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SVOJSTVA SCC MEŠAVINA SA KRUPNIM RECIKLIRANIM AGREGATOM

Rezime:

U radu su prikazani rezultati fizičko-mehaničkih ispitivanja betona sa krupnim recikliranim agregatom. Napravljene su četiri serije samougrađujućeg betona (Self-Compacting Concrete – SCC), sa upotrebom recikliranog agregata od betona (Recycled Concrete Aggregate – RCA) kao zamene za obe frakcije prirodnog krupnog agregata. Ove serije projektovane su uz primenu postupka mešanja iz dve faze (Two Stage Mixing Approach - TSMA) uz praćenje svojstava betona u svežem i očvrslom stanju. Sposobnost tečenja svežeg betona je praćena pomoću testa rasprostiranja sleganjem, a urađena su i ispitivanja uz pomoć V-levka i L-boksa. Utvrđene su vrednosti čvrstoća pri pritisku, kao i čvrstoće pri savijanju, cepanju i prionljivost (pull-off). Sve mešavine pokazale su zadovoljavajuća svojstva, što opravdava upotrebu recikliranog betona u svojstvu agregata za SCC betone.

Ključne reči: agregat od recikliranog betona, samougrađujući betoni, postupak mešanja

PROPERTIES OF SCC MIXTURES WITH COARSE RECYCLED AGGREGATES

Summary:

Paper presents the results of physical and mechanical testing of concrete mixtures prepared with recycled concrete aggregate. Four series of Self-Compacting Concrete (SCC) were made, with the use of recycled concrete aggregate (RCA), as a substitute for both natural coarse aggregate fractions. These series were designed using the Two Stage Mixing Approach (TSMA), and the properties of the obtained concrete mixtures in fresh and hardened state were recorded. Flowability of fresh mix was determined using slump flow test, while V-funnel and L-box tests were also performed. Compressive strength and also flexural, splitting and bond (pull-off) strength were determined. All the mixtures showed favourable properties, proving the possibility of the recycled concrete aggregate use for production of worthy SCC.

Key words: recycled concrete aggregate, self-compacting concrete, mixing method

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1 INTRODUCTION

Unquestionably, construction industry presents a branch of industry with significant environmental impact. Contemporary approach, in accordance with sustainable development postulates, integrates three main stages: a critical study as the first, followed by a thorough analysis as the second and, in the case that it is possible and practical, modernization by implementing the philosophy of sustainable development. In this regard, all activities of construction (planning, design, implementation, operation, duration and life expectancy, etc.) are constantly under review, providing more sustainable use of resources, promotion of energy efficiency and sustainability of buildings, with an emphasis on recyclable materials and minimizing waste. [1]

In general, concrete is one of the most commonly used material in the construction industry and the above considerations provide a significant impact on its current evolution. Conventional concrete is placed using vibrating equipment to provide reduction in entrained air content, eliminating the presence of caverns and weak spots on the contact with reinforcement bars and formwork (so-called Normal Vibrated Concrete - NVC).

Extrapolation of the concept of superplasticizers use in the direction of obtaining fluid consistency of concrete has led to the concept 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 20^{th} century, enabled the successful implementation of SCC. The definition of self-compacting concrete states that this concrete, without the use of mechanical means of placement (quite 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.

Having in mind the fact that for the production of 1 m^3 of concrete almost 1 m^3 of aggregate is utilized [3], a reduction in natural aggregate consumption represents a logical step towards implementation of sustainable development postulates in this production. Different kinds of recycled aggregate are made and experimented with, and C&D (construction and demolition) waste concrete (as recycled concrete aggregate – RCA) became one of the logical solutions to this problem [4].

The dominant disadvantage of RCA in comparison to the natural aggregate (NA), river gravel or crushed stone, is the so-called 'residual cement paste' that stays as part of RCA particles after crushing of C&D concrete. This is actually a part of the hardened cement paste around the NA aggregate particles in the original concrete being recycled. The main implication of the presence of this residual cement paste is higher water absorption of RCA compared with NA, and therefore fast and reliable measurement of water absorption becomes a very important segment in determination of aggregate properties before the production of new concrete [5].

Tam et al. [6] came up with a new mixing approach which they defined as the two stage mixing approach (TSMA) and experimentally observed that this technique for mixing of ingredient of concrete (consisting of new sequence of mixing ingredient) gives better compressive strength.

Regardless of the water absorption measurement, and the method applied to reduce the negative impact of this to the water to cement ratio in concrete, this parameter remains critical, especially when it comes to the production of SCC, which is, almost by default, sensitive to the water content, and the water content changes. Also, the aspect of mechanical properties reduction with the use of RCA amplifies when SCC with RCA is produced. It is of high importance to have recycled aggregate of high quality, in order to obtain favourable physical and mechanical properties of concrete. This is not always the case, having in mind that the C&D concrete waste does not necessarily have the needed properties.

2 EXPERIMENTAL PROGRAMME

2.1 SCOPE AND OBJECTIVE

The aim of this study was to investigate the influence of the coarse recycled concrete aggregate on physical and mechanical properties of self-compacting concrete mixtures, both in fresh and hardened state. Mixture of aggregate consisted of natural and recycled aggregate, divided in three standard fractions: I (0/4 mm), II (4/8 mm), and III (8/16 mm). For this purpose four different mixtures were prepared:

- Referent mixture, designated as SCC I, prepared with natural river aggregate,
- Mixture designated as SCC II, made with fraction II (4/8 mm) composed only of recycled concrete aggregate, and with natural river aggregate fraction III (8/16 mm),
- Mixture designated as SCC III, made with natural river aggregate fraction II (4/8 mm), and with fraction III (8/16 mm) composed only of recycled concrete aggregate,
- Mixture with both II and III fractions composed only of recycled concrete aggregate, designated as SCC IV.

Mixtures were defined using the principle of equal effective water/cement ratios. Mixtures containing recycled concrete aggregate had additional amount of water 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. Mixing technique was consistent with the algorithm shown in Figure 1.

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 degrade, due to the use of recycled concrete aggregate instead of natural aggregate, and also to investigate the recycled aggregate grain size as the parameter.

2.2 MATERIALS

Aggregates used for preparing the concrete mixtures were natural river aggregate, separated in three fractions and coarse recycled concrete aggregate, separated in two fractions. 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 mass of the aggregate. Second fraction (4/8 mm) was used in 32.2% (530 kg/m^3)and third fraction (8/16 mm) in 18.2% (310 kg/m^3).

Natural aggregate was standard, commercially available river gravel from the Danube river.

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 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 [7,8].

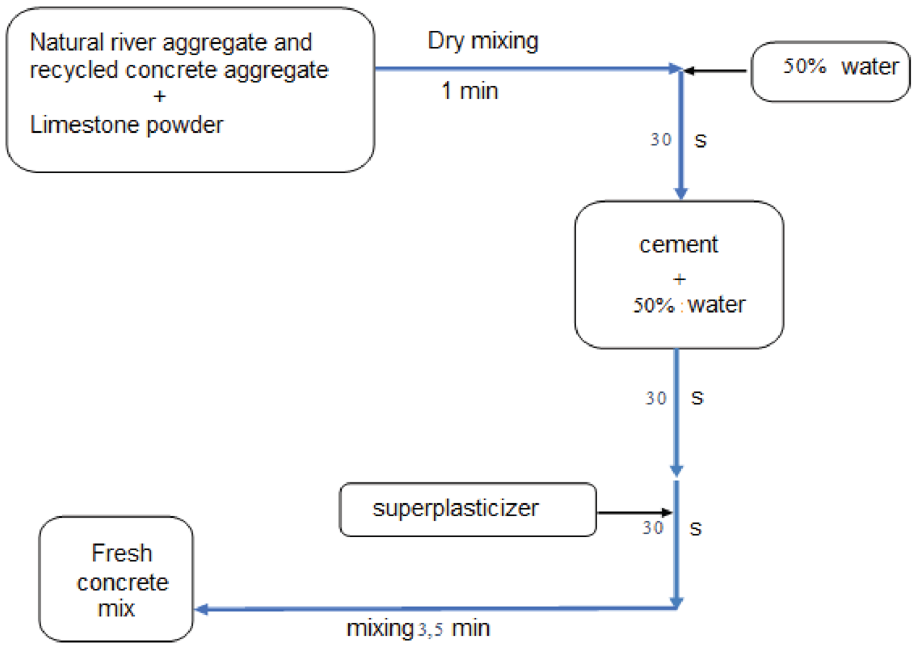

Figure 1 – Scheme of the TSMA used for preparation of concrete mixture

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. True density of cement was 3.040 g/cm^3, with specific surface of 4240 cm^2/g.

Superplasticizer Cementol Hiperplast 463 produced by TKK, Srpenica, was also applied with density of 1.08 g/cm^3 [7,8].

2.3 MIXTURES

Composition of the four 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 mixtures with quantity of powder component of more than 550 kg/m^3. The quantities of the superplasticizer were also the same for all the mixtures, providing practically similar values of the slump flow. The fine aggregate fraction I (0/4 mm) was natural aggregate for all the mixtures.

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

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

3 RESULTS AND DISCUSSION

Various tests of fresh and hardened concrete were performed in order to estimate the possibility of using recycled concrete aggregate within SCC mixtures. Flowability of fresh mix was determined using slump flow test [9], viscosity of concrete was tested using V-funnel [10] and flowability and passing ability were determined using L-box test [11]. 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.

3.1 FRESH MIX PROPERTIES

Bulk densities of fresh mixes varied from 2352 kg/m^3 (mixture SCC IV) to 2386 kg/m^3 (mixture SCCII). Table 2 incorporates the following results: final flow diameter (SF) and time in which concrete sample reaches diameter of 500 mm (t_{500}), V-funnel time (t_v), hight ratio within L box (PA) and related time t_f.

According to limits defined in specifications and guidelines for SCC [12], concrete mix named SCC III belongs to SF3 class, while all the other mixtures had slump-flow diameter larger than the upper limit for this class (850 mm). Time t_{500}, measured during slump flow test, placed all the mixtures in VS2 class. These results show that all the mixtures had very good flowability. Differences between the properties of fresh mixtures were more noticeable when comparing their viscosity, through V-funnel test. Mixtures SCC I and SCC III belong to VF1 class, according to V-funnel test, while mixtures SCC II and SCC IV belong to VF2 class. It can be noted that the highest viscosity was obtained for mixtures with the highest amount of recycled concrete aggregate. These observations were confirmed with the time measured during the L-box test (t_f). The highest values for t_f were measured for the mixture SCC IV followed by mixture SCC II. All the mixtures satisfy the condition for PA2 class in relation to the hight ratio results of the L-box test. No blocking effect was noticed for any of the mixtures.

Table 2 – Fresh mix properties

Property	SCC I	SCC II	SCC III	SCC IV
SF (mm)	890	865	840	870
t_{500} (s)	2.0	2.1	2.3	2.5
t_v (s)	7.4	11.2	7.5	12.4
PA (-)	1.00	0.97	0.94	0.94
t_f(s)	3.8	5.1	4.1	7.1

3.2 HARDENED CONCRETE PROPERTIES

Compressive strength was tested for all the mixtures after 1, 7 and 28 days. Tests were performed on the cubes (a=10 cm) according to the SRPS EN 12390-3:2018 [13], and results are presented in Figure 2.

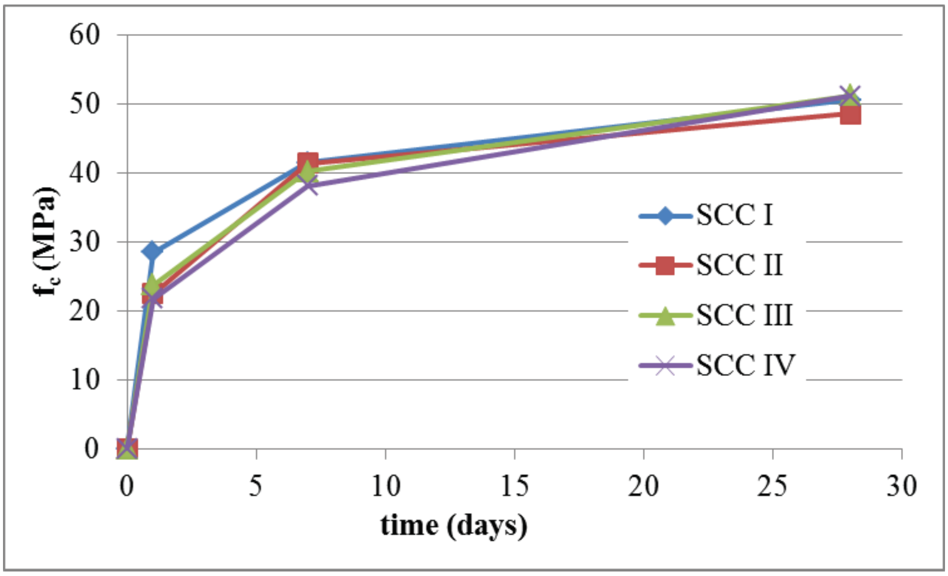

Figure 2 – Compressive strength of concrete mixtures at the ages of 1, 7 and 28 days

Compressive strengths of the studied series reached similar values at all ages. The biggest differences between the measured values can be noticed at the early ages (after 1 day). At this time the referent mixture, SCC I, had the highest value of compressive strength, followed by mixture SCC III that reached 83.5% of the strength of SCC I. Mixtures SCC II and SCC IV at this point had very similar values, equalling 79.1% and 76.0% of the referent mixture strength. At the age of 28 days the differences were considerably smaller. Mixture SCC II had 5% lower strength than referent mixture, while mixtures SCC III and SCC IV reached approximately the same values as referent mixture (1% higher).

Tensile strength of concrete was indirectly tested at the age of 28 days using three different methods: flexural test [14], splitting test [15] and the bond test [16]. Flexural tests were performed on the prismatic samples, 12×12×36 cm as three point bending test. Splitting test was performed on the cubes (a=15 cm), while pull-off test was performed with metal plates (d=50 mm) that were glued using epoxy resin to the surface of concrete. Results of these tests are presented in Figure 3.

Most probably due to the better packing of the sharp-edged recycled aggregate grains, the highest flexural strength was reached for mixtures containing 100% of coarse recycled concrete aggregate (SCC IV) and the mixture where 100% of the III fraction was replaced by recycled concrete aggregate (SCC III). Similarly, these mixtures reached high values of splitting strength, namely 98.4% (SCC IV) and 94.4% (SCC III) of the referent mixture strength.

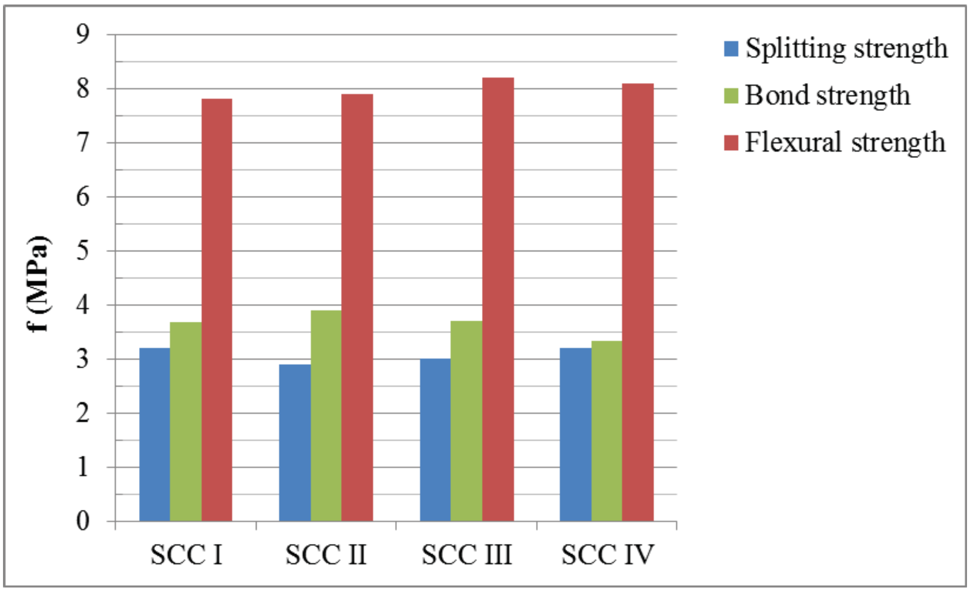

Figure 3 – Flexural, splitting and bond strength (pull-off) of concrete mixtures at 28 days

On the other hand, bond strength (determined by pull-off method) was highest for the mixture SCC II, where fraction II was replaced with recycled concrete aggregate, while the lowest bond strength was recorded for the mixture SCC IV. Flexural strength was 2.5 times higher than splitting strength of concrete for mixtures SCC I and SCC IV, while this ratio equalled 2.7 for mixtures SCC II and SCC III.

Dynamic and static modulus of elasticity were measured at the age of 28 days. As it was expected, dynamic modulus values were higher, but followed the same trend as static modulus values [17]. Dynamic modulus was measured using resonant frequency method [18], while static modulus was measured according to SRPS EN 12390-13 [19]. Results of these tests are presented in Figure 4.

The highest modulus of elasticity was measured for referent mixture, as it was expected, but the mixture SCC III had almost identical values. Static modulus of elasticity for the other two mixtures was less than 5 % lower than the static modulus of the referent mixture. Dynamic modulus of elasticity was the lowest for the mixture SCC IV, which contained the highest content of the recycled concrete aggregate.

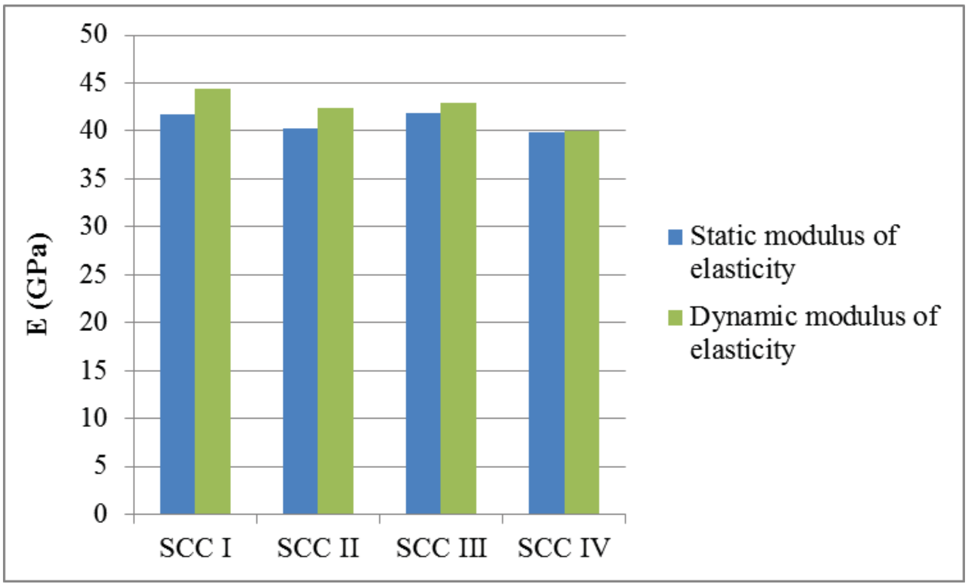

Figure 4 – Static and dynamic modulus of elasticity of concrete at the age of 28 days

4 CONCLUSIONS

In this paper, the influence of recycled concrete aggregate content on the fresh and hardened mix properties was investigated. Based on the results presented in the previous section, the following conclusions can be drawn:

- Mixtures with recycled concrete aggregate showed good flowability, but higher viscosity than referent mixture. This is especially the case for the mixtures SCC II (only fraction II consisted of recycled coarse aggregate) and SCC IV (where the total coarse aggregate consisted of recycled concrete aggregate). No blocking effect was noticed in any of the mixtures.
- Differences in compressive strength were the highest at the early age of mixtures. After 28 days compressive strength was very similar for all the mixtures, being highest for the mixture SCC III (1.4% higher than the strength of the referent mixture) and lowest for the SCC II (3.9% lower than the strength of the referent mixture).
- Flexural strength was the highest for the mixture SCC III, but the differences between the mixtures ranged from 2% to 5%.

- Splitting strength was the highest for the referent mixture, but the differences between this and the other three mixtures were lower than 10%.
- Static modulus of elasticity was equivalent for mixture SCC III and the referent mixture. Differences in comparison to the moduli of mixtures SCC II and SCC IV were lower than 5%.
- Dynamic modulus of elasticity reached higher values than static modulus, but followed the same trend.

Moreover, a note has to be made that there was no negative effect on the mechanical properties due to the presence of additional water for the SCC. Similar properties of all mixtures were achieved for both coarse aggregate fractions replacement, showing no significant differences when aggregate size is taken as a parameter, and this can be explained by the fact that this study was conducted with recycled aggregate of good properties and in laboratory conditions.

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