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Technology and Manufacture of Reinforced Concrete Structures with Application of Silica Fume for Multi-storey House-building in the Republic of Khakassia

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Abstract: Silica fume is a processing waste of ferroalloy factories. The application of silica fume instead of cement allows producing high strength concrete, as well as concrete types of the middle and low classes providing a saving in cement of up to 50 %. The authors have developed a technology for preparing a concrete mixture for reinforced concrete structures with silica fume. The technology is simple and does not require additional expensive equipment having low power intensity. The technological parameters have been investigated. They are related to slump, maturing conditions during steam curing and monolithic casting. The economic efficiency of applying concrete mixtures containing silica fume has been determined.

1. Introduction

One of the main objectives in the construction industry is cutting of construction cost value by utilizing the latest technologies and modern materials. Construction in Khakassia is considered a dynamically developing industry. Most of the building structures related to residential construction are made of monolithic and prefabricated monolithic reinforced concrete. One of the ways to reduce the cost of materials for multi-storey residential buildings is to lower the amount of reinforcement used in the structure by contracting the construction section, which is possible using high strength concrete. The development of production technology of high strength concrete and study of its raw materials sources are of great importance for manufacturing the concrete type. In recent years in all developed regions the high strength concrete containing silica fume has been rather widely spread, which enables to reduce significantly material consumption and to increase durability, frost resistance, water resistance. In Khakassia, the Department of Urban Development made a decision on the design and construction of high-rise residential buildings (17-, 19-, 23-storey buildings). In this regard, the use of high strength concrete containing silica fume is an urgent issue, since applying of silica fume allows producing concrete class B80 and higher using cement of brand 400.

Batrakov V.G., Kaprielov V.S., Schonfeld A.V., Gamaliy E.A., Pertsev V.T., Mkrtchyan A.M. studied the problem of making high strength concrete or concrete types of middle classes having a reduced cement consumption while preserving simultaneously strength and other indicators of concrete containing silica fume [2, 3, 4, 5, 6, 8].

2. Purpose

The purpose of the work consists in selecting concrete compositions of different classes subjected to steam curing in natural conditions that are made of local materials extracted and produced in the

Republic of Khakassia and in studying physical and mechanical properties and technology of manufacturing concrete containing silica fume.

3. Experimental part

Silica fume is a superdispersed material captured by bag filters of gas-cleaning installations at ferroalloy plants. The main component of superdispersedwaste is silicon dioxide having amorphous modification SiO2.

The authors conducted a research to investigate the impact of silica fume on cement stone. The average density of silica fume is 2.1-2.3 g/cm³ (cement 3.1 g/cm³), bulk density is 0.15-0.20 g/cm³, grain size is less than 0.1 μm (50 times smaller than the particle size of cement) specific surface is 200,000-250,000 cm²/g (cement is about 4,600 cm²/g). The silicon oxide content in silica fume reaches 90.7% and sometimes up to 96 %. Oxides of calcium, magnesium and iron predominate among other components.

It is important to take into account a complex of factors and indicators that are reflected in technological and technical characteristics of cement stone: required amount of water, strength, and consumption of SPs (superplasticizers), since silica fume due to its large specific surface area has higher water demand a superplasticizer is applied. The efficiency evaluation of silica fume is shown in Figure 1.

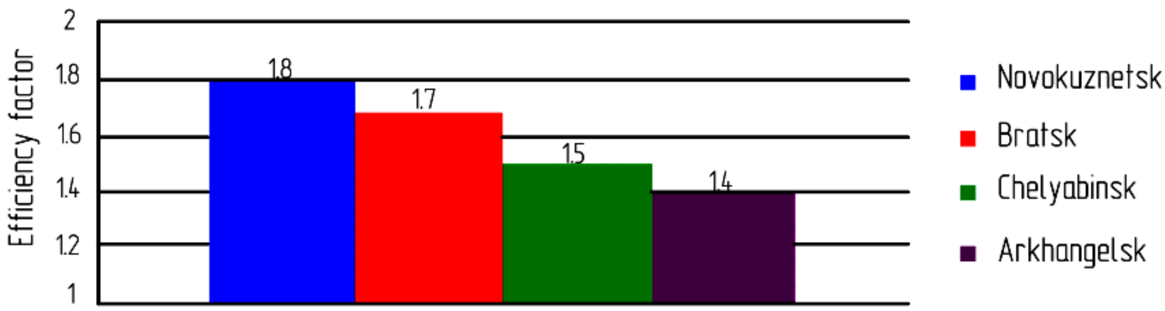

Figure 1. Efficiency of silica fume produced at different plants.

According to Figure 1 it is seen that the most effective waste of ferroalloy production is silica fume made in the city of Novokuznetsk. Namely, we study this substance.

The authors conducted studies of the effect of silica fume on cement stone applying cement brand 400 (produced at Achinsk and Topkinsk plants). To estimate the strength gain at the age of 28 days, an empirical formula (2.1) was proposed, which allows determining this parameter depending on thedosage of silica fume, its pozzolanic activity, degree of hydration, capillary porosity of the system.

The formula, which is quite exact at different dosages of silica fume depending on the weight of cement, is derived on the basis of a number of prerequisites:

- the value of pozzolanic silica fume activity depends on the content of amorphous SiO2;
- the change in the density structure of cement stone when adding silica fume is connected with the volume of gel and capillary pores and to a lesser extent with the volume of macropores;
- gel porosity is determined by the degree of hydration in the cement stone which is affected by SiO2 / Ca(OH)2 ratio. Capillary porosity is determined by water-cement ratio, degree of hydration and, silica fume content.

$$R = K\left(\frac{S}{SI}\right)^2\left(\frac{B-0{,}5\cdot\alpha\cdot P}{10\cdot C}\right)^2\%, \quad (1)$$

K is a coefficient considering the difference in molecular masses of SiO_2 and Ca $(OH)_2$;
S is an absolute content of SiO_2 in the composition of mixed binder, %;
SI is a content of Portland cement in cement stone without silica fume, it is assumed to be 15 %;
α is a degree of hydration of Portland cement, %;
C is a dosage of silica fume, %;

P is a percentage of cement

Figure 2 shows the dependences of concrete strengths on the consumption of cement containing silica fume. The results of Figure 2 indicate that class B 55 concrete produced has a cement consumption of 340-350 kg/m³. Figure 2b shows the saving of cement containing silica fume when comparing it with the control factory strengths of concrete.

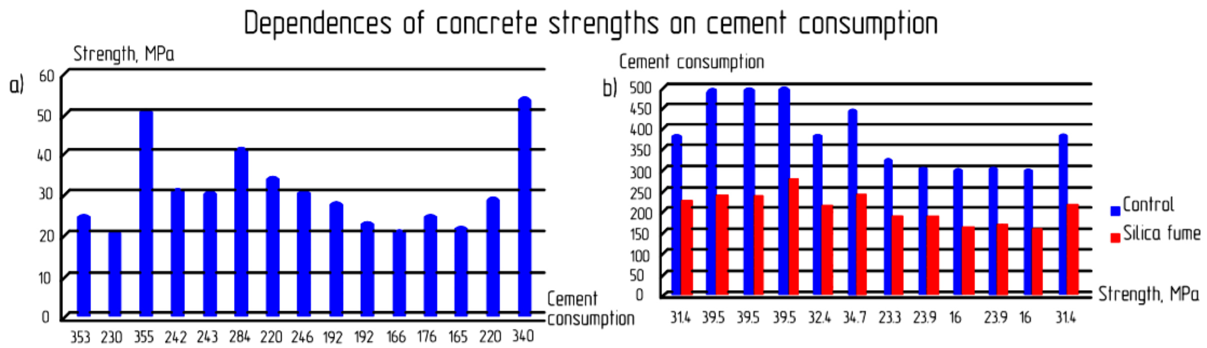

Figure 2. a) Diagram of dependence of strength on consumption of cement containing silica fume; b) diagram of dependence of strength on consumption of cement having control factory strengths and of cement containing silica fume.

The conditions of hardening have been studied. When increasing in dosage of silica fume, the amount of free lime in the cement stone samples decreases. Figure 3a presents the results of determining CaO in samples of cement stone, depending on the conditions of hardening and dosing of silica fume. Practical dosage above 30% of cement weight leads to the fact that this dosage is an efficiency threshold of silica fume. The use of silica fume in combination with the plasticizer SP1 or S3 is an effective means of saving cement in concretes having both low and high cement content. In addition, the received results indicate that along with considerable economy of cement, there is a significant increase in the strength of the material, which provides certain opportunities for obtaining high-strength concrete (Figure 3b).

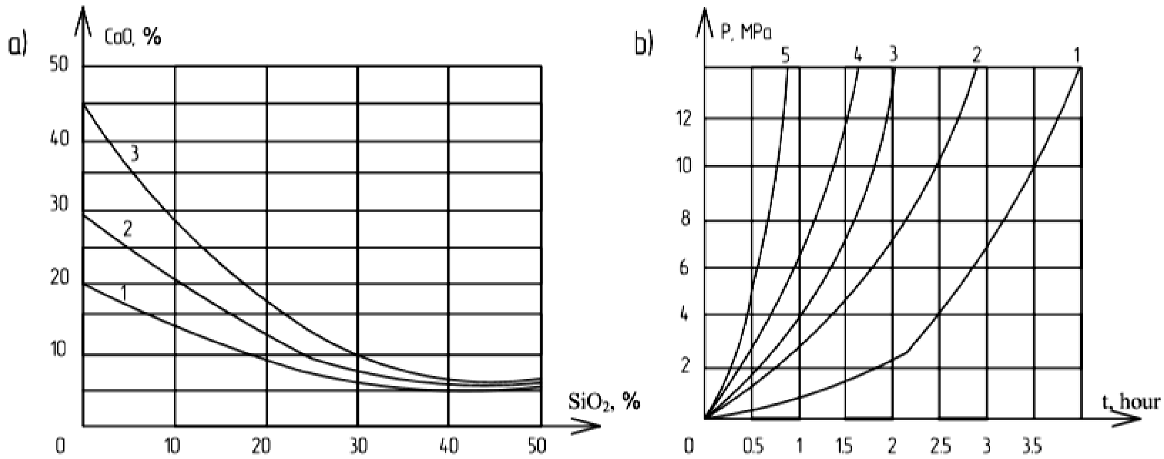

Figure 3. a) Content of free lime in the samples of cement stone with different dosages of silica fume; b) cement without additives, 2-cement +10% of silica fume, 3- cement +20% of silica fume, 4 – cement +30% of silica fume, 5 – cement+40% of silica fume.

In order to evaluate the properties of concrete mixtures and determine the effect of technological sequence of mixture preparing on the properties of concrete the samples made in a forced mixer were tested in two ways. In the first case, fillers were introduced in the mixture of cement and S-3, then after pre-mixing, water was added with S-3 additive. In the second case, the mixture was prepared in the usual sequence, and silica fume was introduced in the concrete mixer in the form of a suspension of 40% concentration with a solution of S-3 additive and water (survivability time of the suspension is three days according to the specification). The mixing time of weighed materials is 3 minutes.

In the course of the experiment the change of the flowability of the mixtures in time and the dependence of placeability characterized by rigidity according to GOST 10181.1-81 on the flowability measured by slump were determined. The strength was defined by testing the samples having edge size of 10 cm which were hardening in normal conditions and during steam curing that was carried out in two modes. The first mode: 3+3+6+2 at the isotherm temperature of 900°C, the second one had the same duration but the isotherm temperature was 60°C.

As a result of the experiment, it has been established that the mixtures prepared by introducing silica fume in the dry form into the mixer lose rapidly their flowability in 10 minutes which creates certain inconveniences by performing works. This is connected with kinetics of measuring the water demand of mixtures until saturation of ultradispersed material with water, which occurs depending on the silica fume dosage in 6-10 minutes after mixing all components of the concrete mixture (see Figure 4).

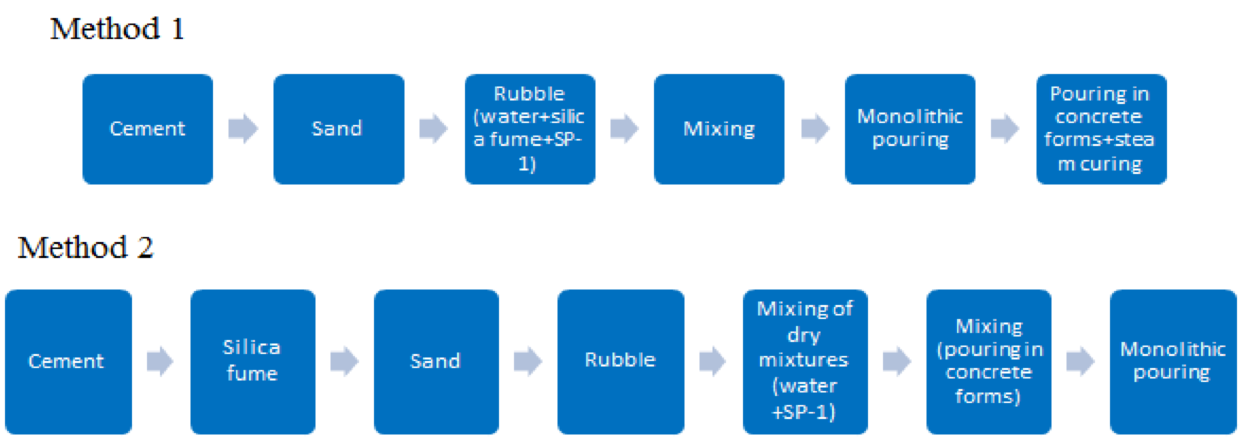

Figure 4. Process flowsheet of producing concrete of different brands.

By preparing mixtures with introduction of silica fume in the form of suspension in the mixer, the flowability in time varies relatively evenly. The consistency of concrete mixtures in time proved to be one of the decisive factors that determined the choice of technology with feeding silica fume to a mixer in the form of suspension.

The data presented in Figure 5 indicate that concrete mixtures containing ultradisperse filler have better placeability, that is, stronger thixotropic properties than ordinary mixtures of the same placeability. It is to mention the placeability increases with an increase in the proportion of cement substituted by silica fume in the mixture composition.

The conditions of hardening have a significant effect on the strength properties of concrete: when hardening in normal conditions an intensive increase in strength occurs within 7-20 days; when hardening occurs in steam curing conditions, the strength increases with increasing isotherm temperature up to 900°C (see Figure 6).

The above stated results lead to the conclusion that the technology of manufacturing a concrete mixture of different brands is simple and does not require special equipment.

Additionally, an autonomous loading of silica fume is provided which depending on the production conditions can be supplied in a dry state or in the form of suspensions (see Figure 6 b).

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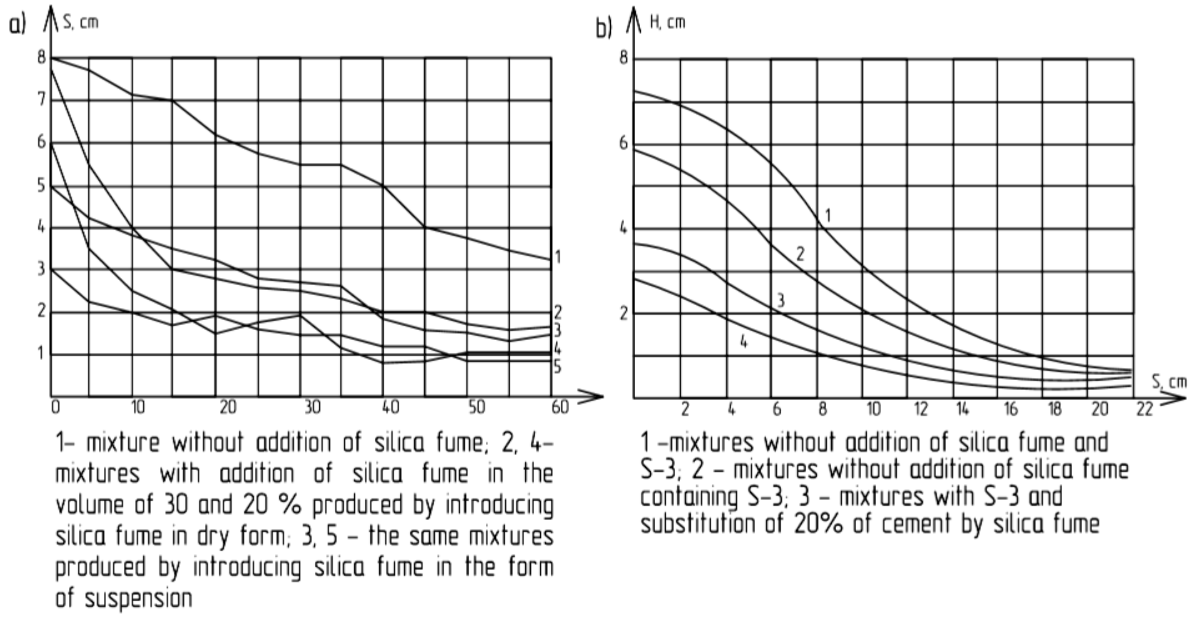

Figure 5. a) Change in the flowability of concrete mixtures in the course of time; b) Changes in the placeability of concrete mixtures using silica fume depending on flowability (Binder consumption is 300 kg/m³).

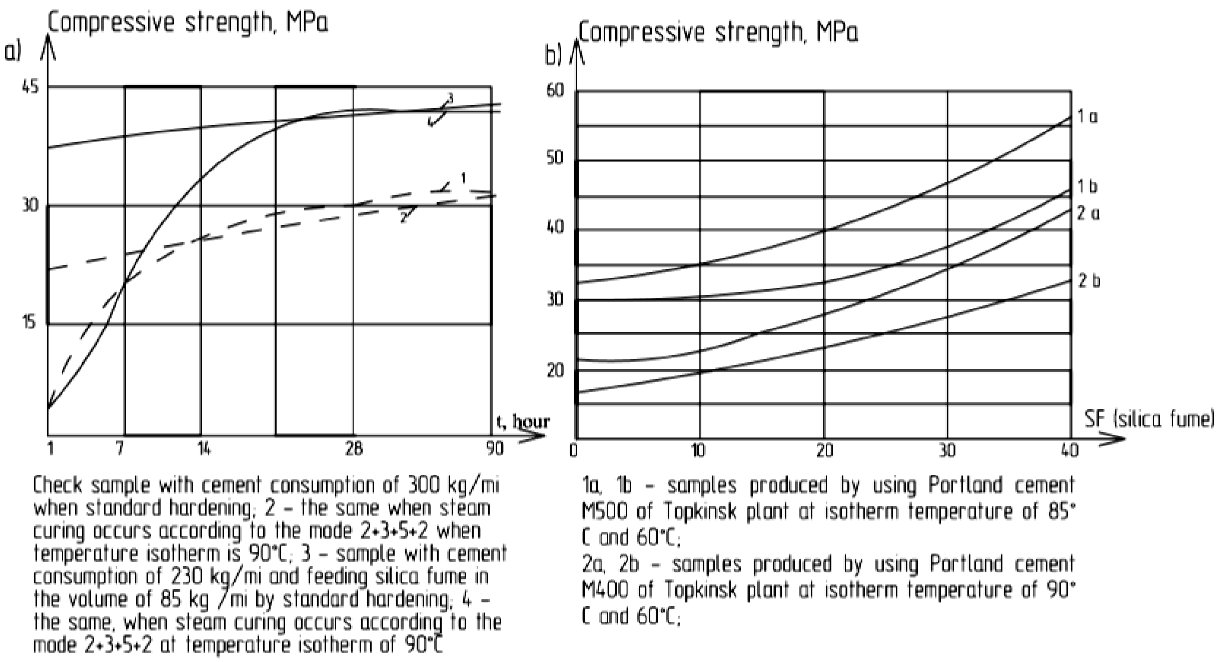

Figure 6. a) Kinetics of hardening concrete samples with addition of silica fume; b) Concrete strength depending on the dosage of silica fume and steam curing mode.

The time variation of flowability of concrete mixtures with silica fume additive depends on the method of their preparation: when preparing mixtures with feeding silica fume into the concrete mixer in the initial state (dry), there is a sharp decrease in flowability of the mixtures; flowability in time changes evenly when supplying silica fume in the form of suspension. From the point of view of

preserving the consistency in time, it is preferable to prepare concrete mixtures supplying silica fume in the form of suspension in the mixer, this applies to the silica fume noncompacted.
Concrete mixtures containing silica fume have pronounced thixotropic properties. This is manifested in increased placeability of low-slump mixtures. Supplying silica fume in concrete compositions at constant cement consumption allows to obtain an increase in the strength of concrete from 40 to 70 %. The positive effect of silica fume additive on the strength properties of concrete can be used to significantly reduce the cost of cement.
The strength of concrete containing silica fume is considerable affected by the mode of steam curing; hardening of concrete occurs more intensively when increasing the isotherm temperature.

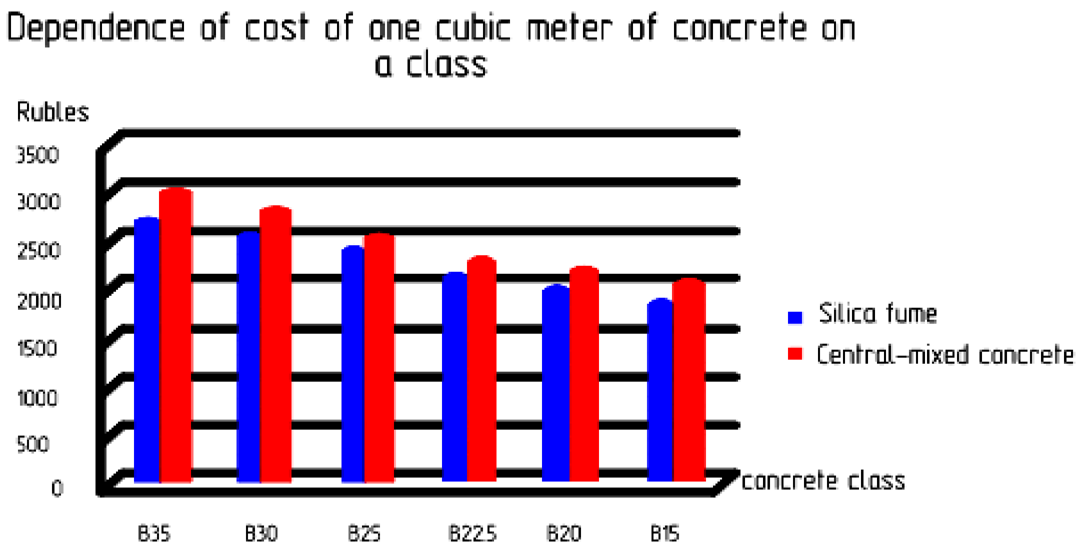

Figure 7. Dependence of cost of one cubic meter of concrete on a class.

4. Conclusion
The study of concretes having middle activity has shown that supplying silica fume in concrete mixture will allow: producing high-strength concrete (or cement saving up to 50%); making concretes that are not steam-cured and have specified delivery strength B30 within 24 hours; reducing the duration of heat and moisture treatment for 3-4 hours; increasing frost résistance F and water resistance w of concrete; as well as increasing sulphate-resistance of concrete made using ordinary Portland cement; and improving bonding of cast concrete mixtures. The safety of reinforcing steel in concrete is ensured at a dosage of silica fume that should be not more than 20% of cement weight (if it is more than 20% steel corrosion inhibitors are to be fed – sodium nitrate). The environmental situation will be also improved while providing a significant effect in the construction industry.

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