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Novi Sad, Srbija
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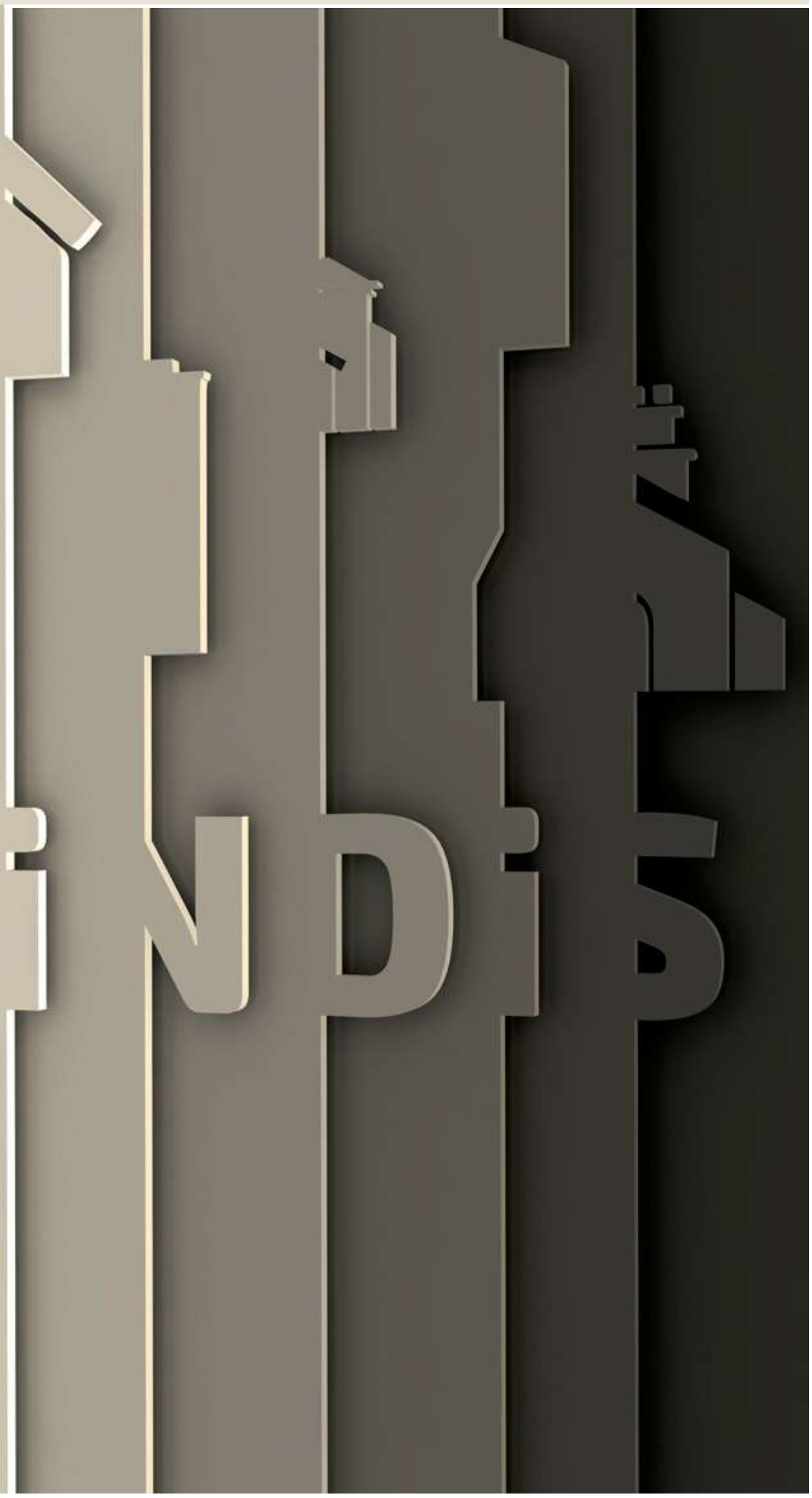

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DEPARTMAN ZA ARHITEKTURU I URBANIZAM

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THE USE OF INDUSTRIAL BYPRODUCTS AS FILLERS IN SELF-COMPACTING CONCRETE

Abstract: This paper presents results of the study conducted on five series of Self-Compacting Concrete (SCC) made with different mineral fillers. Beside the reference series, made with limestone powder as mineral filler, three series were made with 50% of mass replacement of limestone powder with ground recycled concrete, and one made with 50% of mass replacement of limestone powder with fly ash. Slump flow, time t_{500}, density, and temperature were tested on fresh series, while compressive strength and water permeability were tested on hardened concrete. All of the series showed acceptable properties, providing a positive impulse for use of industrial byproducts as mineral fillers for SCC production.

Key words: SCC, mineral filler, fly ash, ground concrete, fresh and hardened concrete

UPOTREBA INDUSTRIJSKIH NUSPRODUKATA U SVOJSTVU FILERA ZA SAMOUGRAĐUJUĆE BETONE

Rezime: U radu su prikazani rezultati istraživanja sprovedenog na pet serija samougrađujućeg (Self-Compacting Concrete – SCC) betona, spravljenih sa različitim mineralnim dodacima. Osim referentne, spravljene sa krečnjačkim brašnom kao mineralnim dodatkom, tri serije su spravljene sa 50% masene zamene krečnjačkog brašna sprašenim recikliranim betonom i jedna sa 50% masene zamene krečnjačkog brašna letećim pepelom. Rasprostiranje sleganjem, vreme t_{500}, zapreminska masa i temperatura su ispitivani na svežem betonu, dok su čvrstoća pri pritisku i vodonepropustljivost ispitivane na očvrslim betonima. Sve serije pokazale su prihvatljiva svojstva, što daje pozitivan impuls za upotrebu industrijskih nusprodukata kao mineralnih filera za proizvodnju SCC betona.

Ključne reči: SCC beton, mineralni filer, leteći pepeo, sprašeni beton, sveži i očvrsli beton

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1. INTRODUCTION

One of the main obstacles to the proper development of the construction industry is the pronounced use of natural resources, mainly natural aggregate, whether of crushed stone, or riverbed origin. Moreover, huge quantities of raw materials (mostly limestone, clay, marl or shale) are used for cement production. The activities connected to building materials production involve energy demanding processes, and usually include emission of unwanted substances (gaseous, liquid or solid waste) materials into the environment. In order to deal with the stated challenges, in an environmentally responsible way, the use of industrial byproducts tends to be implemented in the production processes of certain niches of the construction industry.

The reduction in quantities of waste disposed in landfills can be achieved by utilization of old, demolished concrete as concrete aggregate. This material is already used for production of new concrete, as recycled concrete aggregate, but can be also found in form of the powder [1]. Thus, recycled powder component can be utilized for production of Self-Compacting Concrete (SCC).

Self-Compacting Concrete is characterized by its high fluidity in fresh state, which enables this concrete to fill the formwork and pass through narrow spaces between re-bars without any means of compaction. On the other hand, SCC has to be prone to segregation, which is achieved through the use of mineral fillers (powder component of SCC) and/or Viscosity Modifying Admixtures (VMA).

The filler in SCC is usually limestone or dolomite powder, but sometimes, for this purpose fly ash is used. Fly ash represents the fine material collected during the coal combustion process in the electrostatic precipitation or filter bags in thermal power plants. This material, which has pozzolanic properties, can be regarded as industrial byproduct, because of the huge areas of landfills where it is disposed. In Serbia, these landfills cover more than 1500 hectares [2]. The use of fly ash of thermal power plants in modern concrete can reduce the need for water up to 15-20% [3], which leads to a reduction of the pores and voids, reduction of drying shrinkage, and preventing the penetration of aggressive materials from the environment. The greater the amount of spherical particles of fly ash in the paste, the greater is the lubrication effect of aggregate, and higher mobility of SCC can be achieved.

This paper presents the results of study, where the powder component of SCC was partially replaced with industrial byproduct [4]. This was done in order to valorize the effects of the use of industrial byproducts, utilized as partial replacement of filler, on physical and mechanical properties of SCC. The used byproducts were fly ash, or ground recycled concrete, replacing limestone powder as reference filler.

2. MATERIALS

The materials used in this study were: natural river aggregate, three mentioned types of fillers (limestone powder, fly ash, and ground concrete), cement, chemical admixture and water. This research was performed in the Laboratory for materials, Institute for materials and structures, Faculty of Civil Engineering, University of Belgrade.

2.1. Aggregate

The river aggregate, originated from the Danube river and divided into fractions - I (0/4), II (4/8) and III (8/16), was used for the production of SCC mixes. The gravity of this aggregate was 2.641 g/cm^3, while bulk density in loose state was approximately 1.600 g/cm^3. Sieve passing percentages of the three used aggregate fractions are presented together with the sieve passing curve of a mixture of aggregates on Figure 1.

Modulus of fineness of the fine aggregate (0/4 mm) was 2.92 and satisfied the conditions defined in the standard, with limit values 2.3-3.6. Moduli of fineness of second (4/8 mm) and third (8/16 mm) fraction were 6.04 and 6.99 respectively. Content of fine particles in the first fraction was 0.59% for particles smaller than 0.063 mm, and 1.68% for particles smaller than 0.09 mm. In the coarse aggregate this content was close to zero. Based on the previous tests, sieve passing curve of the mixture was set to 48.9% of the fine aggregate, and 25.5% of second and 25.5% of the third fraction of the coarse aggregate (Fig. 1).

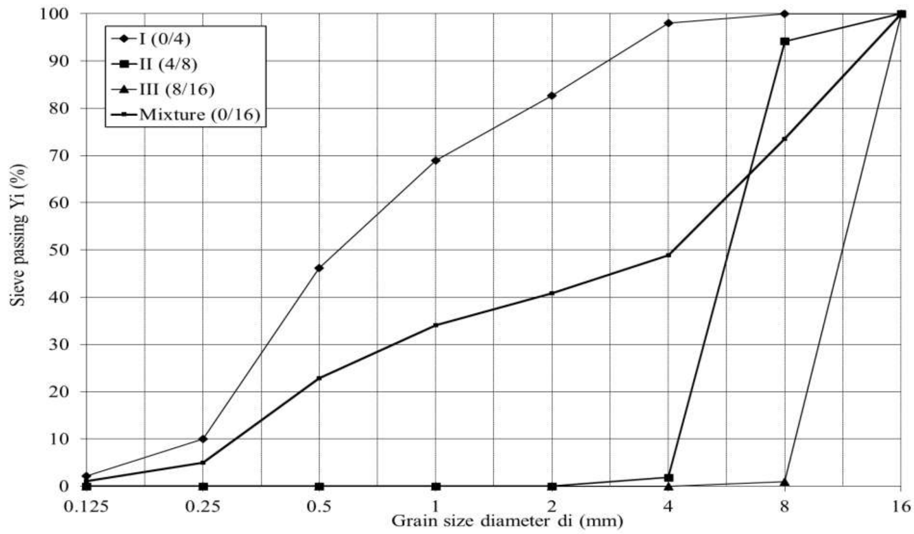

Figure 1 –Sieve passing percentages of the used fractions of aggregate (together with the granulometry of the mixture)

2.2. Fillers

Reference filler component for all of the mixtures was limestone powder produced by "Granit Peščar" Ljig, with an average particle diameter of 250 μm. The specific surface of limestone powder was 3800 cm^2/g, while its density was 2720 kg/m^3. Chemical content of this filler together with chemical content of RCA powders and the used fly ash are presented in Table 1.

RCA powders named mineral fillers RA, RB and RC originated from three types of fine aggregate from three different concrete mixtures with declared content:

- Normally vibrated concrete (NVC) made with natural aggregate. This concrete was crushed and then fractioned. The finest fraction (0/4 mm) was ground to a filler component named mineral filler RA;
- Normally vibrated recycled concrete (RAC50), made with river sand and coarse aggregate that presented combination of 50% of river aggregate and 50% of recycled aggregate (originated from demolished concrete). The concrete was crushed and then fractioned. The finest fraction (0/4 mm) was ground to a filler component named mineral filler RB;
- Normally vibrated recycled concrete (RAC100), made with river sand and coarse recycled aggregate (originated from demolished concrete). The concrete was crushed and fractioned. The finest fraction (0/4 mm) was ground to a filler component named mineral filler RC.

Granulometry of these fillers was similar, while their specific surface was 4400 cm^2/g. The greatest differences in chemical content were as expected in higher content of SiO_2 and Al_2O_3

and lower content of CaO in the RCA filler than in the limestone powder. The content of SiO_2 was the highest in the mineral filler A, due to the exclusive use of river aggregate as coarse aggregate in its „parent" concrete.

For fly ash originating from "Kolubara“, the contents of reactive SiO_2 and CaO were 58.60% and 6.12%. Sampling and packing of fly ash was done by workers of the power plants. 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.

Table 1- Chemical content of the used fillers

Filler (%)	Limestone powder	Mineral filler A	Mineral filler B	Mineral filler C	Fly ash
SiO_2	0.21	67.13	60.55	61.31	58.60
Al_2O_3	0.5	6.58	6.84	6.65	21.92
CaO	54.86	12.94	17.77	16.06	6.12
Fe_2O_3	0.09	1.33	1.32	1.32	5.97
MgO	1.10	0.76	0.94	0.86	1.77
K_2O	0.05	0.86	0.83	0.79	1.50
Na_2O	<0.005	1.27	1.13	1.05	0.37
TiO_2	<0.005	<0.17	<0.17	<0.17	0.49
Loss on ignition	43.64	9.11	10.59	11.93	3.09

2.3. Cement, chemical admixture and water

Portland cement of the type CEM I was used, declared as PC 42.5, produced by Lafarge, Beočin. The specific surface of the cement, according to Blaine, was 4240 cm^2/g, while its density was 3040 kg/m^3. Superplasticizer Glenium Sky 690, produced by BASF Italia (density 1060 kg/m^3) was used, in the amount of 2% of the cement mass, except in the case of mixture with fly ash, where a higher dosage had to be used, to enable this mixture to possess fresh properties of SCC. Water from the city water supply system was used in concrete mixtures. Temperature of water was measured before each mixing, and it ranged between 19 and 22°C.

3. MIXTURES AND METHODS

Five series of SCC were made: reference, three mixtures with different ground recycled concrete, and one series with fly ash, as presented in Table 2.

Table 2- Chemical content of the used fillers

Mixture	Water (kg/m^3)	Cement (kg/m^3)	Limestone powder (kg/m^3)	Mineral filler RA (kg/m^3)	Mineral filler RB (kg/m^3)	Mineral filler RC (kg/m^3)	Fly ash (kg/m^3)	Fine aggregate (0/4mm) (kg/m^3)	Coarse aggregate (4/8mm) (kg/m^3)	Coarse aggregate (8/16mm) (kg/m^3)	Superplasticizer (kg/m^3)
SCC - E	183	380	220	0	0	0	0	840	430	430	7.6
SCC - RA	183	380	110	110	0	0	0	840	430	430	7.6
SCC - RB	183	380	110	0	110	0	0	840	430	430	7.6
SCC - RC	183	380	110	0	0	110	0	840	430	430	7.6
SCC - F	183	380	110	0	0	0	110	840	430	430	11.4

In all of the presented series, the quantity of aggregate was held constant, 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). The quantity of cement was 380 kg/m^3 for all of the series, and the total quantity of filler was 220 kg/m^3. Series SCC-E contained only limestone powder as mineral filler, series SCC-RA, SCC-RB, and SCC-RC contained 50% limestone powder replacement with the corresponding ground recycled concrete, and the same principle was applied for the series SCC-F made with fly ash.

Tests made on fresh SCC series included: fresh concrete density, temperature, slump flow, and time t_{500}, while on hardened concrete compressive strength and water permeability were tested.

4. RESULTS AND DISCUSSION

The results of the fresh SCC tests are presented in Table 3. For each series a result presented in the table is an average of two measurements, except for the density, where the result is an average of five samples densities.

The measurements of all the mentioned properties were made within 15 minutes from the end of the mixing process. Also, temperatures of fresh concrete were monitored and ranged between 20.6°C for the SCC-E and 22.6°C for SCC-RC. Nevertheless, the loss of workability was noticed on the mixture with fly ash, although the temperature of the fresh mixture didn't deviate (22.0°C), and even the quantity of superplasticizer was higher than for the other series.

Table 3 – Fresh SCC properties

Mixture	Fresh concrete density (kg/m^3)	Slump flow (mm)	Time t_{500} (s)
SCC - E	2397	761	2.62
SCC - RA	2387	695	4.78
SCC - RB	2389	720	4.85
SCC - RC	2391	730	4.53
SCC - F	2370	664	10.9

Compressive strength was tested at 3, 7, 28 and 90 days. For each age, five 10 cm cubes were used to determine a compressive strength of each series. The results are presented in the Figure 2.

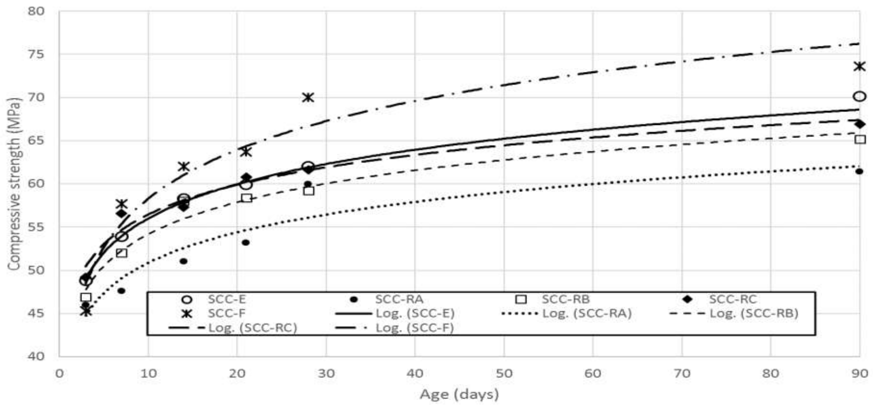

Figure 2 – Compressive strength increase in time

Water penetration depth was measured on three 15 cm cubes for each series, at the age of 63 days, after a following treatment time/pressure: 48h/1bar, then 24h/3bar, and for final 24h/7bar. After the test, samples were split in two, and thus the measurement of maximum penetration heights was calculated, the average value of the tree obtained penetration and the obtained maximum of three is shown in the Table 4.

Table 4 – Water penetration depth for the SCC series

Series	SCC - E		SCC - RA		SCC - RB		SCC – RC		SCC - F	
Water penetration depth (mm)	Aver.	Max.	Aver.	Max.	Aver.	Max.	Aver.	Max.	Aver.	Max.
	9.3	16.3	11.0	17.0	10.7	17.3	11.0	17.7	10.0	15.7

Figure 3 shows the measurement of the maximum penetration obtained on one of the samples from the series with ground recycled concrete.

Figure 3 – Maximum water penetration measurement obtained on a sample from SCC-RB series

5. CONCLUSIONS

In order to study the prospective of domestic fly ash, from the thermal power plant "Kolubara", which was used "as is" - in delivered state (without activation), as well as to valorize the potential of ground recycled concrete as mineral filler, five different series of SCC were made and tested in the fresh and hardened state. This plan of experiment was also influenced by the implementation of environmental aspect and sustainable development in civil engineering industry [5,6,7].

All of the series achieved good properties, regardless of the type of mineral addition used. Nevertheless, it was clear that a higher content of superplasticizer (3% of the cement mass) had to be used, when SCC with fly ash was used. Also, there was a drop in flowability (measured by slump flow) for SCC series with 50% ground recycled concrete (average decrease of 6%) as well as with 50% fly ash (12.7%) in comparison to the reference SCC, made with limestone powder as the only mineral filler. Additionally, time t_{500} was, on average, 80% higher for SCC series with 50% ground recycled concrete, and 3 times higher for SCC series with 50% fly ash.

Compressive strength values of the SCC series made with ground recycled concrete were up to 8.8% lower (for the use of ground normally vibrated concrete) than the compressive strength of the reference SCC series, at the age of 90 days. The presence of fly ash as mineral filler in SCC-F had a positive impact on compressive strength, providing up to 13.2% higher strength at the age of 90 days, for the SCC series with 50% mass replacement of limestone powder with fly ash. It has to be stressed out that this improvement 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.

Water permeability testing conducted on all of the SCC series, showed similar behaviour, testifying of the similar high compactness of all samples with very low values of water penetrations.

The following studies in this area could be systematization of the different influential factors of SCC series. This regards, especially, the properties of “parent” concrete mixtures of the filler (compressive strength, aggregate/cement paste ratio, age, origin, etc.) when ground recycled concrete is used as filler.

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