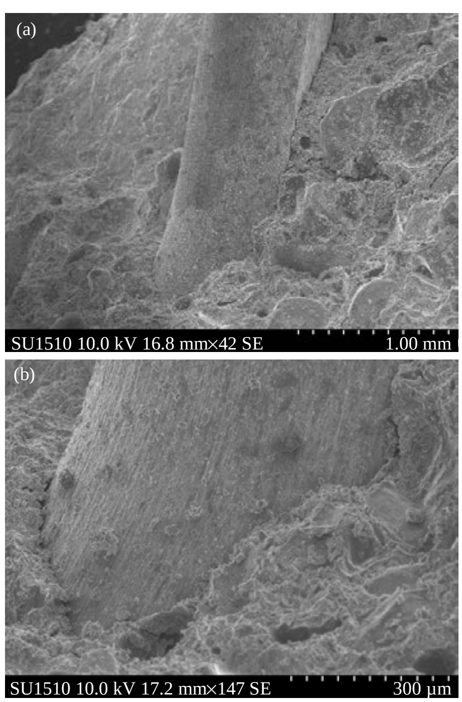

Fig. 4: Microstructure of a contact zone "set cement polypropylene fiber": a) with use of VNV-100 and b) with use of Cem I 42.5N

reinforcement material content in fine-grain concrete and consequently in enhancement of its strength properties.

Fine-grain concrete (composition 4) experiences "over-reinforcement" which leads to deterioration of its strength properties, so the further increase of polypropylene fiber content is not reasonable, this can be explained by the fact that the thickness of set cement between the fibers gets too small and the sample tends to segregation of layers. The results of study of mictrostructure of a contact zone between polypropylene fiber and set cement are given on Fig. 4.

CONCLUSION

There was determined the optimum percentage of polypropylene fiber reinforcement of fine-grain concrete equal to 4 kg/m^3. This value can be explained by the fact that the further increase of fiber reinforcement ratio results in insignificant enhancement of service properties of concrete and in some cases even in impairment of the same due to reduction of concrete layer thickness to the extent when the material tends to segregation.

There were identified the peculiarities of microstructure of a contact zone between polypropylene fiber and cement matrix depending on the type of binding agent, aggregate and superplasticizing agent. There was established the nature of dependence of polypropylene fiber adhesion strength on the type and the value of the above specified parameters.

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