

SELF-COMPACTING CONCRETE WITH INDUSTRIAL BY-PRODUCTS

Aleksandar Savić

Assistant professor, University of Belgrade, Faculty of Civil Engineering, Belgrade, Serbia, Bulevar kralja Aleksandra 73, e-mail: savic.alexandar@gmail.com

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ABSTRACT:

The use of industrial by-products, such as fly ash and recycled concrete, in building industry presents one of the ways to improve the effect of this branch of industry on environment. Experimental investigation shown in this paper had two directions. First direction was focused on investigation of the effect of using different quantities of cement and limestone powder as mineral filler in Self-Compacting Concrete – SCC. The second direction of investigation regarded the effect of the partial mass replacement of limestone filler with fly ash from thermal power plant "Kostolac" in two series, as well as with the ground recycled concrete in one series. The basic design requirement was to obtain the mixtures with good properties in fresh and hardened state. Relevant fresh SCC tests included slump flow, time t_{500} , and density. Hardened concrete tests included change of density with time and compressive strength, up to the age of 28 days. All of the investigated series showed satisfactory properties in fresh state and high values of compressive strength.

1. INTRODUCTION

An ongoing development of building industry is evident worldwide, especially regarding construction of concrete structures. This activity, consequently, stimulates the production of cementitious composites (concrete, mortar, etc.). Increase in the concrete production and wide range of its applications represent motive for innovations in concrete technology regarding: component materials, production technology, achievement of the aimed properties in fresh and hardened state, etc.

Often the mentioned innovations incorporate edge technologies, such as nanotechnologies (for instance for the production of chemical admixtures) or computer design and computerized systems (e.g. for concrete production). With the development of chemical admixtures, namely plasticizers, superplasticizers, easier placing of concrete with lower water/cement ratio was enabled [1]. Using small quantities of superplasticizer (mostly up to 2% in relation to the mass of cement in concrete) a structure of fresh concrete is optimized, so the friction of the particles is reduced, giving as a result more fluid and more workable concrete (fluid consistency concrete), which is easier to cast. Development of the last generation of superplasticizers, based on polycarboxylates, that entered the wider application during the 90-s of the last century, enabled the successful application of Self-Compacting Concrete – SCC. This concrete is referred as Self-Consolidating Concrete, and Self-Leveling Concrete. SCC can be defined as concrete that is able to, without any means of mechanical compaction (and completely independent of the engaged worker competences), fill all the formwork

parts and narrow spaces between the bars of the densely arranged reinforcement bars (as the result of its own weight), ultimately producing compact concrete of higher durability [2].

Nowadays, environmental public awareness and appropriate modern legislation draw changes based on sustainable development principles. These changes are regarded as necessary and are being implemented in all industries, even in civil engineering industry, which is traditionally resistant to any kind of changes. In the SCC production engineering, this means for instance valorizing usage of industrial by-products, such as fly ash and ground recycled concrete.

2. COMPONENT MATERIALS AND SERIES

2.1. Component materials

Natural river aggregate was used in the presented research, separated into three standard fractions, originated from the river Danube. Particle size distribution of the used aggregate was investigated according to [3] and shown in Table 1, together with the particle size distribution curve of the mixture of aggregate. Fineness content in aggregate was investigated according to the related standard [4] and for fraction I (0/4) it amounted to 0.59% for the grains finer than 0.063 mm, and 1.68% for the grains finer than 0.09 mm. In the coarse aggregate (grains coarser than 4 mm) this content was close to zero. Density of the used aggregate amounted to the average of 1560 kg/m³, and specific density was 2640 kg/m³.

Table 1: Particle size distribution of the used fractions of aggregate and mixture of aggregate (%)

Sieve diameter (mm)	0.125	0.25	0.5	1.0	2.0	4.0	8.0	16.0
I (0/4)	2.1	9.9	46.2	68.9	82.7	98.0	100	100
II (4/8)	0	0	0	0	0	1.8	94.2	100
III (8/16)	0	0	0	0	0	0	0.9	100
Mixture	1	5	32	39	45	58	77	100

Cement type CEM I (without mineral additions) declared as PC 42,5R, and produced by Lafarge Beočin cement factory was used in this study. Specific area of cement, according to Blaine, amounted to 4240 cm²/g, and specific density to 3040 kg/m³. Potable water from the local water supply system was used for the production of concrete. Temperature of water remained in narrow limits between 19°C and 22°C. For all of the SCC series, shown in this paper, the same polycarboxilate based superplasticizer was used (specific density of 1060 kg/m³) - Glenium Sky 690, produced by BASF, Italy. The main mineral addition in all of the series was limestone powder produced by "Granit Pešćar" Ljig, with middle particle size of 250 µm. Specific density of this material amounted to 2720 kg/m³, and density was 1105 kg/m³. Fly ash, originated from thermal power plant "Kostolac" was used without any kind of mechanical or chemical activation. It was used in the original (untreated) state. Density of fly ash in loose and compacted state amounted to 690 kg/m³ and 910 kg/m³. Specific density of this pozzolanic material amounted to 2190 kg/m³. On the other hand, the ground recycled concrete in this case was obtained by fine grinding process of recycled fine aggregate, using special grinding device. The parent concrete in this case had controlled origin [5]. This ground filler had specific area of 4400 cm²/g.

2.2. SCC series

The idea of this research was focused in two directions. First direction was to investigate the effect of different quantities of cement and limestone powder as filler in Self-Compacting Concrete – SCC. The second direction of the research depicted in this paper was to study the possibilities of use of different industrial by-products as component materials for the production of SCC. This was done

regarding the use of fly ash (in the original state) or ground recycled concrete as mineral filler. The main aim was to provide the favorable properties of fresh SCC. The idea behind the investigation was to increase the range of available mineral additives for the concrete, and to promote the use of these by-products.

Based on the spread test [6], paste and mortar compositions were investigated, leading to the compositions of SCC series shown in Table 2. In all of the presented series, the quantity of aggregate was held constant, 830 kg/m^3 , with the same quantities of fractions: 840 kg/m^3 of the fine aggregate (0/4mm), and 430 kg/m^3 of fractions II (4/8mm) and III (8/16mm). Regarding quantities of cement, only two different quantities were used, 420 kg/m^3 for the first SCC series (series SC1) and 380 kg/m^3 for the other series (series SC2, SC3, SC4 and SC5). Also, two different quantities of mineral filler were used, 170 kg/m^3 for the first SCC series (series SC1) and 220 kg/m^3 for the other four series (series SC2, SC3, SC4 and SC5). Series SC1 and SC2 contained only limestone powder as mineral filler, while series SC3 and SC4 contained two different mass percentages of limestone powder replacement with fly ash (10% in the SC3 series and 20% in the SC4 series). Mass replacement of limestone powder with ground recycled concrete in series SC5 was 50%. Quantities of water ($179\text{-}187 \text{ kg/m}^3$) and superplasticizer ($4.95\text{-}11.4 \text{ kg/m}^3$) were different in these series, determined by the condition that concrete had to be SCC.

Table 2: Mix of SCC series

Component	SC1	SC2	SC3	SC4	SC5
Cement (kg/m^3)	420	380	380	380	380
Limestone powder (kg/m^3)	170	220	198	176	110
Fly ash (kg/m^3)	-	-	22	44	-
Recycled concrete (kg/m^3)	-	-	-	-	110
Water (kg/m^3)	187	179	185	179	183
Superplasticizer (kg/m^3)	4.95	7.60	7.60	7.60	11.40
Water/cement (w/c) ratio	0.445	0.470	0.487	0.470	0.482
Fluid/cement (f/c) ratio	0.457	0.490	0.507	0.490	0.512
Fluid/powder (f/p) ratio	0.325	0.310	0.321	0.310	0.324

3. EXPERIMENTAL INVESTIGATION

Experimental research shown in this paper was conducted in Laboratory for materials, Institute of Materials and Structures of Civil Engineering Faculty, University of Belgrade. Investigations made on fresh SCC series included following tests: fresh concrete density [7], slump flow and time t_{500} [8]. The results of these tests are shown in Figure 1 and Figure 2.

Values of fresh SCC density were in a narrow range, from 2372 kg/m^3 (for series SC5) up to 2401 kg/m^3 (for series SC1 and SC2). In the case of the series SC2 (without fly ash), SC3 (10% mass replacement of limestone powder with fly ash) and SC4 (20% mass replacement of limestone powder with fly ash), with the increase of fly ash, the densities of fresh SCC declined, despite the highest water content in the series SC3. With the highest dosage of superplasticizer, and the medium quantities of water, the series SC5 showed the lowest value of fresh SCC density.

Slump flow values in this investigation ranged from 620 mm (series SC1) to 860 mm (series SC5). Series SC2, SC3 and SC4 fell into class S2 by [9], while SC1 can be characterized as lower and SC5 higher slump flow class.

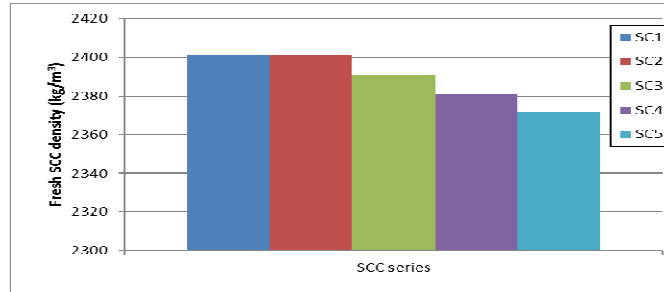
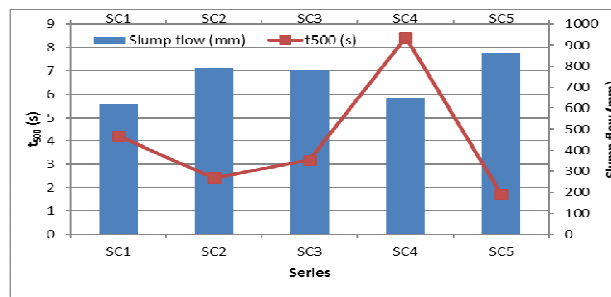


Figure 1: Fresh concrete density of the investigated SCC series

Generally, all the series were of high filling ability, on the basis of t_{500} measurement. Namely, times t_{500} ranged between 1.72 s (series SC5) and 8.43 s (series SC4). The lowest value of t_{500} in the SC5 could be attributed to the high superplasticizer content, regardless of the high ground recycled concrete (50% mass replacement of the limestone powder as a filler) content. Linear increase in the fly ash content through series SC2 (0% of fly ash), SC3 (10% of fly ash) and SC4 (20% of fly ash) resulted in the increase of time t_{500} . This increase (24%) of t_{500} was not so steep in the case of series SC3, due to the higher water content (than in SC2 and in SC4). In the case of series SC4, increase in time t_{500} amounted to 62% in comparison to SC3. This can be attributed to the lower water content and higher content of fly ash than in SC3. Based on the visual inspection (VSI, [10]), there were signs of segregation in the series SC3.

Figure 2: Slump flow and time t_{500} measured on the investigated series

Concrete density in hardened state [11] and compressive strength [12] were measured on three 10 cm cubes at the following ages: 7, 14, 21 and 28 days. Values of the hardened concrete density at the age of 28 days are shown on Fig. 3. As it can be seen from this figure, all series had similar densities at the age of 28 days, ranging between 2366 kg/m³ and 2388 kg/m³. The highest value of hardened SCC density was measured on the series SC1, which had the lowest water/cement ratio.



Figure 3: Hardened SCC density at 28 days

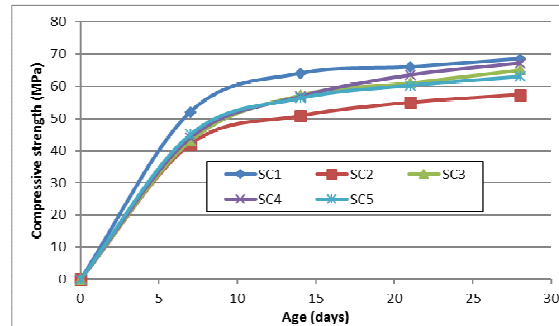


Figure 4: Compressive strength versus time for SCC mixes

Change of the compressive strength through time is presented on Fig. 4. Compressive strength of the investigated SCC series achieved up to 70% of the final value (value at 28 days) in first 7 days. The compressive strength of the concrete designated as SC1 was the highest at all ages, because this series had the lowest w/c factor. Accordingly, higher w/c in the series SC2 resulted with the lowest values of compressive strength at all ages. The values of the compressive strength for the series SC3, SC4 and SC5 were higher than in the case of the series SC2. For the series SC3 and SC4, this is due to the presence of the fly ash, which resulted in the 13.2% and 17.1% higher compressive strengths for the series SC3 and SC4, respectively, when compared to the compressive strength of the SCC series SC2, all at the age of 28 days. This effect can be explained by the pozzolanic reaction in the case of series SC3 and SC4, where fly ash was present. This also implies that the compressive strength will continue to increase in the case of these series, due to the nature of the pozzolanic reaction, and probably reach higher values of compressive strength than the compressive strengths of SCC series SC1. This is more obvious for the series SC4, with the double content of fly ash than in the SCC series SC3. In the case of series SC5, similar value of the compressive strength of this series was recorded (2% higher) as for the series SC2, at the same age.

4. CONCLUSION

In order to investigate the potential of domestic fly ash, from the thermal power plant "Kostolac", in the original (untreated) state (without activation), as well as to valorize the potential of ground recycled concrete as mineral filler, five different series of SCC were made. This plan of experiment was also influenced by the implementation of environmental aspect and sustainable development in civil engineering industry [13].

All of the series achieved good properties, regardless of the type and content of mineral addition used. For the same aggregate content and similar content of fine particles, SCC series with higher f/c (although lower f/p) had higher slump flow and lower t_{500} . The presence of fly ash reduced fresh SCC density, t_{500} and slump flow. The presence of fly ash as mineral filler had positive impact on compressive strength of the series, also, providing up to 17.1% higher strength at the age of 28 days, for the SCC series with 20% mass replacement of limestone powder with fly ash. It has to be stressed out that these improvements occurred without preparation of the input material, as the fly ash was used in original (untreated) state. This is important because it provides decrease in the expenses when fly ash is used, because no money, time or equipment have to be used as means of preparation of fly ash for SCC. In the hardened state, differences in density were not so obvious.

The presence of ground recycled concrete as filler showed no obstacles for the use of this material as filler in SCC, neither based on the investigations in fresh [14], nor in hardened state [15]. In terms of optimization, the content of superplasticizer can be reduced, leading to lower, but still acceptable

slump flow, and higher t_{500} . Use of ground recycled concrete did not have negative influence on compressive strength.

However, more research has to be done in order to completely assess the effects of fly ash and ground recycled concrete in SCC. In addition, many other properties of SCC should be studied, such as: flexural, split and tensile strength, modulus of elasticity, non-destructive testing etc. Also, the parameters of durability in different environments have to be experimentally obtained, in order to achieve a thorough insight in the possibility of wider application of the presented mineral fillers. This research is also aimed to encourage the use of industrial byproducts as mineral fillers for real production.

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REFERENCES

- [1] Jevtić, D.: *Monografija - Svojstva svežeg i očvrstlog betona u funkciji termohigrometrijskih parametara sredine*, Građevinski fakultet Univerziteta u Beogradu, Beograd, 1996,
- [2] Rixom, M. R.: *Development of an admixture to produce flowing or self-compacting concrete*, Precast concrete, Vol. 5, No. 11, 633-637, 1974,
- [3] SRPS EN 933-1:2013 Tests for geometrical properties of aggregates - Part 1: Determination of particle size distribution - Sieving method
- [4] SRPS B.B8.036:1982 Crushed aggregate - Determination of fine particles with the wet sieve analysis
- [5] Ignjatović I., Marinković S., Mišković Z., Savić A.: *Flexural behavior of reinforced recycled aggregate concrete beams under short-term loading*, *Materials and Structures*, 46(6), pp. 1045-1059, (2013)
- [6] Okamura H, Maekawa K, Ozawa K.: *High performance concrete*, Giho-do Press, Tokyo (1993)
- [7] SRPS 12350-6:2010 *Testing fresh concrete - Part 6: Density*
- [8] SRPS 12350-8:2012 *Testing fresh concrete - Part 8: Self-compacting concrete - Slump-flow test*
- [9] *European Guidelines for Self-Compacting Concrete: Specification, Production and Use*, European Project Group, 2005.
- [10] ASTM C1611 / C1611M – 14, *Standard Test Method for Slump Flow of Self-Consolidating Concrete*
- [11] SRPS EN 12390-7:2010 *Testing hardened concrete - Part 7: Density of hardened concrete*
- [12] SRPS EN 12390-3:2010 *Testing hardened concrete - Part 3: Compressive strength of test specimens*
- [13] Savić A., Jevtić D., Marinković S., Volkov-Husović T.: *Properties of Fresh and Hardened Self-Compacting Concrete with Mineral Addmixtures of Industrial Byproducts*, Conference Contemporary civil engineering practice 2017, Proceedings, pp. 145-172.
- [14] Savić A., Marinković S., Jevtić D., Zakić D., Aškračić M.: *Properties of Fresh Self-compacting Concrete with Recycled Concrete Filler*, Construction materials for sustainable future, 1st International Conference COMS 2017, Proceedings, pp. 229-236.
- [15] Savić, A.: *Investigation Of The Properties Of Fresh And Hardened Self-compacting Concrete With Mineral Additions Based On Industrial By-Products*, Doctoral thesis, University of Belgrade, Faculty of Civil Engineering, Beograd, Thesis supervisors: prof. dr Dragica Jevtić, prof. dr Tatjana Volkov Husović (2015)