

Use of Silverbond quartz flour in the design of self-compacting concrete mixtures

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Abstract. The article presents the results of the study of the influence of Silverbond quartz flour of grades 15 and 20 on the physical and mechanical and operational characteristics of self-compacting concretes (SCC) in its partial replacement of portland cement, as well as the research of the possibility of using steel fibers of various types and in different dosages to improve the physical and mechanical and operational characteristics of SCC with quartz flour.

1. Introduction

In the last decade, the scope of structures constructed with SCC has been growing rapidly on the territory of the Russian Federation. The use of this type of concrete, despite its higher cost, allows to reduce labour and time costs, as well as to increase the level of safety at the construction site due to its high mobility, rejection of vibrocompaction and rapid concrete strength development. In comparison with the traditional mixtures of concrete, the SCC is more convenient to use for making structures with complex geometry and small elements, because they provide better bond with the reinforcement and help to obtain a surface of high quality.

Among the disadvantages of using the SCC are their increased creep coefficient and a relatively lower modulus of elasticity due to the increased concentration of cement paste in the concrete mixture and the reduced concentration of large aggregate [1-4].

To achieve the required grade of SCC for workability and segregation resistance, it is important to select the optimal dosage of microaggregates and plasticizing agent [5, 6]. It should be noted that some researchers recommend the use of various active mineral additives (microsilica, slag, fly ash, etc.) instead of the microaggregate [7-10], though their use often leads to an increase in the time of structure formation and, as a consequence, a decrease in early strength and even occurrence of cracks in structures. Also, at the moment there is the problem of instability of the quality of such products, and sometimes their high cost.

As a rule, dolomite, limestone and quartz flour are used among the microaggregates which are a fine fraction of mineral fillers, as well as screenings of crushing of various rocks [11-13]. When choosing a microaggregate, such characteristics as stable grain composition, low content or absence of harmful impurities, close to the spherical shape of the particles, low water consumption and resistance to aggressive environments usually play an important role. Silverbond quartz flour produced by LLC Sibelco Rus is characterized by the abovementioned parameters, which makes it possible to



successfully use it in the design of a SCC with the required classes of workability, segregation resistance, strength, and marks on water impermeability and frost resistance.

In order to improve the segregation resistance, physical and mechanical and operational characteristics of the SCC, various kinds of fiber (steel, polymer) can be introduced into their mixtures. This makes it possible to produce self-compacting concrete of ultra-high-performance with improved strength, frost resistance, water impermeability, resistance to dynamic, temperature and humidity exposures, wear, etc., impact strength and elasticity, crack resistance, fracture toughness, fire resistance, which can exceed values of similar characteristics in traditional SCC in several times [14-16].

This article deals with the following:

- the effect of replacing part of portland cement with Silverbond quartz flour of various grades on the physical and mechanical and operational characteristics of the SCC;
- the effect of using two types of steel fiber in various dosages on technological, physical and mechanical and operational characteristics of the SCC when using the quartz flour.

2. Testing methods and materials employed

Grain composition of the microaggregates was determined by the method of laser diffractometry in accordance with ISO 13320-1:2009, the chemical composition – by energy dispersive spectroscopy in accordance with ASTM E 1508-12a.

The experimental compositions of the SCC were selected taking into account the recommendations of the Experts for Specialized Construction and concrete Systems [17] and in accordance with the methodology of Professor Okamura [18-19].

The mobility of the cone flow and the segregation of concrete mixtures were determined according to GOST 10181 (EN 12350), compressive strength and tensile strength at bending of hardened concrete – according to GOST 10180 (EN 12390), frost resistance grade – according to GOST 10060 (the third method, accelerated) (EN 12390-9), grade for water impermeability – according to GOST 12730.5 (accelerated method).

The following materials were used for the experimental study:

- portland cement CEM II / A-Sh 42,5N according to GOST 31108 produced by JSC "Holsim (Rus) SM";
- natural pit sand of fraction 0-5 mm (coarse sand of grade II according to GOST 8735);
- stones with fraction 5-20 mm in accordance with GOST 26633 and GOST 8267;
- quartz flour Silverbond of grade 15 and Silverbond of grade 20 produced by LLC "Sibelko Rus" (chemical and grain compositions are given in Tables 1-2 and in Figures 1-2);
- plasticizing additive on the basis of polycarboxylate ether GLENIUM®115 produced by BASF;
- steel fiber, L = 50 mm, D = 0,8 mm (hereinafter referred to as F1);
- steel fiber, L = 15 mm, D = 0.3 mm (hereinafter referred to as F2);
- water according to GOST 23732.

Table 1. Chemical composition of Silverbond quartz flour of grades 15 and 20

Oxide	Content, %	
	Silverbond 15	Silverbond 20
SiO ₂	99.85	99.75
Al ₂ O ₃	0.13	0.23
TiO ₂	0.01	0.01
Fe ₂ O ₃	0.01	0.01

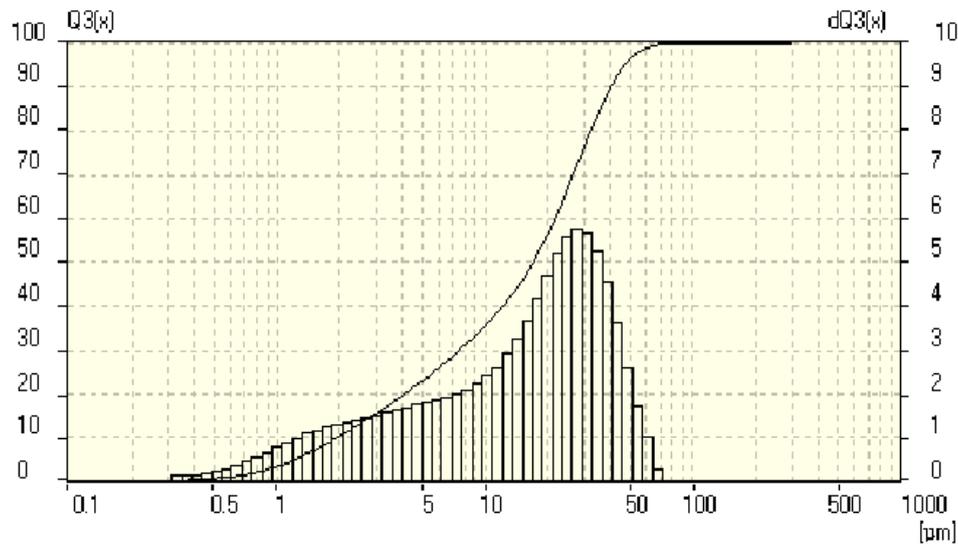


Figure 1. Grain composition of Silverbond quartz flour of grade 15

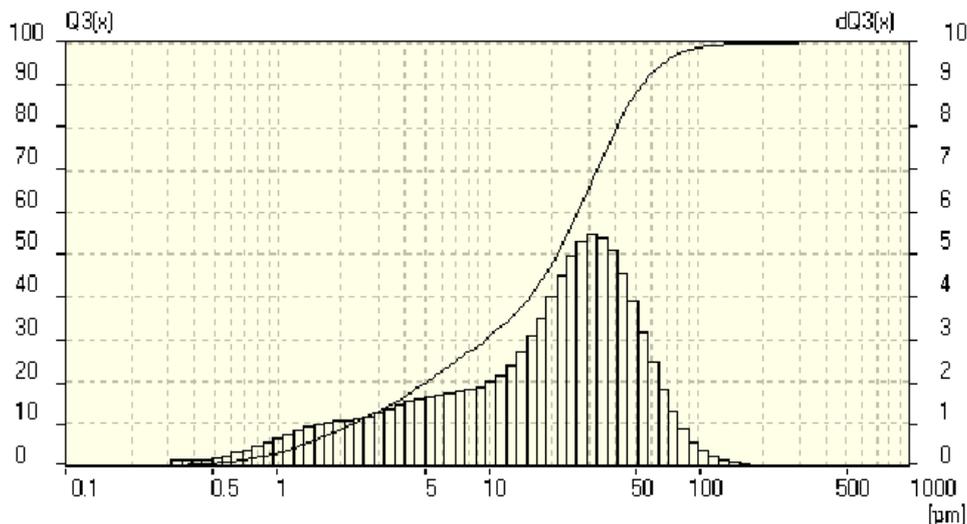


Figure 2. Grain composition of Silverbond quartz flour of grade 20

Table 2. Granulometric characteristics of Silverbond quartz flour of grades 15 and 20

Microaggregate	Average particle size, D50, microns	D99 (size which does not exceed 99% of the particles), microns
Quartz flour Silverbond 15	17	59
Quartz flour Silverbond 20	21	96

3. Research findings

At the first stage of the study, the effect of replacing part of portland cement in the SCC composition with Silverbond quartz flour of grades 15 and 20 was studied. The initial dosage of quartz flour was 100 kg/m³ and increased to 135 and 165 kg/m³ (with a decrease in portland cement consumption by 40 and 100 kg/m³, respectively). At the same time, the content of the plasticizing additive and the consumption of the mixing water were constant.

The experimental compositions are given in Table 3. The technological characteristics of concrete mixtures obtained using one grade of quartz flour, taken in different dosages, were comparable. When

using Silverbond 15, the mobility of cone flow of the SCC is 640 ... 650 mm (class of workability SF1), segregation – 10.0 ... 10.4% (class of segregation resistance SR2); when Silverbond 20 was used, the mobility of cone flow was 670 ... 680 mm (class of workability SF2), segregation – 14.4 ... 14.9% (class of segregation resistance SR2).

Table 3. Experimental compositions of SCC with Silverbond quartz flour of grades 15 and 20

Component	Consumption per 1 m ³ of concrete					
	SB15 (100 kg/m ³)	SB15 (135 kg/m ³)	SB15 (165 kg/m ³)	SB20 (100 kg/m ³)	SB20 (135 kg/m ³)	SB20 (165 kg/m ³)
Portland cement, kg	420	380	320	420	380	320
Sand fr. 0-5 mm, kg	740	740	740	750	750	750
Stones fr. 5-20 mm, kg	860	860	860	960	960	960
Quartz flour Silverbond 15, kg	100	135	165	-	-	-
Quartz flour Silverbond 20, kg	-	-	-	100	135	165
Plasticizing additive, l	6	6	6	6	6	6
Water, l	180	180	180	180	180	180

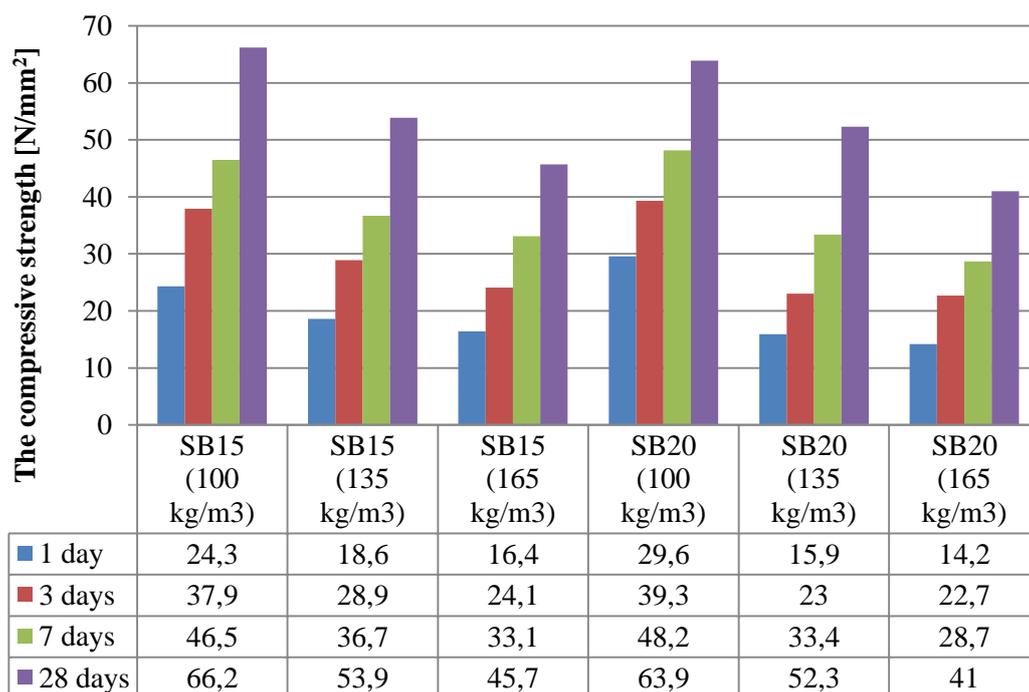


Figure 3. The effect of the replacement of portland cement with quartz flour in the composition of the SCC on their compressive strength at various times of hardening

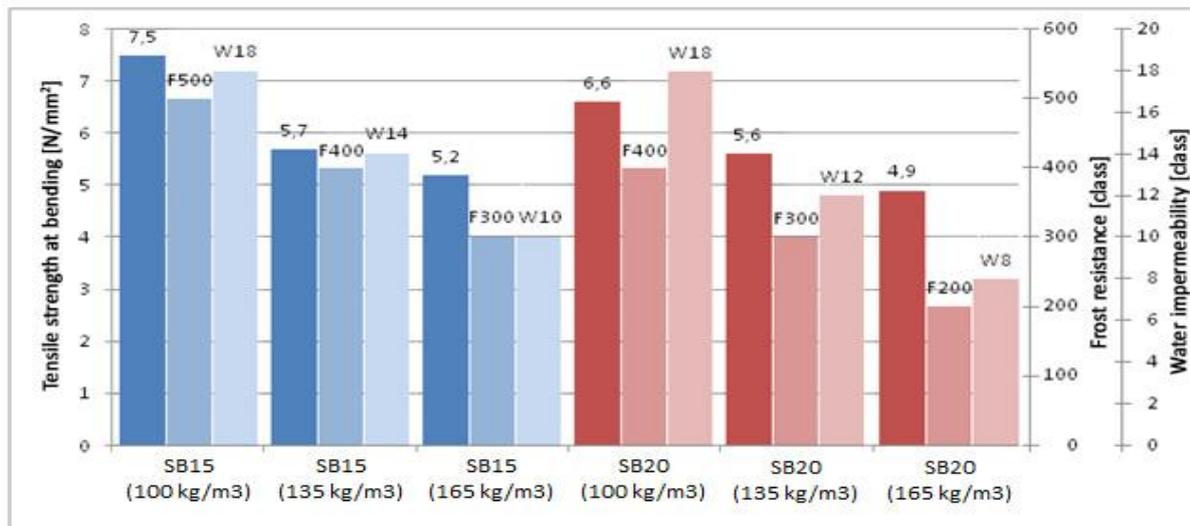


Figure 4. The effect of the replacement of portland cement with quartz flour in the composition of the SCC on their tensile strength at bending, frost resistance and water impermeability resistance

According to the results of the study (Figures 3-4), it was found that with an increase in the degree of substitution of the portland cement with quartz flour in the compositions of the SCC, their compressive strength after 1, 3, 7 and 28 days significantly decreases, especially in the early stages of hardening, as well as the tensile strength at bending, frost resistance and water impermeability.

The experimental compositions of the SCC were characterized by the following physical and mechanical and operational characteristics: the compressive strength class B30 ... B50 (compressive strength 41.0 ... 66.2 N/mm²), the tensile strength at bending class Btb3.6 ... Btb5.6 (ultimate tensile strength at bending 4.9 ... 7.5 N/mm²), frost resistance grade F200 ... F500, water impermeability grade W8 ... W18. Therefore, by varying the degree of substitution of portland cement with quartz flour, it is possible to design the SCC compositions with the required combination of technological, physical and mechanical and operational characteristics.

At the second stage of the study, the influence of two types of steel fiber (F1: L = 50 mm, D = 0.8 mm and F2: L = 15 mm, D = 0.3 mm), taken at dosages of 39, 78 and 117 kg/m³, for technological, physical and mechanical and operational characteristics of the SCC with the use of Silverbond quartz flour 20. The consumption of portland cement, quartz flour, plasticizing additive and mixing water was the same in all experimental compositions (Table 4).

Table 4. Experimental compositions of SCC with quartz flour Silverbond 20 and steel fiber

Component	Consumption per 1 m ³ of concrete						
	Control compositions	F1 (39 kg/m ³)	F1 (78 kg/m ³)	F1 (117 kg/m ³)	F2 (39 kg/m ³)	F2 (78 kg/m ³)	F2 (117 kg/m ³)
Portland cement, kg	400	400	400	400	400	400	400
Sand, kg	760	755	750	740	755	750	740
Stones, kg	820	810	805	800	810	805	800
Silverbond 20, kg	150	150	150	150	150	150	150
Steel fiber F1, kg	-	39	78	117	-	-	-
Steel fiber F2, kg	-	-	-	-	39	78	117
Plasticizing additive, l	7	7	7	7	7	7	7
Water, l	180	180	180	180	180	180	180

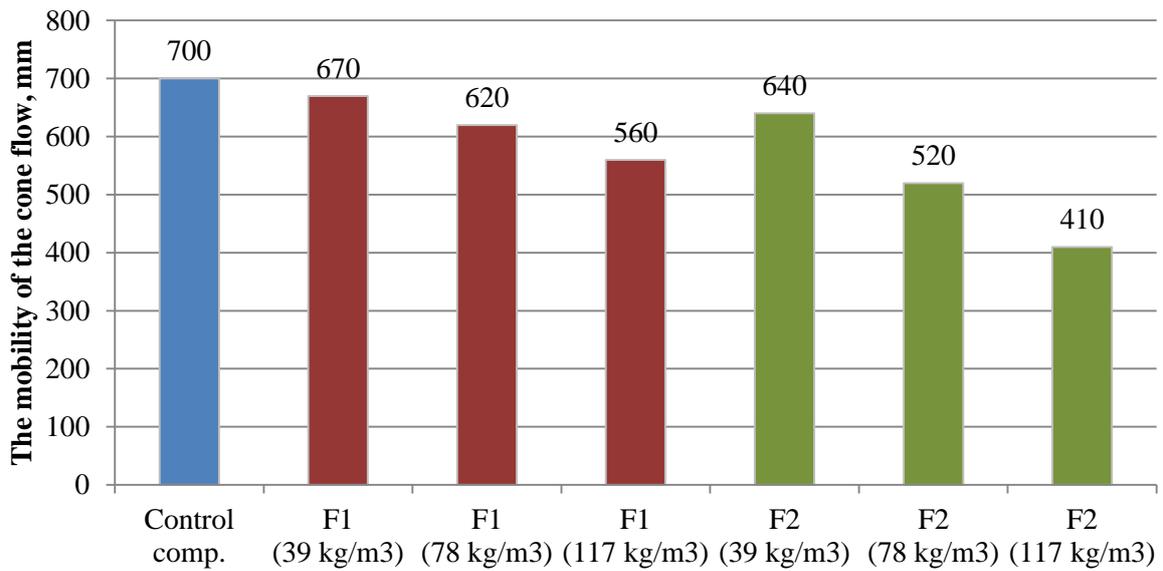


Figure 5. Effect of steel fiber on the mobility of the SCC with the use of quartz flour

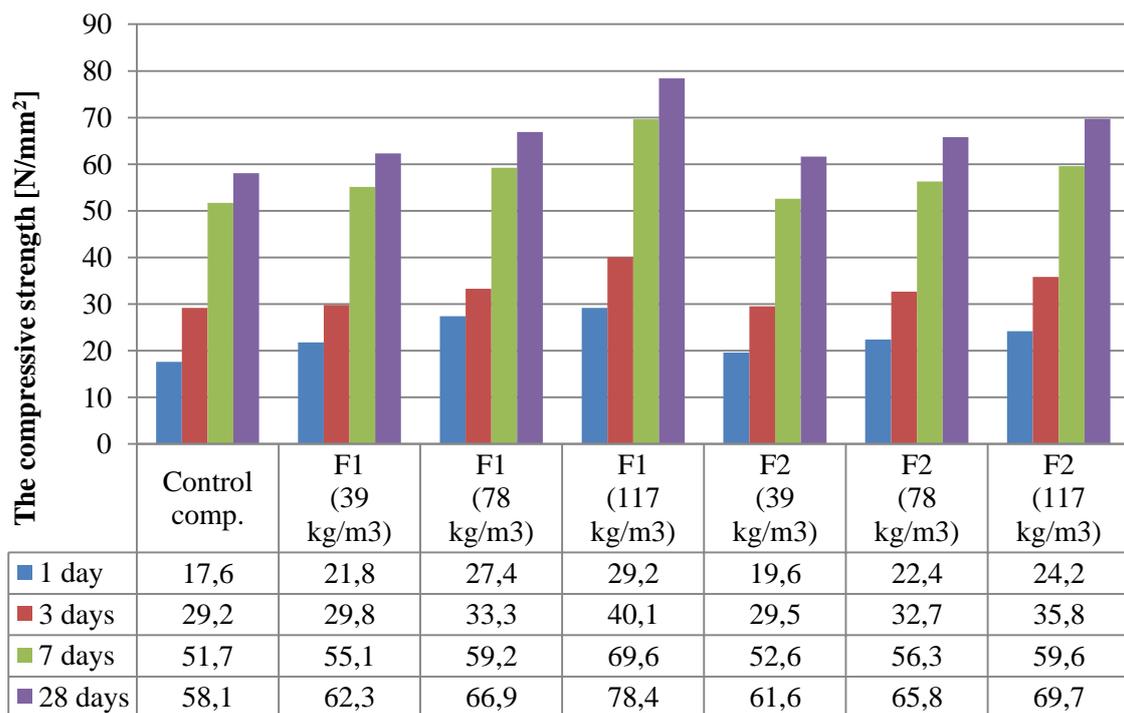


Figure 6. Effect of steel fiber on the compressive strength of the SCC with the use of quartz flour

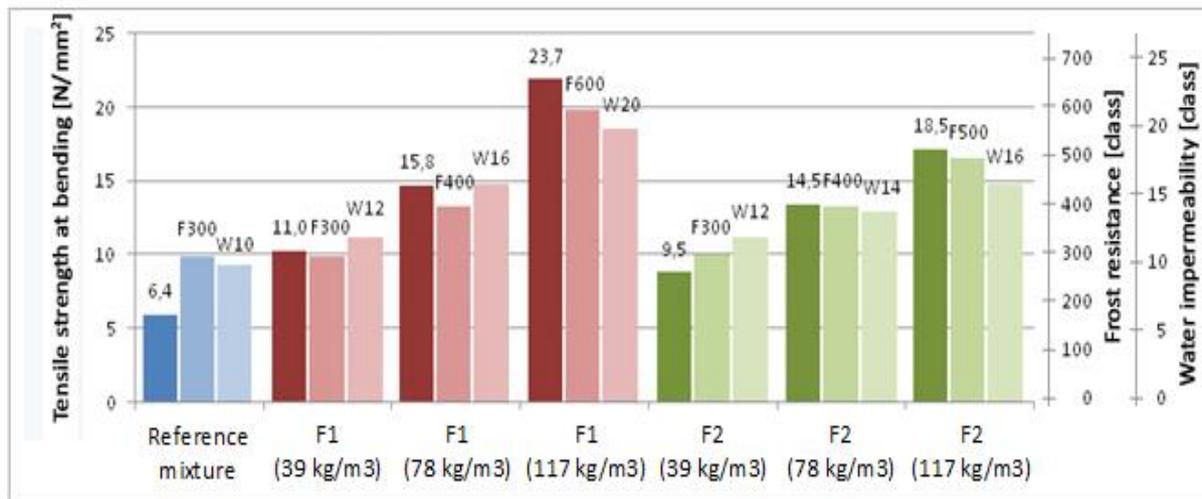


Figure 7. The effect of steel fiber on the tensile strength at bending, frost resistance and water impermeability of the SCC with the use of quartz flour

According to the results of the study, it was found that the introduction of steel fiber into the SCC with quartz flour Silverbond 20 leads to a decrease in the mobility of the cone flow with the increase in the dosage of the fiber. Furthermore, the use of a fiber of smaller length and diameter (F2) provides a more significant decrease in mobility: the cone flow decreases by 9 ... 41%, while the doses of fiber 78 and 117 kg/m³ are not favourable in obtaining concrete mixtures with satisfactory workability. The introduction of steel fiber F1 resulted in a decrease in mobility by 4 ... 20%, at a dosage of 30 kg/m³, the workability grade of the SCC did not change in comparison with the control composition and was SF1, at dosages of 78 and 117 kg/m³ – it decreased to SF1. It should be noted that the mobility of the SCC can be corrected by increasing the dosage of the plasticizing additive. All the experimental compositions studied were characterized by the absence of segregation of the concrete mixture.

The compressive strength of the experimental compositions of the SCC with quartz flour Silverbond 20 was increased with the introduction of steel fiber with an increase in its dosage, with the most significant increase recorded during the 1 day. With the introduction of steel fiber of both types at a dosage of 39 kg/m³, the compression strength class of the SCC did not change in comparison with the control composition and was equal to B45, at a dosage of 78 kg/m³ it increased to B50, in a dosage of 117 kg/m³ – to B55 and B50 with the use of fibers F1 and F2, respectively.

It turned out that the most significant effect of the introduction of steel fiber in the SCC was on the value of the ultimate tensile strength in bending. The compression strength class of the control composition of the SCC was Btb4.8, whereas the SCC with steel fiber was characterized by classes upper than Btb8 (tensile strength at bending was 11.0 ... 23.7 N/mm² with the use of steel fiber F1 and 9.5 ... 18.5 N/mm² with the use of steel fiber F2 in dosages from 39 to 117 kg/m³).

The frost resistance and water impermeability of the SCC also increased with the raise in the dosage of steel fiber, at a dosage of 39 kg/m³ the efficiency of both of its types was the same, and at a dosage of 78 and 117 kg/m³ the steel fiber F1 was more effective than F2. Compositions of the SCC with a frost resistance grade F300 ... F600 and a water impermeability grade W10 ... W20 were obtained.

4. Conclusion

The use of Silverbond quartz flour of grades 15 and 20 allows to design the SCC mixtures with different physical and mechanical and operational characteristics at given technological parameters. Thus, in this work, experimental mixtures of SCC for the workability classes SF1 and SF2, for the segregation resistance SR2, for the compressive strength B30 ... B50, for tensile strength in bending Btb3.6 ... Btb5.6, with marks on frost resistance F200 ... F500 and water impermeability W8 ... W18.

The characteristics of the SCCs with the use of quartz flour can be further improved by introducing steel fiber into their mixtures. This study showed the possibility of improving the class of compressive strength from B45 to B55, the tensile strength at bending from 6.4 N/mm² to 23.7 N/mm², grade for frost resistance from F300 ... F600 and the grade for water impermeability from W10 to W20.

Thus, the possibility of successful use of Silverbond quartz flour of grades 15 and 20 for the development of SCC mixtures with specified characteristics has been experimentally confirmed.

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