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EFFECT OF AGGREGATE TYPE AND FLY ASH CONTENT ON PROPERTIES OF SELF-COMPACTING CONCRETE

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Abstract: The paper presents the results of experimental study of Self-Compacting Concrete in fresh and hardened state. Five mixtures were made, in which the content of the following components was varied: aggregates, fly-ash in as-delivered state and the total amount of the paste (a mixture of water, mineral additive and a binder). Fresh concrete tests included determining the following properties: bulk density, slump-flow, V-funnel time, height ratio of the L-box, as well as ambient temperature measurement. In the hardened state the tested properties included: hardened concrete density, compressive strength, flexural strength, ultrasonic pulse velocity and water penetration depth. Tests have shown that the increase in the content of the paste can improve the workability, as well as reduce the negative effect of the larger fly ash particles presence on the properties of the fresh concrete.

Keywords: concrete, physical, and mechanical properties, fly ash, aggregate.

1. INTRODUCTION

A significant environmental impact characterizes construction industry, and therefore a number of changes have to take place in order for it to become sustainable. Contemporary approach within these changes integrates three main parts: a critical revision of the process from the environmental aspect, followed by a thorough analysis in order to find modalities and grounds of the possible changes, and in the end, if it occurs possible and practical, modernization by implementing the philosophy of sustainable development. In this regard, all construction activities regarding a building, such as: planning, design, realization, and management, must be constantly under review, enabling more sustainable use of resources, promotion of energy efficiency and sustainability, with an emphasis on recyclable materials and minimizing waste [1]. In general, construction industry mainly leans on concrete, as one of irreplaceable materials in it's area of application. Of course, owing to the mentioned facts, concrete is today rapidly evolving.

Conventional concrete (so-called Normal Vibrated Concrete - NVC) is commonly being placed using vibrating equipment (immersion vibrators, towel vibrators, vibrating tables, external formwork vibrators) to provide reduction in entrained air content, eliminating the presence of caverns and providing adequate adhesion on the contact between concrete, reinforcement bars, and formwork. Already mentioned evolution of concrete incorporating the concept of superplasticizers use, in the direction of obtaining fluid concrete types, has led to the development of Self-Compacting Concrete (SCC) as well as to its application [2]. The development of new materials, the latest generation of superplasticizers based on polycarboxylate, that entered the wide use during the last decade of the 20th century, enabled the successful implementation of SCC. This is special kind of concrete that, without the use of mechanical means of placement (and independently of the competence of workers engaged), fills all the corners of the formwork, and the narrow spaces between the reinforcement bars (only under the influence of its own weight) so that, in the final stage, a compact concrete with higher durability is produced. Typically, in order to possess such properties, SCC contains certain quantities of very fine mineral additions; the most commonly applied are limestone powder, dolomite powder, and fly ash.

According to data from the period 1993-2008., generating combustion products of coal in the EU countries (EU 15) amounted to about 60 million tons per year. Fly ash makes up almost 68% of this amount (around 40 million tons per year). Based on data from 2008, approximately 45% of fly ash produced in EU is consumed in the construction and mining industry (18 million tons), app. 47% is spent to ensure open mine pits and quarries, app. 2% is disposed on the temporary locations, and nearly 6% is disposed of to landfills. The amount of fly ash used in concrete has increased from 2.3 million tons in 1993, up to 5.9 million tons in 2007 [3]. Thermal power plants in Serbia use lignite coal and generate roughly 6 million tons of fly ash, which is stored improperly (covering an area of approximately 1,800 ha). It is estimated that the landfills in Serbia hold over 200 million tons of ash from thermal power plants [4], [5], [6].

Due to the spherical shape, and the glassy surface of the majority of fly ash particles, the most of the studies have led to the conclusion that the addition of fly ash in an amount of 10%, relative to the weight of cement, reduces the need for water up to 3-4%. The previous statement incorporates the proviso that the particles of the used fly ash remain smaller than the cement particles, which tends to be satisfied in most cases. However, with a higher content of particles larger than 0.045 mm, an increase in the need for water was recorded, as well as with an increase in content of unburned coal particles (if loss on ignition was more than 1%) [7]. The authors of [8] investigated the influence of replacing the cement with the addition of pozzolana (did not use pure cement) in the amount of 10-70% of fly ash relative to the total weight of the cement in the SCC. Tests have shown that the best effects can be achieved with the 30-50% replacement of cement by mass.

In a study [9], pozzolanic additives (fly ash and granulated blast furnace slag) gave better results in the fresh and hardened SCC in comparison to limestone, basalt, and marble powder. Based on water penetration test, on SCC with mineral additives, the depth of penetration of water under pressure ranged as low as 4.4–12.6 mm. In the research [10] fly ash was found to improve the mechanical properties and potential durability.

Based on the analysis of a large number of papers, an assumption was made that the acceptable properties of SCC can be obtained with a variety of sizes, types, shapes and particle size composition curves of aggregates that meet certain technical requirements. Because of the lower friction forces between the particles, natural river coarse aggregate provides a better filling ability, while the crushed aggregate has a better effect in terms of strength of the concrete [11]. According to the CBI model (the Swedish Institute for testing cement and concrete), the use of crushed aggregate in SCC results in a need for larger quantities of paste, and lower amount of aggregates, in order to avoid the effects of blocking, which is prominent in the case of using aggregates with irregularly shaped grains. Also, SCC made with crushed aggregate demand larger amounts of superplasticizer [12]. In this study, fly ash was used as a partial mass replacement of limestone filler, both in SCC mixtures with river, or with crushed aggregate, see Figure 1.

2. EXPERIMENTAL STUDY

2.1. Extent and the goals of the study

This study was conducted in the Laboratory for materials, Institute of materials and structures, Faculty of Civil Engineering on the University of Belgrade. The aim of this study was to investigate the influence of two parameters, aggregate type and quantity of fly ash used for the production of the SCC mixtures. It was of the primal importance to try and find the effects of aggregate on the physical and mechanical properties of concrete, having in mind that this parameter has one of the most important roles in the behavior of fresh and hardened concrete. Also, as a valuable aid to the wide range of concretes, fly ash can be used in SCC, but this has consequences in terms of properties of concrete as well. This fact is additionally made more complex when properties of fly ash, such as the origin, composition, and potential activations are taken into account. One must have in mind the fact that SCC is more sensitive to the variation in components then most of the conventional concretes, and that the parameters of fresh SCC play key role in its successful production. Therefore, a special attention was paid to tests of the fresh SCC.

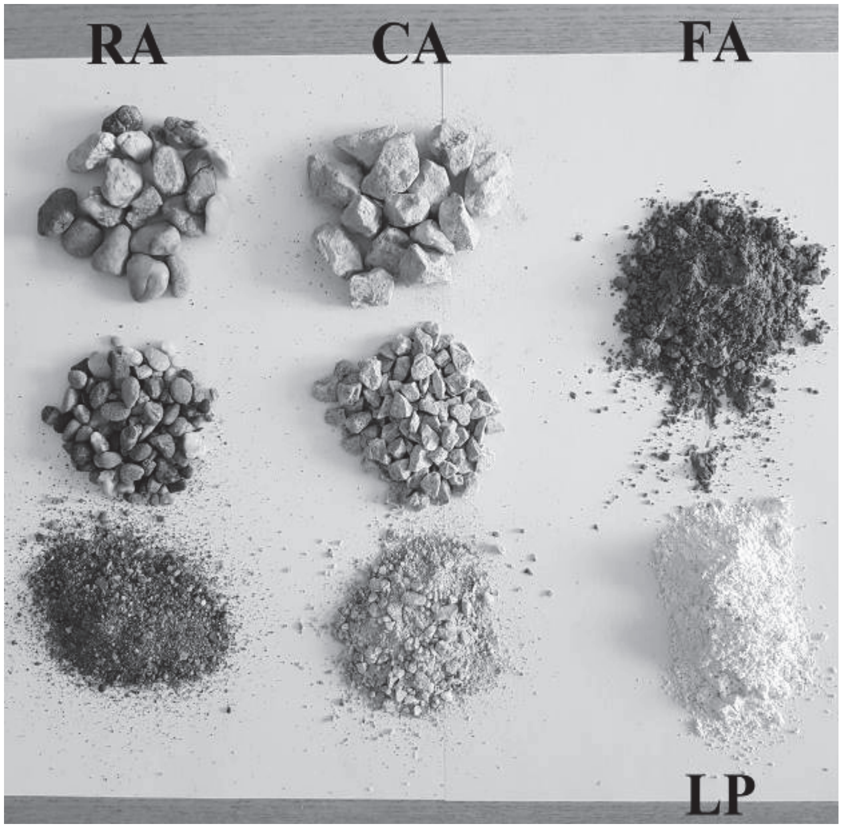

Figure 1. River aggregate (RA), crushed aggregate (CA), fly ash (FA) and limestone powder (LP) used in this study

2.2. Materials

Aggregates used for the production of these mixtures were either river (mixtures SCC I, SCC II, and SCC III) or crushed (SCC IV, and SCC V). River aggregate was obtained from the local manufacturer and was designated as Danube river origin. Crushed aggregate was of limestone origin, and was from Sitnica location near Herceg Novi. The targeted grain size distribution was adopted from the previous successful mixture, and was same for all mixtures. Mixture of aggregate consisted of natural aggregate, devided in three standard fractions: I (0/4 mm), II (4/8 mm), and III (8/16 mm). Grain size distribution of the used aggregate mixture is presented in Figure 2. Gravity of river aggregate was 2,671 g/cm^3, while bulk density in loose state was approximately 1,500 g/cm^3. Gravity of crushed aggregate was 2,715 g/cm^3, while bulk density in loose state was approximately 1,515 g/cm^3.

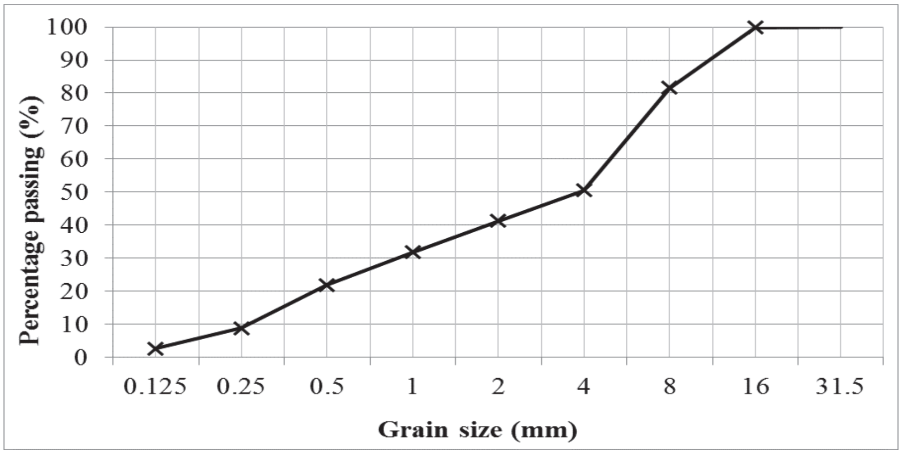

Figure 2. Grain size distribution of the aggregate mixture used for the production of SCC mixtures

Cement PC 20M(S-L) 42.5R "Lafarge" Beočin was used. Gravity of this cement amounted to 2,940 g/cm^3. Limestone powder from "Granit Peščar" Ljig, with average diameter of 250 μm and density of 2,720 g/cm^3, was used as mineral filler in all mixtures.

As it was already stated, fly ash used in this research originated from power plant "Kolubara". Gravity of this type of fly ash was 2,190 g/cm^3. Bulk density in loose state was 0,690 g/cm^3. For the used fly ash, the contents of reactive SiO_2 and CaO were 58,60% and 6,12%. Grain size distribution curve of this fly ash is shown on Figure 3.

Sampling and packing of fly ash was done by workers of the power plant. Fly ash was transported in plastic bags and held protected from moisture and temperature changes until experimental research. Fly ash was used in the delivered state, without any additional means of preparation (sieving, crushing, etc.), and it was dosed with the cement and powder component, during the mixing process.

The amount of fly ash was restricted to the maximum 40 kg/m^3, as it was obvious to contain larger grains, and also unburnt coal particles. In the case of tested concrete mixtures, it means that mass of fly ash amounted to maximum 10.8% of total mass of cement, and maximum 1.7% of total mass of SCC. Such (lower) quantity of fly ash was chosen in order to reduce the influence of fly ash on the robustness of SCC mixtures, and therefore to provide higher stability in situation when change in properties (or small changes of quantities) of components of SCC occur.

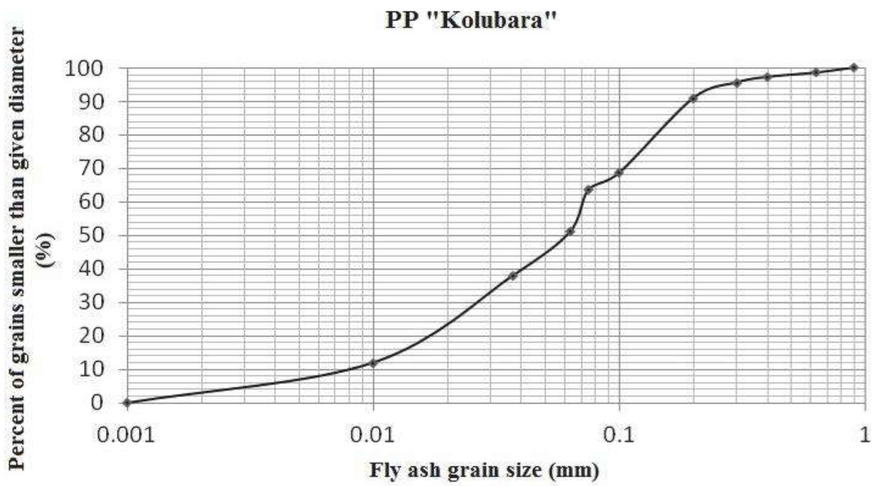

Figure 3. Grain size distribution curve of fly ash from "Kolubara"

Polycarboxylate based superplasticizer Adium 132 (gravity 1.06 kg/dm^3), produced by Isomat, was used as a HRWR in all concrete mixtures described in this paper.

2.3. Mixtures

Five different mixtures were prepared with limestone powder as a filler, and the addition of fly ash in four of the SCC mixtures, as follows:

− Control mixture, designated as SCC I, prepared with natural river aggregate and without fly ash,

− Mixture designated as SCC II, made with natural river aggregate and with 20 kg/m^3 of fly ash,

− Mixture designated as SCC III, made with natural river aggregate and with 40 kg/m^3 of fly ash,

− Mixture with natural crushed aggregate and with 20 kg/m^3 of fly ash, designated as SCC IV,

− Mixture with natural crushed aggregate and with 40 kg/m^3 of fly ash, designated as SCC V.

Pilot mixtures were made in order to find proper composition of SCC mixtures which falls between classes SF2 and SF3, with 750 mm of slump flow, according to limits provided in guidelines for SCC [13]. Presented concrete mixtures were defined using the principle of equal effective water/cement ratios (0.450), meaning that all of them were expected to achieve the same compressive strength (if fly ash influence on compressive strength was to be excluded). Mixtures containing crushed aggregate had higher quantity of paste than the mixtures with river aggregate, but, as stated, the same water to cement ratio. Also, the quantities of aggregate fractions were different when crushed aggregate was made, in order to preserve the target particle size curve in the mixture. Quantities of aggregate in SCC mixtures with crushed aggregate were lower than in SCC mixtures with river aggregate, due to the higher amount of paste in the same volume of concrete. Mixing technique was performed according to the algorithm shown in Figure 4.

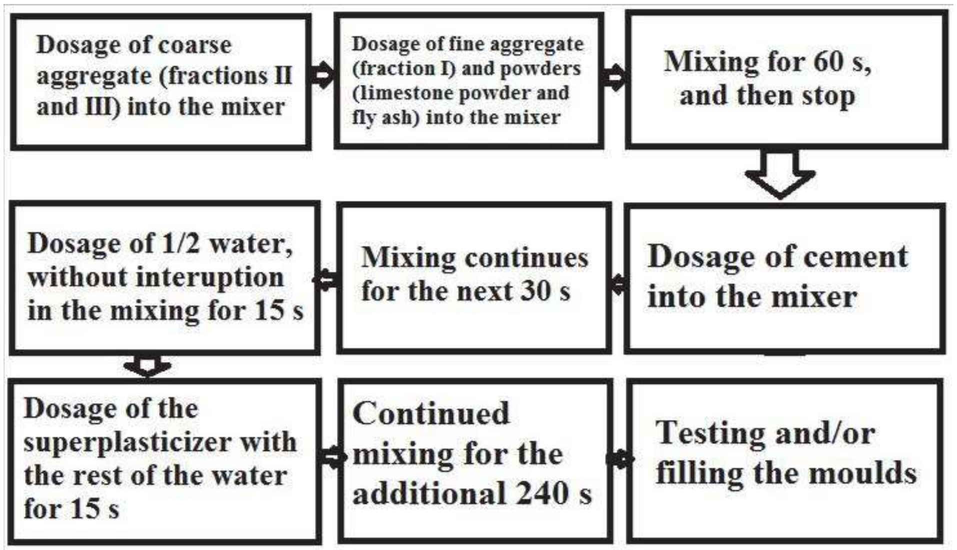

Figure 4. Mixing technique adopted for the studied SCC mixtures

These mixtures can be referred to as powder type mixtures with quantity of powder component of more than 550kg/m^3. The quantity of superplasticizer was set to be 2% of the cement mass. Composition of the five tested mixtures is presented in Table 1.

Table 1. Mix composition of SCC mixtures (kg/m^3)

Mixture		*SCC I*	*SCC II*	*SCC III*	*SCC IV*	*SCC V*
Cement		369	369	369	445	445
Limestone powder		187	187	187	187	187
Fly ash		0	20	40	20	40
Water		166	166	166	200	200
Natural river aggregate	I (0/4 mm)	824	824	824	-	-
	II (4/8 mm)	604	604	604	-	-
	III (8/16 mm)	202	202	202	-	-
Natural crushed aggregate	I (0/4 mm)	-	-	-	810	810
	II (4/8 mm)	-	-	-	493	493
	III (8/16 mm)	-	-	-	246	246
Superplasticizer		7.4	7.4	7.4	8.9	8.9

3. RESULTS AND DISCUSSION

A wide range of tests of fresh and hardened concrete were performed in order to estimate the effect of different types of aggregate and fly ash incorporation within SCC mixtures. Flowability of fresh mix was determined using slump flow test [14], viscosity of concrete was tested using V-funnel [15] and flowability and passing ability were determined using L-box test [16]. Ambient temperature was also measured, during production of SCC mixtures. Compressive strength as the most important property of concrete was measured after 1, 7 and 28 days [17]. Hardened concrete density [18] was recorded at the same ages when compressive strength was tested. Tensile strength properties of concrete mixtures were estimated through splitting strength testing [19]. Ultrasonic pulse velocity [20] and Schmidt hammer [21] tests were performed as non-destructive parameters, to estimate the correlation between these properties and compressive strength of the investigated mixtures. Water permeability [22] of these SCC mixtures was also tested.

3.1. Fresh mix properties

Table 2 incorporates the following results: bulk density of fresh SCC mixes, final flow diameter in slump-flow test and time in which concrete sample reaches diameter of 500 mm (t_{500}), V-funnel time (t_v), and height ratio within L-box (PA). Ambient temperature measured during mixture preparation was at all times 21±1°C.

Bulk densities of fresh mixtures varied from 2381 kg/m^3 (mixture SCC V) to 2432 kg/m^3 (mixture SCC I). These values correlate to the composition of the concrete mixtures, because mixtures with higher amount of fly ash have lower densities, and mixtures with higher content of paste have lower densities as well (consequently having lower quantity of aggregate per m^3). For river aggregate (mixtures SCC I to SCC III), this decrease in density, due to the fly ash presence, was more noticeable for incorporation of higher content of fly ash. This trend was not linear, but exponential, most probably due to the additional negative effect of decreased consistency of SCC mixtures with higher content of fly ash. For mixtures with crushed aggregate, this decrease was not as pronounced, but still obvious. Most probably due to the higher amount of paste, relative to which fly ash had lower content, milder effects in density change were recorded, in comparison to the effects in mixtures with river aggregate.

According to limits defined in previously mentioned guidelines, concrete mix SCC III belongs to SF1 class, while all the other mixtures had slump-flow diameter close to the limit between SF2 and SF3 (750-760 mm). Obviously, there was a drop in time t_{500}, measured during slump flow test, which placed all of the mixtures in VS2 class, with measured flow time higher than 2s. Nevertheless, the results show that all of the mixtures had very good flowability, excluding mixture SCC III. Differences between the properties of fresh mixtures became more conspicuous for V-funnel test results. All of the SCC mixtures belong to VF1 class, according to V-funnel test, with time t_v lower than 8 s, excluding mixture SCC III which fell in higher class VF2. This SCC mixture substantially exceeded upper limit for this test (25 s). The highest value for t_v was measured for the mixture SCC III, followed by mixture SCC II. All the mixtures satisfy the condition for PA2 class in respect to the height ratio results of the L-box test, except SCC mixture SCC III (ratio lower than 0.80). No blocking effect was noticed for any of the mixtures.

It can be noted that lower flowability and passing ability were recorded on SCC mixtures with higher amount of fly ash. All of the properties were noticeably different in the mixture SCC III, which can be attributed solely to the fly ash incorporation.

Table 2. Fresh SCC mixtures properties

Property	SCC I	SCC II	SCC III	SCC IV	SCC V
Fresh concrete density (kg/m^3)	2432	2429	2406	2396	2381
Slump-flow (mm)	760	740	590	780	760
t_{500} (s)	5.3	5.8	14.7	4.3	5.2
t_v (s)	10.4	20.4	60.6	14.4	18.6
L-box PA (-)	0.92	0.86	0.75	0.94	0.90

3.2. Hardened mix properties

Measured densities of hardened SCC mixtures followed the trends recorded on fresh mixtures. Namely, mixtures with higher content of paste component (mixtures with crushed aggregate) and mixtures with higher content of fly ash had somewhat lower densities at 28 days, where the highest difference was 33 kg/m^3 between the first (without fly ash) and the last SCC mixture (with 40 kg/m^3 of fly ash, and with more cement paste).

Compressive strength was tested on three samples for all SCC mixtures, after 1, 7 and 28 days. Tests were performed on the 10 cm cubes, and results are presented in Table 3.

Table 3. Compressive strength of concrete mixtures at the ages of 1, 7 and 28 days

Compressive strength at different ages	SCC I	SCC II	SCC III	SCC IV	SCC V
$f_{c,1}$ (MPa)	33.0	33.4	33.4	42.9	41.5
$f_{c,7}$ (MPa)	51.5	51.8	54.9	57.4	56.9
$f_{c,28}$ (MPa)	56.0	61.5	61.9	66.8	63.1

Compressive strengths of the studied mixtures reached similar values at the same ages. At all ages mixtures made with river aggregate (SCC I, SCC II, and SCC III) had lower values of compressive strength, when compared to the mixtures SCC IV, and SCC V, both with crushed aggregate. Decreases of the mean values for the group of first three mixtures, in comparison to the mean of the last two mixtures were 22%, 8%, and 8%, for ages of 1, 7, and 28 days, respectively. These differences between the measured values can be attributed to the type of aggregate.

Looking at each mixture separately, the increase of the compressive strength was the highest at the age of 1 day, when mixtures achieved from 54% (for mixtures SCC II and SCC III) to 66% (for mixture SCC V) of the final strength at the age of 28 days. When compressive strengths at the age of 28 days are compared, the highest value was recorded for the mixture with crushed aggregate and with 20 kg/m^3 of fly ash, although the mixture with the same composition, but with higher content of fly ash (40 kg/m^3), didn't have much lower value of compressive strength (approximately 5.5% lower). At the same age, both mixtures with fly ash achieved similar values of compressive strength, which was approximately 9%.

In addition, a notice has to be made that all of the SCC mixtures behaved similarly in terms of compressive strength, having values of compressive strength in the relatively narrow range at all ages, approving the concept of the same water to cement ratio incorporated in their design.

Tensile strength of concrete was indirectly tested at the age of 28 days using splitting test performed on three cylinders (d/h=15/15 cm) for each mixture. Results of this test are presented in Figure 5. As it can be seen, all of the mixtures behaved similarly in terms of splitting tensile strength, with values ranging from 3.1 MPa for SCC I up to 4.1 MPa for SCC V. Speculations can be made regarding positive effect of fly ash incorporation, but the improvements stay in the domain of statistical error. Further on, crushed aggregate, which was expected to behave improved in this loading (in comparison to river aggregate), showed no positive effect, most likely due to the presence of higher content of cement paste.

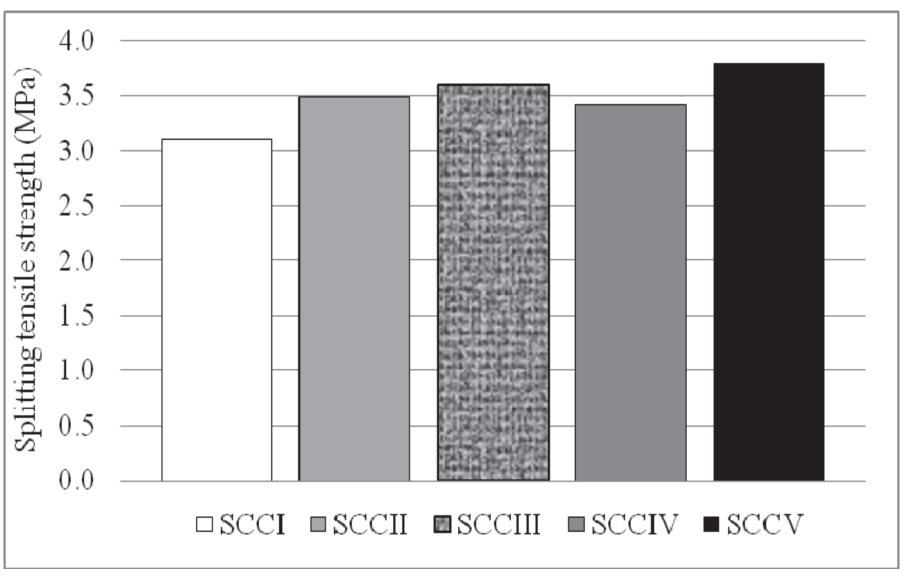

Figure 5. Splitting strength test results, at 28 days

Ultrasonic pulse velocity was measured on three prisms 12x12x36 cm for each mixture, at the ages of 1, 3, 7, 21, 28, and 60 days. The results of this test are shown on Figure 6.

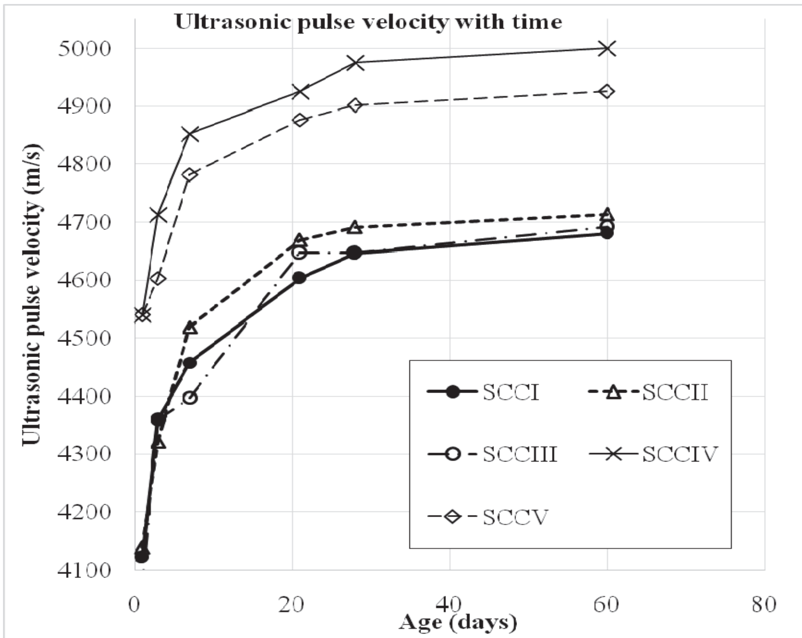

Figure 6. Ultrasonic pulse velocity test results

The highest increase in the ultrasonic pulse velocity was at early ages, while after 28 days changes in this property were much lower. Final values of ultrasonic pulse velocity range approximately between 4700 m/s and 5000 m/s, testifying of good compaction of all of the mixtures, regardless of the fact that no compaction machinery was used after concrete was poured into moulds. Further on, a clear distinction can be made between the SCC mixtures made with river aggregate (mixtures designated as SCC I, SCC II, and SCC III), and the ones made with crushed aggregate (mixtures designated as SCC IV, and SCC V). Both mixtures made with crushed aggregate displayed much higher values of ultrasonic pulse velocity, when compared to the mixtures made with river aggregate. This difference stayed at around 300 m/s at all ages. Within the two mentioned groups of SCC mixtures (one with river and the other with crushed aggregate), a clearer difference was noticed for SCC mixtures with crushed aggregate, and this can be attributed to the effect of fly ash particles presence. Namely, incorporation of fly ash adversely influenced ultrasonic pulse velocity in the SCC mixtures with crushed aggregate. This influence was ambiguous in the SCC mixtures made with river aggregate.

Schmidt hammer, also known as sclerometer is usually related to the in situ investigations of the ready mix concrete quality, and, as a non-destructive method, provides valuable data for the detailed assessment of the concrete in structure which is being evaluated. Nevertheless, the results of this investigation (a rebound number) must always be correlated to the compressive strength of the core samples from the structure, in order for this method to have sense. In these tests, for each mixture, investigation with Schmidt hammer was performed prior to compressive strength test, two times on two sides of the three 10 cm cubes, planned for compressive strength test. This way, a total of 12 values were obtained for each mixture, at each age, and the average results are shown in Table 4. Thus, an appropriate correlation could be made after the compressive strength test. As it can be noticed from the table, the rebound numbers for each mixture increase with age of the concrete.

Table 4. Average values of rebound numbers at the ages of 1, 7, and 28 days

Rebound numbers at different ages	SCC I	SCC II	SCC III	SCC IV	SCC V
I_1	43.0	41.8	41.0	43.8	42.3
I_7	46.0	47.8	51.0	48.5	48.3
I_{28}	50.0	55.0	54.0	54.0	53.8

A correlation between strengths at all ages, for all mixtures, and measured ultrasonic pulse velocities is shown on Figure 7. Although all of the mixtures show similar trends of increase of compressive strength with increase in ultrasonic pulse velocity, this increase can be characterized as mainly linear, for all of the mixtures. Further on, two different groups of paired values emerge from the graphical interpretation of the correlation, which clearly indicate different behavior of SCC mixtures made with river aggregate and SCC mixtures made with crushed aggregate. Therefore, two different regression trend lines were proposed and plotted on the chart, one for the mixtures with river aggregate, and the other for the mixtures with crushed aggregate. The formulas describing these correlations are displayed on the chart also, together with their coefficients of correlations, which indicate high correlation formed. All of the stated implies substantially lower effect of the fly ash on this correlation, which is why this effect was neglected.

Finally, a statement can be made regarding mutual position of the two plotted correlations a conclusion can be drawn that the same values of ultrasonic pulse velocities for both groups of mixtures imply lower values of compressive strengths in the group of SCC mixtures made with river aggregate, then in the group of SCC mixtures made with crushed aggregate. In addition to this remark is the fact that these correlations posses very similar slopes, indicating similar trends of change of compressive strength with ultrasonic pulse velocity.

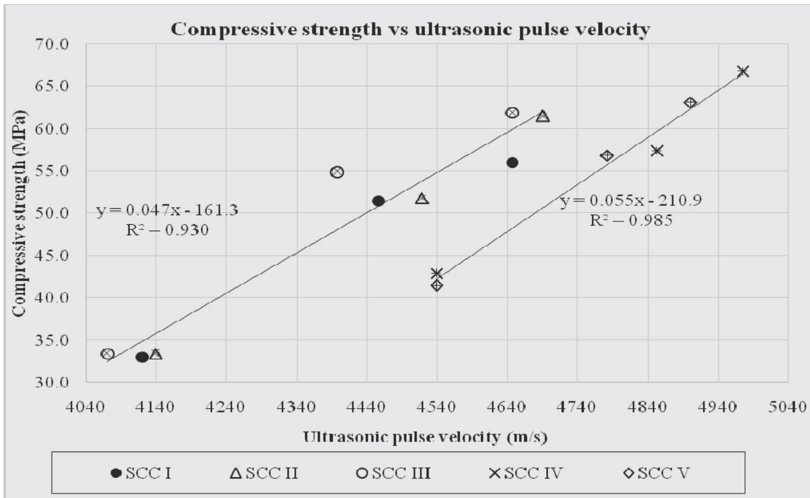

Figure 7. Correlation between compressive strength and ultrasonic pulse velocity for SCC mixtures

Similarly, analogue to the correlation formed between the compressive strength and ultrasonic pulse velocity, a correlation can be made also, for dependence of compressive strength from Schmidt rebound number. This correlation is shown on Figure 8 for all of the SCC mixtures, and all of the ages within each mixture. In this case, it was unclear how to interpret the influence of fly ash and even the influence of the aggregate used in the mixtures, unlike the previous analysis regarding ultrasonic pulse velocity. Therefore, a correlation was made with the respect to all of the pairs of values of compressive strength and rebound number, neglecting changes, both in fly ash content, and aggregate type. In that manner, a good linear correlation was obtained, with relatively high correlation coefficient of 0.889.

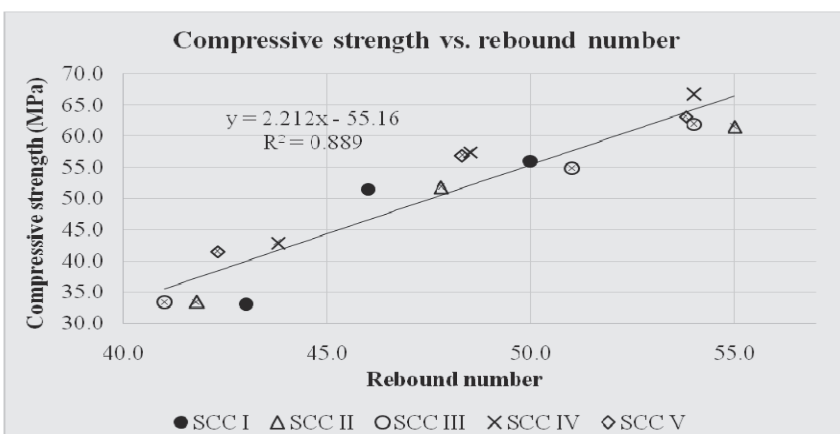

Figure 8. Correlation between compressive strength and rebound number for SCC mixtures

Water permeability was tested on three cylinders (d/h=15/15 cm) for each SCC mixture, in order to gather the information concerning the effect of control parameters (fly ash content, aggregate type, and indirectly paste content) on properties of SCC mixtures. This procedure starts with the samples (older than 28 days) exposed to water under pressure of 5 bar for 72 hours. After this, samples were split, and the water penetration height was measured, immediately after the splitting of samples. Figure 9 shows the result of this investigation on one of the samples, and Table 5 incorporates the mean results of measurements for each SCC mixture. Although extremely low values were obtained for all of the SCC mixtures, proving them to be waterproof, the water penetration height occurred to be lower with the increase of fly ash in mixtures with river aggregate. In the SCC mixtures with crushed concrete, the water penetration was practically inestimably low.

Table 5. Average values of water penetration heights for the SCC mixtures

Mixture	SCC I	SCC II	SCC III	SCC IV	SCC V
Water penetration height (mm)	5	3	2	0	0

Figure 9. Appearance of the sample after the splitting for water penetration measurement

4. CONCLUSIONS

In this paper, the influence of fly ash (used in "as delivered" state) and different types of aggregate on the fresh and hardened SCC mixtures properties was investigated. The quantities of fly ash added were kept relatively low, due to the negative effect on fresh properties. The crushed aggregate mixture used had the same particle size distribution as the river aggregate, but influenced increase in the quantity of paste component, with water to cement ratio kept the same for all of the SCC mixtures. Based on the results presented in the previous section, the following conclusions can be drawn:

- The incorporation of fly ash, increased quantity of cement paste resulted in lower densities, where decrease in density due to the fly ash presence for natural river aggregate (mixtures SCC I to SCC III) was more pronounced, exponential, most probably due to the additional negative effect of fly ash on consistency of SCC mixtures. In SCC mixtures with natural crushed aggregate, this decrease was not as high, most probably due to the higher amount of paste in these mixtures.

- The use of up to 40 kg/m^3 of fly ash in "as delivered" state resulted in reduction in placing, flowing and passing abilities of concretes, resulting in drastically lower performances measured by slump-flow test, V-funnel and L-box. Although slump-flow test showed acceptable results, major differences were recorded after V-funnel test, therefore both tests are recomended to be used every time. The possible effects of the second parameter, aggregate, was annuled by the higher quantity of paste for the SCC mixtures with crushed aggregate, having similar slump-flow, L-box and V-funnel results as SCC mixtures with river aggregate.

- This study showed that incorporation of higher amount of paste is an effective way to reduce the negative impact of the larger fly ash particles presence on the properties of the fresh concrete.

- When it comes to the hardened concrete properties, the incorporation of fly ash showed improvement of at least 10% at the age of 28 days. There was no noticable negative effects of lower flowability and passing ability of mixture SCC III on compressive strength, but also on any of the other measured hardened mechanical properties. Crushed aggregate use influenced higher compressive strengths. Higher paste content showed no negative influence on compressive strength of SCC mixtures with crushed aggregate.

- Ultrasonic pulse velocity test showed lower velocities in SCC mixtures with river aggregate. A conclusion can be made that increase in paste in mixtures with crushed aggregate didn't influence adversely to the ultrasonic pulse velocity. The use of crushed aggregate led to the increase of ultrasonic pulse velocity. The incorporation of fly ash adversely influenced ultrasonic pulse velocity in the SCC mixtures with crushed aggregate.

• A correlation between strengths, and measured ultrasonic pulse velocities at all ages, for all mixtures showed to be insensitive to the fly ash content. The second parameter, type of aggregate provoked higher correlation values for the SCC mixtures with crushed aggregate.

• In a correlation between strengths, and measured rebound number at all ages, for all mixtures, it was unclear how to interpret the influence of fly ash and even the influence of the aggregate used in the mixtures. Therefore a good correlation was formed regarding all of the investigated mixtures (showing them to be very similar regarding this property).

• Water penetration test showed low values, proving all of the SCC mixtures to be waterproof, and the water penetration height decreased with the increase of fly ash in mixtures with river aggregate. In the SCC mixtures with crushed aggregate, the water didn't penetrate any of the samples, thus the conclusion can be made that in these mixtures an excellent paste component was incorporated. Increased content of fly ash didn't compromise structure of concrete. A conclusion can be made that all of the mixtures had high durability, based on the structure assessment by water penetration test.

Based on the presented results, a conclusion can be drawn that SCC mixtures made with crushed aggregate had better properties than the SCC mixtures made with river aggregate. The use of fly ash led to the improvement of properties of hardened SCC mixtures. Having in mind pozzolanic properties of fly ash, a further increase in strength of SCC mixtures with fly ash is expected, at ages more than 90 days.

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УТИЦАЈ ВРСТЕ АГРЕГАТА И САДРЖАЈА ЛЕТЕЋЕГ ПЕПЕЛА НА СВОЈСТВА САМОУГРАЂУЈУЋИХ БЕТОНА

Апстракт: У раду се приказују резултати експерименталног испитивања самоуграђујућих бетона у свежем и очврслом стању. Справљано је пет мешавина, у којима је вариран садржај следећих компонената: агрегата, летећег пепела у допремљеном стању и укупне количине пасте (мешавина воде, минералног додатка и везива). Испитивања у свежем стању укључила су одређивање следећих својстава: запреминске масе, распростирања слегањем, времена V-левка, односа висина код L-бокса, као и температуре амбијента. У очврслом стању испитани су: запреминска маса очврслог бетона, чврстоћа при притиску, чврстоћа при савијању, брзина простирања ултразвучног импулса и водонепропустљивост. Испитивања су показала да се повећањем садржаја пасте може побољшати уградљивост, као и редуковати негативан ефекат присуства крупнијих честица летећег пепела на својства свежег бетона. Такође, показано је да додатак мале количине летећег пепела може значајно допринети повећању чврстоће при притиску бетона.

Кључне ријечи: бетони, физичко-механичка својства, летећи пепео, агрегат.