IRASA

INTERNATIONAL SCIENTIFIC CONFERENCE

SCIENCE, EDUCATION, TECHNOLOGY AND INNOVATION

SETI I

BOOK OF PROCEEDINGS

BELGRADE,
APRIL 12, 2019

Publisher	IRASA – International Research Academy of Science and Art
For the Publisher	Academician Prof. Vladica Ristić, PhD
Editors	Academician Prof. Vladica Ristić, PhD Academician Prof. Marija Maksin, PhD Academician Prof. Slobodanka Đolić, PhD Academician Prof. Gordana Dražić, PhD
Reviewers	Academician Prof. Vladica Ristić, PhD; Academician Prof. Enes Huseinagić, PhD Academician Prof. Slobodanka Đolić, PhD Academician Prof. Gordana Dražić, PhD Academician Prof. Jelena Bošković, PhD Academician Prof. Marija Maksin, PhD Academician Slavka Zeković, PhD Academician Prof. Dobrica Vesić, PhD Academician Prof. Dragana Spasić, PhD Academician Prof. Željko Bjelajac, PhD Academician Prof. Vladimir Marković, PhD Prof. Igor Jokanović, PhD Prof. Antoan Dayoub, PhD Assist. Prof. Milena Premović, PhD
IT support	
Print run	100
Printed by	
ISBN	

Publication of the Book of Abstracts has been co-financed by the Ministry of Education, Science and Technological Development of the Republic of Serbia.

INVESTIGATION OF GREEN SELF-COMPACTING CONCRETE MADE WITH RECYCLED CONCRETE AGGREGATE

Aleksandar Savić[15]; *Ivana Jelić*[16]; *Marina Aškrabić*[17];
Danijela Pavlović[18]; *Brankica Kovačević*[19];

Abstract

The use of Self-Compacting Concrete (SCC), like concrete that enables placing without compaction equipment, provides a range of benefits for the contemporary civil engineering practice. The ecological aspect, through the possibility of using recycled aggregate obtained by grinding waste concrete, is presented in the paper. This study deals with the physicomechanical investigation of three concrete mixtures: reference mixture and two mixtures prepared with recycled concrete aggregate. One mixture contained 50% mass replacement of coarse river aggregate with recycled concrete aggregate, and in the other one, the total mass of coarse aggregate consisted of recycled concrete aggregate. These series were designed using the Two-Stage Mixing Approach (TSMA). Fresh mix tests included: measurement of density, slump flow, V-funnel, and L-box tests. Compressive, flexural, splitting and bond (pull-off) strength were determined on hardened concrete. All mixtures showed good properties, encouraging the possibility of recycled concrete aggregate usage for proper SCC production.

Key words: *Recycled concrete aggregate, self-compacting concrete*

Introduction

One thing almost all agree on is that the industry, in the form that we recognize it today, is expected to stay for decades. At the same time, there is a global awareness of its' disturbing impact on the environment, and the fact is that it has to evolve into more sustainable form. Therefore, the raise in the global consciousness of the approaching environmental catastrophe presents only the first step in the hard

[15] Aleksandar Savić, Ph.D, Assistant professor, Corresponding Academician of IRASA, University of Belgrade, Faculty of Civil Engineering, Bulevar kralja Aleksandra 73, 11000 Belgrade, Republic of Serbia, savic.alexandar@gmail.com

[16]Ivana Jelic, PhD, Assistant professor, Corresponding Academician of IRASA, Research and Development Institute Lola Ltd., Kneza Viseslava 70a, 11030 Belgrad, Republic of Serbia, ivana.jelic@li.rs

[17] Marina Aškrabić, MSc, Ph.D student, Teaching Assistant, University of Belgrade, Faculty of Civil Engineering, Bulevar kralja Aleksandra 73, 11000 Belgrade, Republic of Serbia, amarina@grf.bg.ac.rs

[18] Danijela Pavlović, MSc, University of Belgrade, Faculty of Civil Engineering, Bulevar kralja Aleksandra 73, 11000 Belgrade, Republic of Serbia, danijelapavlovic86@yahoo.com

[19] Brankica Kovačević, MSc, University of Belgrade, Faculty of Civil Engineering, Bulevar kralja Aleksandra 73, 11000 Belgrade, Republic of Serbia, brankica_ko@yahoo.com

process of preserving the planets ecosystem and the life on Earth. Success is not guaranteed in this complex task.
In order to make the best impact of implementing sustainability in various branches of industry, specific skills have to be adopted by the professionals in the area. These skills include not only the excellent knowledge of the way things work in the areas of expertise, but also cutting edge knowledge in the materials, technologies and environmental effects of the processes in such working scenarios.
In the area of civil engineering industry, a lot can be said on the topic of neglect of the sustainability doctrines, given that this industry changes in a sluggish pace, and not always in the right direction.
Nevertheless, a number of new materials and technologies are developed, and improved, with the respect to and implementation of environmental protection. Such cases show that from now on evolution of civil engineering can, and must be strongly bonded with sustainable development [1]. One of these examples is the possibility of recycled aggregate use in Self-Compacting Concrete.
Self-Compacting Concrete (SCC), developed in two last decades of the XX century, is defined as such concrete, that can be placed in the formwork without any need for vibration equipment, providing (only as a result of the gravity action) the effect of filling even the most complicated formwork geometry, and flowing between densely spaced reinforcement steel bars. Obviously, numerous benefits in construction (faster placement, lower energy demand, no noise pollution, less workers on site, etc.) are obtained through such behaviour. In order to accomplish such properties, SCC possesses unique composition – in the first place, super plasticizing and viscosity modifying admixtures are present, together with the proper dosage of mineral additives, such as fly ash, dolomite or limestone powder, silica fume etc.
Besides the specifics of the SCC technology, following the sustainability requests, this paper presents the contemporary techniques that provide successful use of recycled concrete aggregate (RCA) in new concrete. Nowadays, crushed and destroyed (C&D) waste concrete from old buildings can be used not only as secondary granulate for fillings and embankments, but also (if possessing the proper physical and mechanical potential) for production of new high strength structural concrete.
The paper presents the comparison of different physical and mechanical properties of fresh and hardened mixtures. It was important to find out the scale in which the properties of concrete will change (most likely degrade), due to the use of recycled concrete aggregate instead of natural aggregate.

Materials

To fabricate a good quality concrete, precisely determined size fractions of aggregate are used, where fine aggregate (0/4mm) is usually referred to as sand, and the other fractions are (4/8 mm), and (8/16 mm). For the SCC mixtures presented in this paper, both natural and recycled aggregates were used.
The use of fine recycled aggregate (0/4 mm) is not advised for the production of any concrete with recycled aggregate. This suggestion arises from the high water absorption rates of fine fraction of recycled concrete aggregate (due to the high content of the porous cement paste in such aggregate). Therefore, fine aggregate (0/4

mm) of river origin was used in all the mixtures in the percent of 50.6% (860 kg/m^3) compared to the total mass of the aggregate. The final mixture of recycled concrete aggregate was set to 32.2% (530 kg/m^3) of second fraction (4/8 mm) and 18.2% (310 kg/m^3) of third fraction (8/16 mm).

Natural aggregate was commercially available river sand and gravel from the Danube river, and is regularly used for production of concrete. Recycled concrete aggregate was obtained from a demolished concrete sub-structure for tram rails in Vojvode Stepe Street, Belgrade. At the moment of crushing, this concrete was more than 30 years old. According to the performed tests, class of the original concrete was C35/45 at the moment of crushing. True density of recycled concrete aggregate was 2.425 g/cm^3, while it's water absorption equalled 3.4% for both fractions of recycled concrete aggregate [2, 3]. Both types of aggregate, natural and recycled, in form of fractions are shown on Figure 1.

Figure 1: Illustration of the used aggregate, granulated into fractions

Other components of concrete included: limestone powder as mineral additive, cement, superplasticizer as chemical admixture, and water. Limestone powder, produced by Granit peščar Ljig, was used. True density of limestone powder was 2.720 g/cm^3. Portland cement PC 20M (S-L) 42.5R, produced by Lafarge Beočin was used in all the mixes. According to the producer's data, this cement is blended type of cement with 5-20% of ground granulated slag and limestone, thus reducing the quantity of Portland cement (and therefore the carbon footprint) of the produced concrete mixtures. True density of cement was 3.040 g/cm^3, with specific surface of 4240 cm^2/g (obtained by Blaine method). Superplasticizer Cementol Hiperplast 463 (with density of 1.08 g/cm^3) produced by TKK, Srpenica, was also applied [2, 3]. The used water was plain drinking water, obtained from the water supply pipeline.

Mixture proportioning principles and composition

The aim of the study presented in this paper was to verify and, if possible, to valorise the materials and methods referring to the RCA use in the case of SCC mixtures. This was done through the investigation of the influence of the coarse recycled concrete aggregate on physical and mechanical properties of SCC mixtures, both in fresh and hardened state. For this purpose, three different mixtures were selected:

1. Referent mixture, designated as SCC I, prepared with natural river aggregate,
2. Mixture designated as SCC II, with both II (4/8 mm) and III (8/16 mm) fractions composed only of recycled concrete aggregate,
3. Mixture designated as SCC III, made with the equal amounts (50% mass) of both natural river aggregate, and recycled concrete aggregate of both fractions: II (4/8 mm) and III (8/16 mm).

Composition of the three tested mixtures is presented in Table 1. The quantities of the cement and limestone powder were held constant (380 kg/m^3 and 250 kg/m^3 respectively). These mixtures can be referred to as powder type SCC mixtures with quantity of powder component of more than 550 kg/m^3. The quantity of the superplasticizer was also the same for all of the mixtures, providing practically similar values of the slump flow.

Table 1: Composition of mixtures (kg/m^3)

Mixture		SCC I	SCC II	SCC III
Cement		380	380	380
Limestone powder		250	250	250
Water		194	205	208
Natural river aggregate	I (0/4 mm)	860	860	860
	II (4/8 mm)	530	-	265
	III (8/16 mm)	310	-	155
Recycled concrete aggregate	II (4/8 mm)	-	530	265
	III (8/16 mm)	-	310	155
Superplasticizer		5.7	5.7	5.7

Mixtures were proportioned using the principle of equal effective water/cement ratios. Mixtures containing recycled concrete aggregate had additional amount of water, which is needed due to higher water absorption of this kind of aggregate. Also, Two-Stage Mixing Approach (TSMA) was used to improve the interface zone of the recycled concrete aggregate grains and cement paste in the concrete [2, 3]. Mixing technique was consistent with the algorithm shown in Figure 2.

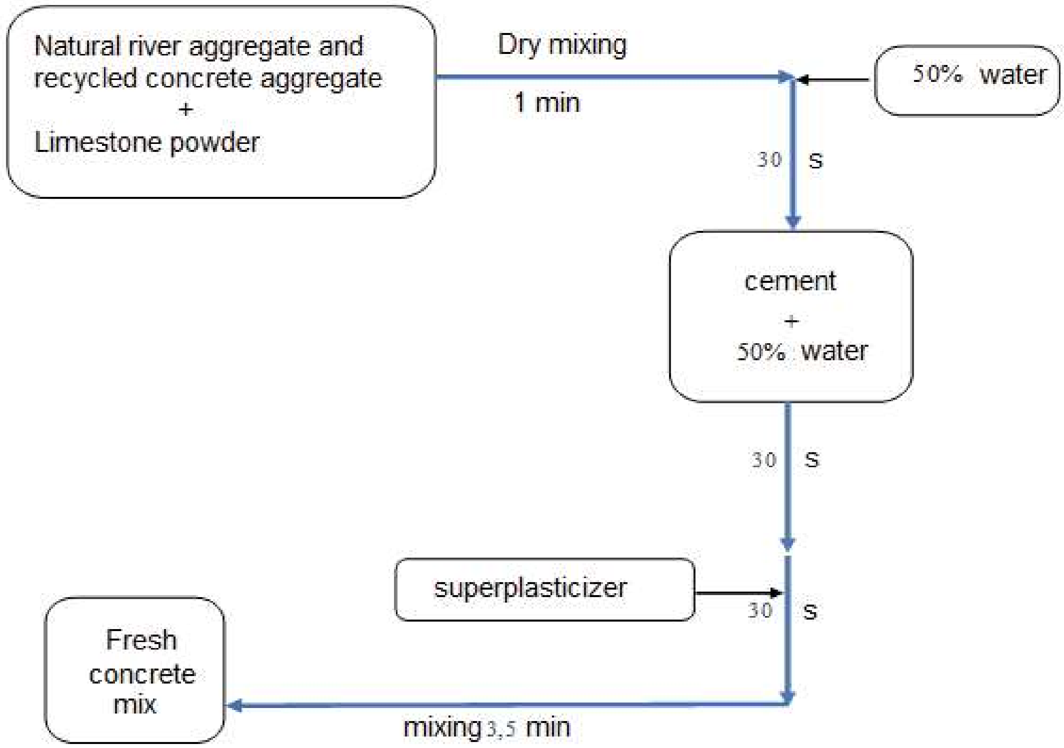

Figure 2: Scheme of the TSMA used for preparation of SCC mixtures

The scope of the conducted experimental tests

A number of tests were performed in order to estimate the possibility of recycled concrete aggregate use in SCC mixtures. These tests included both fresh and hardened concrete properties, regarded as important from the engineering point of view for the use in reinforced concrete structures. Flowability of fresh mix was determined using slump flow test [4], viscosity of concrete was tested using V-funnel [5], while both flowability and passing ability were determined using L-box test [6]. As for the tests conducted on hardened SCC mixtures, compressive strength as the most important property of concrete was measured after 1, 7 and 28 days [7]. Tensile strength properties of concrete mixtures were estimated at 28 days through several tests: flexural [8], splitting [9] and bond strength [10]. In addition, static [11] and dynamic moduli [12] of elasticity were obtained for all mixtures, at the age of 28 days. The tests were conducted in triplicate.

Properties of the fresh SCC mixtures

All of the fresh SCC mixtures properties obtained by testing are shown in the Table 2. The values of the slump flow (SF=840-890 mm) classified all of the mixtures close to the upper limit of the third consistency class SF3, according to the standard SRPS EN 206:2017 [13]. The mixtures SCC I and SCC II exceeded the limit of 850 mm. With the same amount of aggregates, but different amounts of water, the property of

flowability of all three SCC mixtures can be regarded as adequate, especially having in mind the fact that in time it can drastically drop, due to the water absorption of aggregate, and fading of the superplasticizer effect.
Measured time t_{500} was ≥2 s (class VS2), being the lowest (fastest flow) for the reference SCC I, and the highest (slowest flow) for SCC III – made with equal contents of coarse natural river aggregate, and recycled concrete aggregate. The range of the t_v values recorded in the V-funnel test were the broadest, putting SCC I in class VF1 and mixtures SCC II and SCC III in class VF2 (values higher than 9 s). Again, the mixture SCC III had the slowest flow, but only 2.2 s slower than SCC II (made without coarse natural aggregate). The L-box test with three rebars showed total levelling of SCC I and SCC III (PL2=1.00), while the final SCC II position in the horizontal part of the L-box had almost horizontal surface (PL2=0.94).
As expected, bulk density of the fresh SCC I had the highest value of 2380 kg/m^3, and the value for SCC II was the lowest – 2352 kg/m^3. This relation of the values can be explained by the lower bulk density of recycled concrete aggregate in comparison with natural aggregate. Although expected around the average of the previous two, the value of bulk density for SCC III (2355 kg/m^3) was closer to the SCC II. Most probably, the higher content of water in this fresh mixture, along with the worse packing of the aggregate grains, was the reasons for this.

Table 2: Fresh SCC mixtures properties

Mixture	SCC I	SCC II	SCC III
Slump flow - SF (mm)	890	870	840
Time t_{500} (s)	2.0	2.5	3.7
Time t_V (s)	7.4	12.4	14.6
L-box test PL (-)	1.00	0.95	1.00
Bulk density of fresh SCC (kg/m^3)	2380	2352	2355

Properties of the hardened SCC mixtures

Compressive strength, as the most important property of concrete, was measured after 1, 7 and 28 days. Tensile strength properties of concrete mixtures were estimated through several tests: flexural, splitting, and bond strength. In addition, static and dynamic moduli of elasticity were obtained for all mixtures.
Compressive strength increase in time is shown on Figure 3. As it can be seen on the graph, all of the SCC mixtures achieved similar values of target 28 days' strength ranging from 52.1 MPa (for SCC III), through 53.2 MPa for SCC II, up to 53.8 MPa for SCC I. These values are related directly to the strength law, governed by the same water to cement ratio. Therefore, the obtained differences can be attributed to the stochastic character of the investigation. Also, the obtained values of compressive strength correspond to the strength class C40/50, according to the SRPS EN 206:2017, which is higher than conventionally used concrete.
The more noticeable difference in the compressive strength values of the mixtures at the ages of 1 and 7 days indicate the different behaviour of younger SCC mixtures, which is most probably due to the difference in the aggregate used (natural in SCC I, both natural and RCA in SCC III, and RCA in SCC II). Namely, the fastest increase in

strength can be found in SCC I, reaching 56.4% of the final 28d strength at the age of 1 day, and 82.1% of the final strength at the age of 7 days. Slower compressive strength increase trend is noticeable for the mixture SCC III (49.9% and 78.9% for 1 day and 7 days respectively) and the lowest for the SCC II mixture (42.4% and 74.5% for 1 day and 7 days respectively).

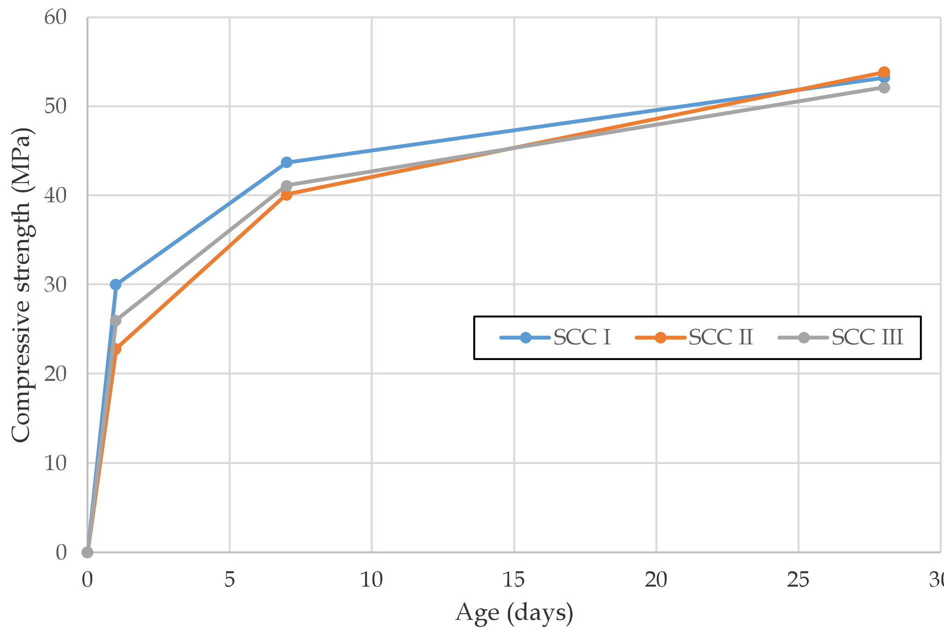

Figure 3: Compressive strength increase in time

The tensile strengths (flexural, splitting and adhesion) of the SCC mixtures at the age of 28 days are presented on Figure 4. Obviously, all mixtures had similar values for each of the strengths investigated. The achieved splitting and adhesion (bond) strengths were similar, approximately 3-3.5 MPa. As for the flexural strength, the achieved values were approximately twice higher than that, reaching 6.5-6.8 MPa.

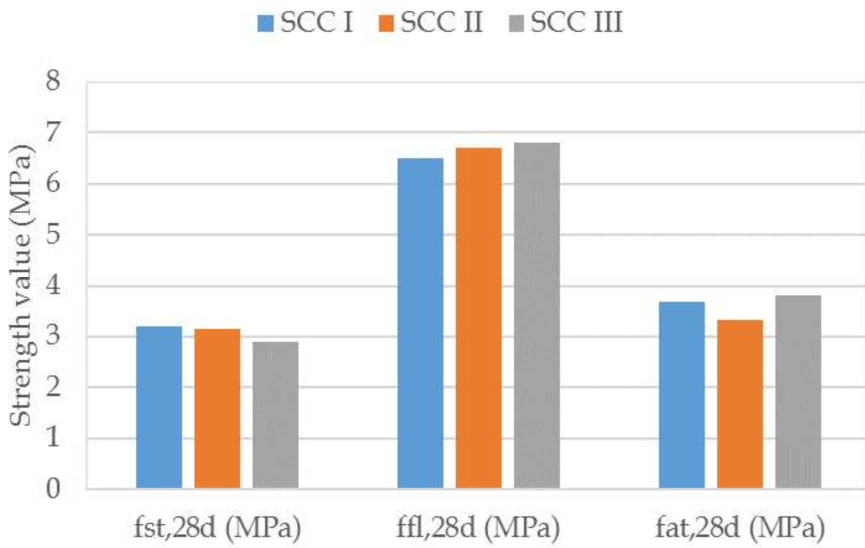

Figure 4: Tensile 28d strengths (splitting f_{st}, flexural f_{fl}, and adhesion f_{at})

The static and dynamic moduli of elasticity of the SCC mixtures at the age of 28 days are presented on Figure 5. The values of static modulus of elasticity ranged between 39.8 GPa and 41.8 GPa, while values of dynamic modulus of elasticity ranged between 40.1 GPa and 44.4 GPa. The obtained values fall in quite narrow range, testifying of the similar properties of the tested mixtures.

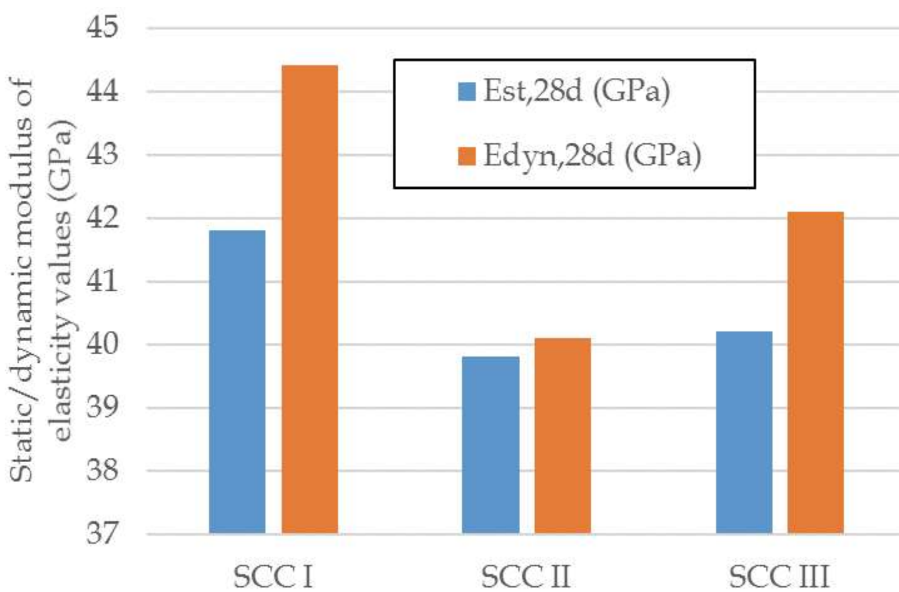

Figure 5: Static E_{st} and dynamic E_{dyn} moduli of elasticity of the SCC mixtures at 28d

As expected, values of dynamic modulus of elasticity are higher than the values of static modulus of elasticity for all mixtures. The reference mixture SCC I had the highest values of both moduli of elasticity, most probably due to the use of solely natural aggregates. On the other end of the range SCC II is found, with the lowest values of both moduli of elasticity, due to the use of coarse recycled concrete aggregate. Also, values of static and dynamic moduli of elasticity are the closest for this mixture. Both the difference between the values of static and dynamic moduli of elasticity, and their absolute values for SCC II were found to be between the two already mentioned mixtures, which can be connected to the miscellaneous coarse aggregate in this mixture.

Conclusions

This paper addresses the current issues in contemporary building industry, more precisely, concrete technology. The complex principles implemented in production of modern special type of concrete, Self-Compacting Concrete (SCC) were applied, together with the ones regarding the omnipresent topic of sustainable development through the use of waste recycled concrete aggregate.

When SCC is being made, one must have in mind the composition of the mixtures and the consequences of the variations in components ratios. Also, a set of investigations is compulsory to provide a proper categorization of SCC, concerning its fresh properties.

Regarding the use of recycled coarse aggregate, the insight into its properties, and main distinctions from natural aggregate, play a key role in successful design of "green" concrete mixtures. These mixtures should be applied more often, in order to push building industry faster, towards sustainability.

In this study, the negative effect of the higher water absorption and lower mechanical properties of recycled concrete aggregate were shown to be minimized through measurements of water absorption, and the use of Two Stage Mixing Approach.

In fresh state, all studied mixtures were placed on the upper bond of slump flow values for SCC, reaching approximately 850 mm (lowest bond value being 550 mm). Having in mind that, with time, slump flow value of this kind of concrete can drop fast, all three SCC mixtures can be regarded as adequate. All the other tests, done on fresh SCC mixtures (t_{500}, t_v, L-box), showed acceptable results. Bulk density of the fresh SCC mixtures displayed the expected trend of decrease, with the increase in recycled concrete aggregate content.

Hardened SCC mixtures tests included compressive strength (at 1, 7 and 28 days), tensile strength (through flexural, splitting and bond strength, all at the age of 28 days) and finally, static and dynamic moduli of elasticity at the age of 28 days.

The values of 28d compressive strength correspond to the higher than typical strength class C40/50, according to the SRPS EN 206:2017, for all three SCC mixtures. A note should be made that early strengths of the SCC mixtures with recycled concrete aggregate were found to be lower than reference. All three tensile strength achieved the values usual for conventional concretes, and similar values were obtained for all SCC mixtures. The obtained values of static and dynamic moduli fall in quite narrow range.

The studied results, in particular the values of compressive strength, show that similar properties were recorded for all mixtures, regardless of the aggregate type used. From the point of sustainable development, this argument serves as a verification of the methodology used, and proves that the successful application of recycled concrete aggregate in SCC mixtures is not only possible, but also necessary.

Acknowledgements

The work reported in this paper is a part of the investigation within the research project TR 36017 ''Utilization of by-products and recycled waste materials in concrete composites in the scope of sustainable construction development in Serbia: investigation and environmental assessment of possible applications'', supported by the Ministry of Science and Technology, Republic of Serbia. This support is gratefully acknowledged.

References

[1] 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, Belgrade, 2015.

[2] Pavlović, D., *Fizičko-mehanička svojstva SCC betona sa recikliranim agregatom*, Master thesis, Faculty of Civil Engineering, Belgrade, 2017.

[3] Kovačević, B., *Ispitivanje SCC betona sa delimičnom zamenom prirodnog agregata recikliranim*, Master thesis, Faculty of Civil Engineering, Belgrade, 2017.

[4] SRPS EN 12350-8:2012, *Testing fresh concrete - Part 8: Self-compacting concrete - Slump-flow test*, Institute for standardization of Serbia, 2012.

[5] SRPS EN 12350-9:2012, *Testing fresh concrete - Part 9: Self-compacting concrete - V-funnel test*, Institute for standardization of Serbia, 2012.

[6] SRPS EN 12350-10:2012, *Testing fresh concrete - Part 10: Self-compacting concrete - L box test*, Institute for standardization of Serbia, 2012.

[7] SRPS EN 12390-3:2018, *Testing hardened concrete - Part 3: Compressive strength of test specimens*, Institute for standardization of Serbia, 2018.

[8] SRPS EN 12390-5:2018, *Testing hardened concrete - Part 5: Flexural strength of test specimens*, Institute for standardization of Serbia, 2018.

[9] SRPS EN 12390-6:2012, *Testing hardened concrete - Part 6: Tensile splitting strength of test specimens*, Institute for standardization of Serbia, 2012.

[10] SRPS EN 1542:2010, *Products and systems for the protection and repair of concrete structures - Test methods - Measurement of bond strength by pull-off*, Institute for standardization of Serbia, 2010.

[11] SRPS EN 12390-6:2012, *Testing hardened concrete - Part 13: Determination of secant modulus of elasticity in compression*, Institute for standardization of Serbia, 2012.

[12] SRPS U.M1.026:1993, *Concrete - Determination of the dynamic modulus of elasticity and Poisson's ratio*, Institute for standardization of Serbia, 1993.

[13] SRPS EN 206:2017, *Concrete - Specification, performance, production and conformity*, Institute for standardization of Serbia, 1993.

GEOPOLYMERS BASED ON RED MUD