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Technological Properties of Self-Compacting Concrete Mixtures with Ground Quartz Sand

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Abstract*: *Quantitative parameters of influence of grain composition of ground quartz sand and its quantity on the workability and segregation of self-compacting fresh concrete were determined at the constant amount of mixing water and water-cement ratio. Ground quartz sand in the amount of 50-150 kg/m^3 was added instead of fine and coarse aggregates with changing the amount of polycarboxylate superplasticizer. It is stated that the use of ground quartz sand of finer grinding provides higher values of workability at the same quantity of water and superplasticizer. Segregation of the fresh concrete occurs when using increased amount of ground quartz sand of coarser grinding and increased amount of superplasticizer. Experimental studies have shown the effectiveness of the use of ground quartz sand to obtain self-compacting fresh concrete of different classes of workability SF1 and SF2 as well as classes of segregation resistance SR1 and SR2. The results of the experiments allow to state that the use of ground quartz sand of coarser grinding leads to segregation of fresh concrete at its low workability, while the use of ground quartz sand of finer grinding allows to obtain fresh concrete with resistance to segregation.

Keywords*: *self-compacting concrete, ground quartz sand, workability, mineral additives, segregation, superplasticizer, granulometric composition.

I. INTRODUCTION

In recent decades the self-compacting concretes have been in demand in transport and underground construction [1-4]. They are characterized by the ability to spread and condense under their own weight and fill the formwork with thick reinforcement, channels and other places where it is difficult to use traditional compaction with vibration [5,6]. The main requirements for the technological properties of self-compacting concrete mixtures: high workability, lack of segregation to ensure the homogeneity of the hardened concrete, the stability of technological properties during transportation or changes of quantity and properties of the initial components [7-9].

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Self-compacting concrete can be produced with different strengths by changing the water quantity as well as the ratio between the quantity of Portland cement and mineral additives. However, the possibility of combining high spreadability in the absence of segregation with a rapid set of strength, with increased water resistance and frost resistance as well as resistance to aggressive environments is a distinctive feature of self-compacting concrete (SCC). These properties are achieved by careful selection of the granulometric composition of the mixture, the high quantity of the powdered component and the use of highly effective superplastizer [10,11].

The first approaches to the design of SCC compositions mainly focused on the selection of the water-binder ratio of cement paste and the amount of superplasticizer to achieve the required performance of technological properties. With the development of the SCC direction the researchers are paying more attention to the design of the grain size distribution of mixtures taking into account both the grain shape and the grain size distribution of fine and coarse aggregates as well as the particle size distribution of cement and mineral additives.

The use of mineral additives reduces the Portland cement consumption provides the required viscosity of the mixture and also allows to increase the durability of concrete [12-14]. Powders based on dolomite and limestone, rock crushing waste, quartz flour, etc. can be used as a mineral additive [15]. At the same time the high requirements for the particle size distribution should be imposed on the mineral additive since its small changes can have a significant impact on the rheology of the SCC [2,16]. Requirements for the absence of harmful impurities in aggregates and mineral additives, especially clays, which often require a significant amount overruns of the superplasticizer, should also be taken into account [17,18]. A feature of the selection of self-compacting concrete composition is the presence of mineral additives, superplasticizer, optimal grain composition of fine and coarse aggregates [19,20]. High workability of mixtures is provided by the presence of superplasticizer as well as by the presence of rheologically active mineral additives [2,13,19,21]. In paper [13] the classification of mineral additives on rheologically active and rheologically inert mineral additives are developed that consider the most commonly used mineral additive in Portland cement systems: granulated blast furnace slag, fly ash, ground rocks, metakaolin, silica fume etc.

In papers [2,13,19,21] it is shown that a significant increase of workability of cement pastes containing mineral additive and superplasticizer occurs in comparison with cement pastes with the same water quantity and superplasticizer but on the basis of pure Portland cement. Such mineral additives as ground limestone, ground quartz sand, ground granite with a certain fineness of grinding can be attributed to rheologically active mineral additives [13]. Fineness of grinding and quantity of mineral additives are the main characteristics that cause the increase of workability of plasticized mixtures [13]. The influence of the optimal grain composition of fine and coarse aggregates on the increase of workability and ensuring the segregation resistance of the mixtures is shown in papers [22-24].

To avoid false setting of cement systems containing superplasticizer it is necessary to pay attention to the choice of Portland cement with the appropriate chemical-mineralogical composition. Reduction of plasticizing or water-reducing ability of superplasticizers was noted in Portland cement with the high content of C_3A and R_2O [25-27].

Ground quartz sand is characterized by low water demand and high resistance to aggressive environments, so it can be one of the promising mineral additives for SCC in transport and underground construction. It can be assumed that the fineness of grinding of quartz sand and its consumption will have a significant impact on the workability and segregation of SCC at the constant quantity of mixing water and superplasticizer since the grinding of quartz sand contributes to the formation of electro-acceptor centres on the surface of particles. This has been experimentally verified in this study.

Crystal lattice of SiO_2 quartz has three-dimensional structure, which is heterogeneous in geometric, chemical and electronic sense. It is the basis of the grains of quartz sand. Geometric heterogeneity is caused by the appearance of different faces of the quartz crystal with different adsorption and chemical activity as well as the presence on the surface of macrodefects, mainly cracks. Negatively charged active centres on the surface of ground quartz sand particles usually prevail [28,29]. The synergistic effect in the form of increase of the plasticizing ability of superplasticizer is observed when adding a superplasticizer based on polycarboxylate esters into a fresh concrete with ground quartz sand [2, 28, 29].

The positive effect of ground quartz sand on the properties of fresh and hardened concrete is well known. Ground quartz sand is used to produce high-performance concrete [2,30,31]. The presence of ground quartz sand makes it possible to obtain workable mixtures at low water dmand with a uniform distribution of micro- or microfibers [32-34]. Ground quartz sand with grain composition of 0.01-0.1 mm is used in the compositions of modern types of high-strength strain-hardening cement-based composites, the feature of which is very low water demand and high amount of micro-fibers [33,34]. Increasing the early strength of concrete with fine-grained quartz sand of dispersion of 1-4 μm in the amount of 5-10% of Portland cement mass is stated in papers [29,35]. The possibility of reducing the dosage of polycarboxylate superplasticizer with the addition of ground quartz sand with the particle size up to 4μm in the amount of 5-10% of Portland cement mass in equally workable fresh concrete is shown in papers [2,19]. Thus, the technological properties of fresh concrete and the properties of hardened concrete can be changed using ground quartz sand of different fineness of grinding.

The problem of the influence of granulometric composition of ground quartz sand on the technological properties of self-compacting concrete requires additional research. The purpose of the study is to determine the quantitative parameters of the influence of granulometric composition of ground quartz sand and its quantity on the spreadability and segregation of self-compacting concrete mixtures at the constant quantity of mixing water and superplasticizer. Ground quartz sand in this study was added instead of aggregates.

II. MATERIALS AND METHODS OF RESEARCH

The granulometric composition of ground quartz sand was studed by laser diffractometry using laser microanalyzer of particle sizes "Analysette 22" in accordance with ISO 13320-1:2009 "Particle size analysis — laser diffraction methods". The slump flow and segregetion of fresh concrete were measured in accordance with EN 12350 "Testing fresh concrete" and Guidelines [8].

The following materials were used for experimental research:

- Portland cement CEM I 42.5;
- natural quarry sand fractions 0-5 mm;
- crushed stone of fraction 5-20 mm;
- two types of ground quartz sand of Luga Deposit with SiO_2 more than 95%, characterized by fineness of grinding D_{50}= 16μm and D_{50}= 31μm (particles smaller than 16μm and 31μm are contained in the amount of 50%, respectively);
- microsilica with specific surface S_{sp}=41400 cm^2/g;
- superplasticizer additive based on polycarboxylate ether named Stachement 2000;
- mixing water – tap drinking water.

Granulometric composition of ground quartz sand is presented in Table 1.

Table 1. The particle size distributions of ground quartz

Designation of ground quartz	The quantity of particles with size less then, %								
	1 μm	5 μm	10 μm	16 μm	31 μm	50 μm	80 μm	100 μm	125 μm
Q16	0.9	8.3	26.2	50	64.3	72.1	96.4	100	100
Q31	0.7	6.9	14.9	23.5	50	63.7	78.3	97.8	100

Granulometric compositions of fine and coarse aggregate are presented in Table 2.

Experimental compositions of SCC were selected to study the influence of the fineness of ground quartz sand and its amount on the flow characteristics at the constant quantity of mixing water and superplasticizer. The compositions were selected taking into account the recommendations [8]. Ground quartz sand was added into the concrete mix in the amount of 50, 100 and 150 kg/m^3. Consumption of superplasticizer was 1%; 1.2% and 1.4% of Portland cement mass. Superplasticizer was added in liquid form with mixing water.

Water consumption for all concrete mixtures was 190 kg/m^3. The water quantity was recalculated taking into account the water in superplasticizer.

Table 2. Granulometric compositions of fine and coarse aggregate

Sieve's aperture size, mm	Sieve residue, %	
	Sand	Crushed stone
0,160	22,9	—
0,315	31,1	—
0,630	24,3	—
1,25	11,3	3,9
2,5	10,4	4,5
5	—	39,3
10	—	51,5
20	—	0,8
40	—	0

The presence of segregation in experimental concrete mixtures was first stated visually. In the absence of visible signs the segregation of mixtures was determined by Guidelines [8].

III. RESEARCH RESULTS AND DISCUSSION

When designing the SCC composition special attention is paid to the selection of granulometric composition of aggregates. In this case the use of increased consumption of the powdered component is a prerequisite. The use of mineral powder components provides the reduction of segregation and water separation of SCC.

The results of the study are given in Tables 3 and 4. Influence of amount of ground quartz and superplasticizer on slump flow of SCC is given in Figures 1 and 2.

Table 3. Compositions and technological characteristics of SCC with ground quartz sand Q16

Component, kg	Quantity per 1 m^3 of concrete								
CEM I 42.5	400	400	400	400	400	400	400	400	400
Microsilika	40	40	40	40	40	40	40	40	40
Sand	740	740	740	720	720	720	690	600	690
Coarse aggregate	920	920	920	890	890	890	870	870	870
Q16	50	50	50	100	100	100	150	150	150
SP	4	4.8	5.6	4	4.8	5.6	4	4.8	5.6
Water	190	190	190	190	190	190	190	190	190
Technological characteristics									
Slump flow, mm	570	580	590	580	610	640	580	640	690
Segregation (visually)	no	no	yes	no	no	yes	no	no	no
Segregation, %	12.1	14.3	-	10.2	11.3	-	9.6	9.9	10.7

According to the obtained data the concrete mixtures with ground quartz sand Q31 were characterized either by a low spreadability value and could not be classified as self-compacting or a significant segregation was observed at achieving the satisfactory spreadability. It is important to note that the increase of superplasticizer amount causes a sharper increase of the spreadability of the fresh concrete with quartz flour of coarser grinding. However, the large diameter of the slump flow was due to the strong segregation of the mixture and the water separation.

Table 4. Compositions and technological characteristics of SCC with ground quartz sand Q31

Component, kg	Quantity per 1 m^3 of concrete								
CEM I 42.5	400	400	400	400	400	400	400	400	400
Microsilika	40	40	40	40	40	40	40	40	40
Sand	740	740	740	720	720	720	690	600	690
Coarse aggregate	920	920	920	890	890	890	870	870	870
Q31	50	50	50	100	100	100	150	150	150
SP	4	4.8	5.6	4	4.8	5.6	4	4.8	5.6
Water	190	190	190	190	190	190	190	190	190
Technological characteristics									
Slump flow, mm	560	580	600	540	570	610	520	560	630
Segregation (visually)	no	yes	yes	no	no	yes	no	no	yes
Segregation, %	14.5	-	-	12.4	12.7	-	11.6	12.4	-

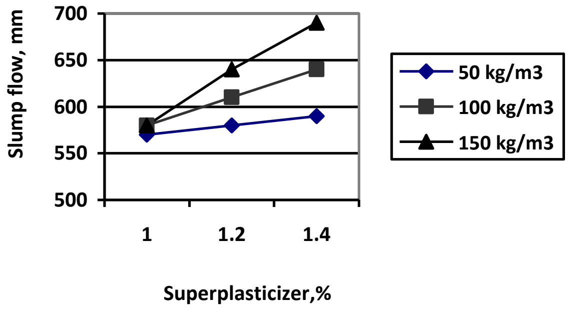

Figure 1. Influence of amount of ground quartz Q16 and superplasticizer on slump flow of SCC

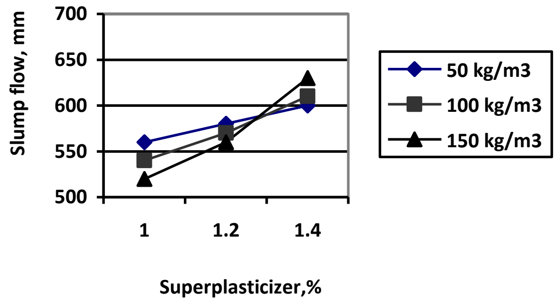

Figure 2. Influence of amount of ground quartz Q31 and superplasticizer on slump flow of SCC

Self-compacting concrete with slump flow of more than 550 mm were obtained by using ground quartz sand Q16 at all studied amounts of ground sand 50-150 kg/m^3 and superplasticizer 1-1.4%. However, the segregation of mixtures was observed at the high dosage of superplasticizer equal to 1.4% and the lower amount of ground quartz sand of 50-100 kg/m3. It was shown that SCC of SF1 (550-650 mm) workability class can be obtained by changing the quantity of ground quartz sand and superplasticizer in the studied ranges. An additional change of the ratio of the components is required to obtain the SCC of SF2 and SF3 workability classes. It can be noted that the use of quartz flour of finer grinding provides higher values of workability in case of the same amount of superplasticizer and mixing water.

This proves the results on the increase of the plasticizing ability of the superplasticizer in mixtures with fine-grained quartz sand obtained by other authors [1,2,13,28,29].

As it can be seen from the grain composition of Table 1 and the test results of concrete mixtures, even a slight change in the composition of the fine fraction of less 0.01 mm can lead to significant changes in the technological properties of SCC. The results obtained are consistent with the data on the influence of grain composition of mineral additives and aggregates on the rheological properties of mixtures [36-42]. This can be used for the development of construction technologies [43-48].

It is stated that the increase of quantity of ground quartz sand reduces the segregation of SCC. This may be due to the optimization of the grain composition of the mixture, and as a consequence, due to the decrease of the proportion of free water. It can be assumed that an additional framework in fresh concrete structure is created by using quartz flour. This helps to reduce the segregation of fresh concrete. In the study the class of segregation resistance of SCC was increased from SR1 to SR2 with the increase of Q16 ground quartz sand.

IV. CONCLUSION

Experimental studies have shown the effectiveness of the use of ground quartz sand to obtain self-compacting concrete of SF1 workability class and SR2 segregation resistance class provided the correct selection of quartz flour quantity and fineness. The main trends of the influence of amount and fineness of quartz flour as well as the superplasticizer amount on the technological properties of SCC were revealed in the study.

Quantitative parameters of influence of grain composition of ground quartz sand and its amount on spreadability and segregation of self-compacting fresh concrete were determined at the constant quantity of mixing water. Ground quartz sand in the amount of 50-150 kg/m^3 was added instead of fine and coarse aggregates at changing the polycarboxylate superplasticizer dosage. It is stated that the use of ground quartz sand of finer grinding provides higher values of SCC workability at same quantity of water and superplasticizer.

Experimental studies have shown the effectiveness of the use of ground quartz sand to obtain self-compacting fresh concrete of different classes of workability SF1 and SF2 as well as classes of segregation resistance SR1 and SR2. The results of the experiments allow to state that the use of ground quartz sand of coarser grinding leads to segregation of fresh concrete at its low workability, while the use of ground quartz sand of finer grinding allows to obtain fresh concrete with resistance to segregation.

It is stated that the use of ground quartz sand with the particle size less than 31 μm in the amount of 50% of the mineral additive mass leads to insufficient optimization of the granulometric composition of SCC and, as a consequence, the segregation of fresh concrete. A thinner fraction of D_{50} = 16 μm of ground quartz sand allows to obtain SSC that is resistant to segregation.

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