Fine-aggregate concrete with polymer and basalt fiber

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Abstract. The article covers the results of research and experimental studies aimed at determination of the impact of polymer and basalt fibre as well as plasticizing agents on the properties of fine-aggregate concrete. The authors identified the physical and mechanical properties of fine-aggregate fibre-reinforced concrete depending on the amount of basalt and polymer fibres. The article also dwells on the impact of different plasticizing agents on the properties of fine-aggregate fibre-reinforced concrete. It was determined that the optimal concentration of polymer and basalt fibre is 0.9-1.0 kg/m³ when maximum compression strength and tension in bending have been reached. The authors managed to select efficient superplasticizing agents Sika ViscoCrete 5-800 and POLIPLAST SP-4 which provided maximum increase in strength of fine-aggregate concrete. It was determined that the use of polymer and basalt fibres ensures increase in strength and crack resistance of the obtained fine-aggregate concrete compositions.

1. Introduction
The performed theoretical and experimental studies have shown that concrete strengthened with polymer and basalt fibres demonstrate high physical and mechanical properties. Reinforcement with fine-grained fibre fillers improve key disadvantages of conventional concrete - low tensile strength and brittle failure (crack resistance). Fibre-reinforced concrete has a higher strength in shear, impact strength, fracture toughness, freeze-thaw resistance, waterproofing, etc. [1-23].

2. Relevance
Use of fine-grained fibre fillers in cement concrete exerts positive impact on structurization, physical and mechanical properties as well as operational characteristics of concrete. This is achieved by means of better adhesion of fibres to cement matrix, a relatively high strength and elasticity modulus of synthetic fibres, their resistivity to alkaline environment.

3. Problem statement
Synthetic fibres are rarely used in Russia, and they are mainly imported. As such, polypropylene fibres are produced by (Fibrin, Krenit, Crackstop), Adfil (England), Belgian fibres N.V. (Belgium), PP EUROFIBER manufactured by P. Baumhueter GmbH (Germany). Diameter of such fibres is about 20 mcm, and tensile strength is up to 300 MPa [9]. However, wide use of polymer fibres is restricted by their low mechanic properties and high cost.

C-AIRLAIID company and South Ural State University have performed many experiments to develop Russian synthetic fibres with improved physical and mechanic properties. As a result, they
have received polymer fibres having high elasticity modulus and tearing strength due to chemical and ultra-fine components introduced into the nucleus polymer [9].

Fibres obtained in C-AIRLAID from high modulus thermoplastic polymer have a diameter of 20-50 mcm and a length of 3-18 mm with tearing strength reaching 500 MPa. Recommended practices have been prepared to describe the application of construction micro-reinforcing fibres in construction mixtures and concrete. The practices have been issued as technical specification TU 2272-006-13429727-2007.

Basalt fibres manufactured by ZAO “Mineral 7” as per TU V V.2.7-26.8-32673353-001-2007 are based on basaltic rocks, have a diameter of 13-17 mcm and a length of 6-12 mm, their tensile strength is up to 2000 MPa.

4. Theoretical part
Use of polymer and basalt fibres facilitates the formation of rheologically homogeneous mixture at the stage of mixing. This mixture has high plasticity and is nonsegregating. After hardening the obtained fibre-reinforced concrete has a three-dimension reinforced micro-structure of cement stone that prevents from the formation of shrinkage cracks.

The task of scientific research is to improve the efficiency of the process of production of modified fine-aggregate fibre-reinforced concrete mixture with the view to improve its compressive strength and tension in bending using components than strengthen the fibre-reinforced concrete structure the micro-level.

The studies of the impact of fine-aggregate fibre fillers have been performed using construction micro-reinforcing fibre (CMRF) manufactured by C-AIRLAID [9] as using basalt fibre having a diameter of 13-17 mcm and a length of 6-12 mm.

Fire-reinforced concrete composition was selected using software [12]. Micro-reinforcing fibre was added at the stage of mixing of dry components of the mixture. The obtained specimens of fibre-reinforced concrete are shown in Fig. 1.

The size of the specimens of fibre-reinforced concrete is 40x40x160 mm as per the Russian standard GOST 10180.

5. Results of experimental studies
The results of the studies aimed at determination of mechanical properties of fine-aggregate fibre-reinforced concrete are given in Table 1.
The analysis of the studies results has shown that compared to the reference concrete having no CMRF and basalt fibre, compressive and tensile strength in bending is increased in all mixtures of fine-aggregate fibre-reinforced concrete with fibre content from 0.6 to 1.2 g/m³.

Table 1. Impact of high-disperse fibres on the strength of fibre-reinforced concrete.

| No. | Fibre content, kg/m³ | Basalt fibre | Construction micro-reinforcing fibre (CMRF) |
|-----|----------------------|--------------|-------------------------------------------|
|     | Tensile strength in bending, MPa | Compression strength, MPa | Tensile strength in bending, MPa | Compression strength, MPa |
| 1   | 0                     | 3.49         | 31.36                                    | 3.41                       | 31.28                      |
| 2   | 0.6                   | 3.57         | 31.64                                    | 3.50                       | 31.59                      |
| 3   | 0.7                   | 3.63         | 32.22                                    | 3.57                       | 32.17                      |
| 4   | 0.8                   | 3.71         | 33.73                                    | 3.64                       | 33.61                      |
| 5   | 0.9                   | 3.82         | 36.25                                    | 3.83                       | 36.68                      |
| 6   | 1.0                   | 3.91         | 36.77                                    | 3.71                       | 36.18                      |
| 7   | 1.1                   | 3.79         | 36.60                                    | 3.76                       | 36.54                      |
| 8   | 1.2                   | 3.71         | 34.81                                    | 3.62                       | 34.77                      |

Use of fibre increased the bonding with cement-sand matrix and, consequently, increase the compression and bending strength of the specimens. Fig. 2 shows the photo of the destroyed specimen of fibre-reinforced concrete using polymer CMRF fibre. The figure demonstrates that the main crack that formed during loading did not tear the specimen into two parts, and the specimen was not destroyed. The life of specimen of concretes with polymer and basalt fibre is significantly longer than the life of specimen of ordinary fine-aggregate concrete. The increasing of crack resistance and, consequently, of life performance of fibre-reinforced concrete is related to macro-reinforcing capacity of fibres and relaxation of stress at the matrix-filler contact surfaces. As a result the time of formation of a macro-crack that divides the specimen into parts can significantly exceed the duration of preparatory stages of destruction at micro- and nano-levels.

Figure 2. Specimen with polymer fibre after testing.
The optimal composition of fibre-reinforced concrete is with concentration of polypropylene fibre equalling 0.9 kg/m³; it demonstrated an increase of compression strength by 17 % and an increase of tensile strength in bending by 12.3 %.

The mixture with basalt fibre concentration equalling 1.0 kg/m³ demonstrated an increase of compression strength by 17.3% and of bending strength by 12%.

Further increase of fibre content resulted in formation of lumps, decreasing of compression strength and tension in bending and to unnecessary increase in the cost of fibre-reinforced concrete.

Thus, the use of polymer CMRF fibre and basalt fibre in concrete mixtures helps to reduce the consumption of an expensive bonding material, reduce the labour costs for reinforcement of reinforced concrete products and increase its crack resistance and lifetime.

In order to improve the physical and mechanical properties of fibre-reinforced concrete it is necessary to study the impact of plasticising agents on the strength of cement-sand mixture. In order to study the impact of plasticising agent we have made bar specimen having dimensions 40x40x160 mm of cement-sand mixture having composition C:S=1:3 with water-cement ratio W/C=0.53. Key materials that have been used were cement manufactured by ZAO Oskolcement grade CEM I 42.5N (Portland cement, M500 D0), sand by ZAO Orlovskiy Sand Pit with fineness modulus 1.91. During the study we have considered the following plasticising agents: D-11 plasticising agent, superplasticising agents S-3, Poliplast SP-3, Supranaft, Muraplast FK 88 (050), POLIPLAST SP-4, Sika ViscoCrete 5-800, SikaPlast 2135. Superplasticising agents were added to the concrete mixture with tempering water at the ratio 0.5 % of cement mass. Bar specimens acquired strength in normal conditions at a temperature of 22°C and humidity 80-100 %. The strength of the samples was determined by ultrasonic nondestructive control method as per the Russian standard GOST 17624 using Pulsar-1.2 device on the 28th day.

The results of the performed studies are provided in Table 2 and in Figure 3.

| Name            | Cone flow diameter, mm | Density kg/m³ | Strength of cement-sand solution, MPa |
|-----------------|------------------------|---------------|---------------------------------------|
| Reference specimen | 107                    | 2017.58       | 2.75 bending                          | 29.82 compression |
| Sika Plast 2135  | 142                    | 2070.315      | 3.2 bending                          | 32.61 compression |
| VC 5-800         | 149                    | 1994.14       | 3.15 bending                          | 34.05 compression |
| Supranaft        | 145                    | 2009.765      | 3.15 bending                          | 31.08 compression |
| SP3              | 145                    | 1996.09       | 3.3 bending                          | 30.27 compression |
| SP4              | 159                    | 1955.08       | 3.45 bending                          | 33.78 compression |
| С3              | 147                    | 2041.015      | 2.8 bending                          | 32.16 compression |
| D11             | 126                    | 1984.375      | 2.7 bending                          | 29.55 compression |

Plasticization effect of different fillers were studied using shaker apparatus and slump cone. The analysis of the results showed that the best plasticization effect is achieved when adding superplasticising agents POLIPLAST SP-4 that was determined by the cone flow diameter equalling 159 mm whereas reference test (without fillers) demonstrated only 107 mm. Plasticization effect of different fillers were studied using shaker apparatus and slump cone. The highest compression strength was demonstrated by compositions which include superplasticising agents Sika ViscoCrete 5-800 and POLIPLAST SP-4. Their strength increased by 13.3-14.2 % compared to the reference specimen.
Figure 3. Impact of plasticising agents on the strength of the cement-sand solution.

6. Conclusions
The results of the experiments show the positive influence of fibre and superplasticising agents on physical and mechanical properties of the cement-sand solution.

Introduction of POLIPLAST SP-4 and Sika ViscoCrete 5-80 agents provided an increase in strength and fluidity of the solution.

Use of superplasticising agents also results in decrease of the consumption of mixing water with preservation of the solution fluidity that is important for fine-aggregate fibre-reinforced concrete.

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