UNIVERSITY OF BELGRADE

TECHNICAL FACULTY BOR

52nd International October Conference on Mining and Metallurgy

PROCEEDINGS

Edited by

Saša Stojadinović

and

Dejan Petrović

November 29th – 30th 2021

Bor, Serbia

UNIVERSITY OF BELGRADE

TECHNICAL FACULTY IN BOR

52nd International October Conference on Mining and Metallurgy

IOC2021
International October Conference

PROCEEDINGS

Edited by

Saša Stojadinović

and

Dejan Petrović

November 29th – 30th 2021

Bor, Serbia

52nd International October Conference

on Mining and Metallurgy, IOC 2021

PUBLISHER:
UNIVERSITY OF BELGRADE - TECHNICAL FACULTY IN BOR, BOR, NOVEMBER 2021

FOR THE PUBLISHER:
DEAN: Prof. dr Nada Štrbac

EDITORS:
Prof. dr Saša Stojadinović
Doc. dr Dejan Petrović

TECHNICAL EDITOR
Pavle Stojković, MSc.

PRINTED BY:
»Štamparija Atlantis d.o.o.« Niš

CIRCULATION: 100 Copies

CIP – Каталогизација у публикацији –

Народна библиотека Србије, Београд

622(082)
669(082)

INTERNATIONAL October Conference on Mining and Metallurgy (52 ; 2021 ; Bor)
Proceedings / 52nd International October Conference on Mining and Metallurgy - IOC 2021, November 29th - 30th 2021 Bor, Serbia ; [organizer] University of Belgrade, Technical Faculty in Bor ; [co-organizer Institute for Mining and Metallurgy Bor] ; edited by Saša Stojadinović and Dejan Petrović. - Bor : University of Belgrade, Technical Faculty, 2021 (Niš : Atlantis). - V, 228 str. : ilustr. ; 25 cm

Tiraž 100. - Bibliografija uz svaki rad.

ISBN 978-86-6305-119-5

a) Рударство -- Зборници б) Металургија -- Зборници

COBISS.SR-ID 52072201

RECYCLED COARSE AGGREGATE AND FLY ASH EFFECT ON COMPRESSIVE STRENGTH OF SELF-COMPACTING CONCRETE

Aleksandar Savić[1], Ivana Jelić[2], Marija Šljivić-Ivanović[2], Slavko Dimović[2], Nikola Pudar[3], Aleksandar Pfandler[4]

[1]Faculty of Civil Engineering, University of Belgrade, B.K.A. 73, 11000 Belgrade, Serbia

[2]Vinca Institute of Nuclear Sciences, University of Belgrade, M.P.A. 12-14, 11351Belgrade, Serbia

[3]First Technical High School, R.D. 8, Kragujevac, Serbia

[4]Energoprojekt (Head of concrete laboratory, retired), B.M.P. 12, Belgrade, Serbia

Abstract

The paper presents experimental results of the tests conducted on Self-Compacting Concrete (SCC) with recycled coarse aggregate, and fly ash as filler component. A fine fraction of aggregate originated from a riverbed, while coarse aggregate was obtained either from a riverbed or by crushing laboratory concrete cubes as recycled concrete aggregate. The larger coarse aggregate grains than typical for SCC were used, to highlight the possibility of application in structure elements with sparse reinforcement bars. Four mixtures of concrete were made, in order to compressive strength as the dominant property of any concrete. All of the fresh concrete mixtures displayed proper behavior for this kind of concrete, whereas recycled concrete aggregate induced several challenges. Hardened concrete mixtures showed that beyond the use of natural coarse aggregate, there is the possibility to obtain proper mechanical behavior needed for structural concrete, with moderate amounts of cement. Such an approach paves a way for a cleaner and more sustainable civil engineering practice.

***Keywords**: self-compacting concrete, recycled aggregate, fly ash, sustainable development.*

1. INTRODUCTION

Concrete is the most used material in the world for decades, after water. The estimated amount of annual production of concrete worldwide is estimated to be more than three tons per inhabitant of the planet and continues to grow [1]. Consequently, concrete production is considered to be the highest issue in terms of energy efficiency and climate change. However, its accelerating production also acts upon the consumption of natural resources, i.e. aggregates. One cubic meter of concrete contains nearly one cubic meter of aggregates, and the growing trend of aggregates excessive consumption raises the issue of depletion of natural resources of coarse aggregates and the need to find new opportunities to obtain their replacements. As a sustainable solution to this problem, as well as the problem of construction and demolition waste generation, the process of waste construction materials recycling, primarily concrete, has been imposed [1]. Based on these facts, the recycled aggregate is getting growingly applied in concrete production.

Likewise, the reuse of industrial waste and by-products (e.g. fly ash, sludge, etc.) in concrete production represents the appropriate way for developing sustainable construction. Fly ash represents a fine powder collected on electrostatic precipitators from flue gases in thermal power plants [2]. As a waste, it is deposited in landfills that are typically located near thermal power plants, representing a global concern for which the solutions are constantly pursued [3]. Its use reduces the consumption of non-renewable natural resources and has economic significance. Most commonly, it is used as a supplementary cementitious material in the production of

Portland cement concrete due to its pozzolanic properties. The reuse of fly ash decreases its negative impact on the environment, also reducing its quantities in landfills.

The development of Self-Compacting Concrete (SCC) is an additional way to boost the sustainability of construction, due to the reduction of energy use, i.e. energy required for its preparation. It simplifies implementation by reducing the engagement of highly skilled workers and machines (vibrators). In addition to the benefits obtained in terms of safety of the working environment, noise reduction, savings on energy, human resources, and execution time, there are also benefits in terms of durability. Namely, the influence of human error is eliminated from this phase of concrete works on site. The utilization of recycled concrete aggregate and fly ash in SCC also has the potential to reduce both the environmental impact and financial cost associated with the increasing demand for this construction material. The usage of SCC obtained by fly ash and recycled aggregate leads to a significant reduction in natural resources consumption and waste disposal, especially when the concrete compositions are optimized [4-5].

The aim of this study was to investigate the impact of used recycled aggregate and fly ash on the properties of SCC. The usage of the fourth fraction of aggregate (16 – 31.5mm, the grain size uncommon for SCC) was hereby promoted, in such cases whenever there are no restrictions for its application. Within this experimental work, four series of SCC were made. All series were prepared with the addition of fly ash. The first and the third series were made with natural aggregate. The second and the fourth series were made with recycled aggregate. The third and the fourth series were prepared with reduced cement content and increased content of fly ash in order to increase the energy efficiency of the produced SCC additionally.

2. EXPERIMENTAL

For the production of SCC samples, the natural aggregate was used in the common fractions: I (0/4), II (4/8), III (8/16), and IV (16/31.5) declared by origin as "Dunavac", as well as the recycled aggregate, i.e. crashed control concrete cubes, sieved into the IV (16/31.5) fraction.

Densities of the natural river aggregate were 1.60 t/m^{3}for the fraction I (0/4), 1.49 t/m^3 for the fraction II (4/8), 1.45 t/m^{3}for the fraction III (8/16), and 1.47 t/m^{3}for the fraction IV (16/31.5) in loose state, and 1.74 t/m^3, 1.64 t/m^3, 1.63 t/m^3 and 1.56 t/m^3 in compacted state, respectively.For the only one used recycled aggregate fraction IV (16/31.5), the loose and compacted state densities amounted to 1.31 t/m^{3}and 1.46 t/m^3, respectively.

The pure cement without additions CEM I was used in all of the mixtures. The fly ash used in this study was generated and stored within the complex of the thermal power plant Nikola Tesla B, Obrenovac, Serbia. Its chemical composition was previously found to be in accordance with conditions prescribed by the standards and recommendations [3,6-7]. Fly ash was used without prior activation, as the only filler component.

The amount of the polycarboxylate based superplasticizer TKK CementolHiperplast 463 was the same 6 kg/ m^3 in all of the mixtures.

The defined compositions of the SCC series are listed in Table 1.

The samples were molded and cured for 1 day in the air, covered with a wet cloth. After demolding, the samples were cured in 20˚C water for 28 days and removed from water a little prior to testing.

Table 1 – Compositions of the series

	Quantities [kg/m^3]			
Component	I	II	III	IV
Cement	300.0	300.0	270.0	270.0
Water	155.8	155.8	155.8	155.8
Additional absorption water	11.5	49.2	11.5	49.2
Fly ash	150.0	150.0	180.0	180.0
Natural aggregate, I fraction (0<d<4mm)	657.0	657.0	657.0	657.0
Natural aggregate, II fraction (4<d<8mm)	274.0	274.0	274.0	274.0
Natural aggregate, III fraction (8<d<16mm)	402.0	402.0	402.0	402.0
Natural aggregate, IV fraction (16<d<31.5mm)	492.0	-	492.0	-
Recycled aggregate, IV fraction (16<d<31.5mm)	-	492.0	-	492.0

3. RESULTS AND DISCUSSION

All of the fresh concrete mixtures displayed proper behavior for this kind of concrete, with slump-flow diameters ranging between 650 and 800 mm; whereas recycled concrete aggregate induced several challenges. For instance, the amount of water had to be carefully waged, based on absorption values. Therefore, the consistency of the series with the recycled coarse aggregate was more fluid immediately after mixing. Due to the absorption process, the consistency of the series with recycled concrete was more rapidly changing in time, in comparison to the series without recycled concrete aggregate.

The compressive strength tests were performed according to the standard SRPS EN 12390-3:2010 on triplet 10 cm cubic samples [8]. The test was performed with a gradual load increase until the sample failure, Amsler, with a range of 2500 kN. The loading rate was 0.6 ± 0.4 MPa/s.The results are presented in Figure 1. The test was conducted at the age of concrete of 28 days.

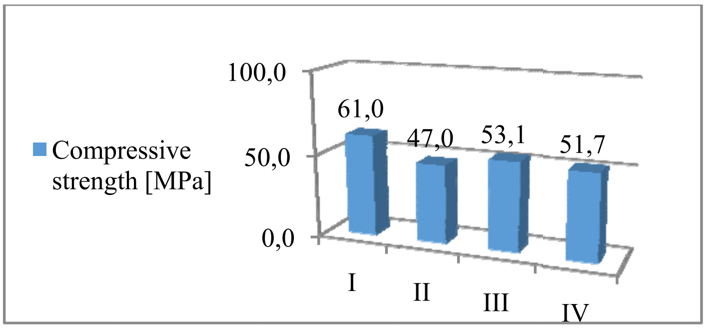

Figure 1. Compressive strength results at the age of 28 days

For similar values of the water to cement ratio, the studies showed that the compressive strength does not differ significantly in SCC and Normally Vibrated Concrete (NVC). However, the choice of aggregates (riverbed, crushed, recycled) has a much greater influence on compressive strengths in NVC than in SCC due to substantial homogeneous matrix in SCC and lower content of coarse aggregate, which reduces its impact [9]. Therefore, the results obtained on the tested series showed this trend, meaning that the differences in the results would be much higher if the NVC was made with the same aggregate composition and water to cement ratio.As far as the compressive strength of concrete is concerned, a noticeable decrease was recorded in the cases of samples with recycled aggregate and fly ash with regard to the first, referenced series, made with natural aggregate.The addition of fly ash mixed with recycled aggregate showed a positive effect by the increase in compressive strength.

4. CONCLUSION

The experimental results of the compressive strength test conducted on SCC with recycled coarse aggregate, and fly ash as filler component, were discussed. Although all of the mixtures were characterized as SCC with a slump-flow diameter of more than 650 mm, the introduction of recycled concrete aggregate induced challenges regarding the consistency as expected. The consistency of the series with the recycled coarse aggregate was both more fluid and more rapidly thickening, in comparison to the series without recycled concrete aggregate. Fly ash was used in the SCC mixtures as the solitary filler and without prior activation. The compressive tests were obtained at the age of 28 days, and a further increase of compressive strength was expected due to the presence of fly ash. Although the reference series showed the highest compressive strength, the coarse recycled aggregate had a moderate influence on a drop in strength. The series with a lower amount of cement and with fly ash had higher values of strength than the reference altered with recycled aggregate, most probably due to the positive influence of fly ash. Also, the differences of the SCC series made with and without the recycled coarse aggregate were almost neglectable (2.6%).

The aggregate fraction IV (16/31.5 mm) was used to highlight the possibility of SCC application in structure elements with sparse reinforcement bars, and where the large quantities of concrete have to be used without a need for vibration. The sustainability aspect of SCC was improved through the use of recycled concrete aggregate and fly ash, with respect to the reduction in cement and natural aggregate for concrete, which illustrates the potential of concrete to improve in light of its environmental and sustainability impacts.

ACKNOWLEDGEMENTS

The research presented in this paper was done with the financial support of the Ministry of Education, Science and Technological Development of the Republic of Serbia, within the funding of scientific research work at the University of Belgrade, Faculty of Civil Engineering (No. 200092) and the University of Belgrade, Vinca Institute of Nuclear Sciences (Contract No. 451-03-9/2021-14/200017).

REFERENCES

[1] C. Lian, Y. Zhuge, Constr. Build. Mater., 24 (12)(2002) 2664-2671.
[2] M. Muravljov, Construction materials,Construction book, Belgrade, 2011.
[3] A. Savic, D. Antonijevic, I. Jelic, D. Zakic, Energy Build., 229 (110511)(2020) 1-7.
[4] C.K. Sarath, P.S. Bendapudi, Int. J. Earth Sci. Eng., 4 (6)(2011) 1017-1023.
[5] M. Vasić, Physical and Mechanical Properties of Green Self-Compacting Concrete Designed by the Method of Maximum Density of Grain Packaging, Faculty of Civil Engineering, University of Belgrade, Belgrade, 2019.
[6] SRPS EN 450-1:201, Fly ash for Concrete – Part 1: Definition, specifications, and conformity criteria.
[7] ASTM C618-19: Standard Specification for Coal Fly Ash and Raw or Calcined Natural Pozzolan for Use in Concrete.
[8] SRPS EN 12390-3:2010, Testing hardened concrete – Part 3: Compressive strength of test specimen.
[9] R. Martínez-García, P. Jagadesh, G. Búrdalo-Salcedo, C. Palencia, M. Fernández-Raga, F.J. Fraile-Fernández, Materials, 14 (13)(2021) 3480-3492.