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RECYCLED CONCRETE AGGREGATE EFFECT ON SELF-COMPACTING CONCRETE AT LOW TEMPERATURES

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Abstract
The paper presents experimental results of the tests conducted on Self-Compacting Concrete (SCC) with recycled concrete aggregate in order to investigate compressive strength at low temperatures. Recycled concrete aggregate was obtained by crushing laboratory concrete cubes. Four mixtures of concrete were made. This approach to concrete proportioning paves a way for a cleaner and more sustainable civil engineering practice.

Keywords: self-compacting concrete, recycled aggregate, sustainable development

INTRODUCTION

One of the greatest challenges, and at the same time the imperative of the modern age, is sustainable development. As constructing is an activity which is harmful to the environment in many ways, there is plenty of room for the principles of sustainable development implementation [1]. Civil engineering generates construction and demolition waste, accounting for almost 75% of waste worldwide [2,3]. The production and utilization of recycled aggregate is a response to several key environmental problems resulting from construction and demolition activity. Namely, concrete is the most used construction material (after water), and for the most part, it is made of aggregates, which leads to the uncontrolled depletion of natural aggregate deposits [1]. Apart from the fact that natural resources are limited, their exploitation also has a great impact on the environment (transformation of the terrain, change of ecosystems, carbon dioxide emissions, etc.). On the other hand, the demolition of buildings due to aging, natural disasters, war destruction, etc., results in huge amounts of construction and demolition waste (CDW). This waste is most often disposed in designated, but often illegal, so-called "wild" landfills, whose areas are constantly increasing.

Self-Compacting Concrete (SCC) is defined as concrete that, without any need for special installation-vibrating means, is installed by itself, under the influence of gravity, passes between reinforcement bars, no matter how densely they are placed, wraps them, and fills the formwork, while achieving high compactness and the required class of concrete [4,5]. This technology originated in Japan in the 1980s, primarily to increase the durability of concrete structures, as well as to protect workers from noise and vibration during concrete installation. The research was led by the Japanese scientist Hajime Okamura from the University of Tokyo [6]. Japanese scientists had significant "potential capital" due to developed technology for the production of chemical additives such as superplasticizers, with high water reduction power. It was only necessary to find a way how much concrete, with a high degree of fluidity, at the same time has a high resistance to segregation of large aggregate and separation of water in the mixture. It was relatively easy to conclude that the share of the smallest particles should be increased, which, with adequate reduction of the share of the largest fraction and limitation of its largest grain, would achieve better cohesiveness of the mixture. Only one more step remained until the final goal, which was done by applying a new type of additive-modifier of viscosity VMA (Viscosity Modifying Admixture) which, without affecting the fluidity of the mixture, further increased the degree of its cohesion [6].

Great progress has been made in the application of SCC concrete with the adoption of European guidelines that have defined both requirements and test methods, recommendations for production, and installation. Subsequently, based on these guidelines, a set of European standards EN 12350 (parts 8 to 12) only for SCC were developed, which was a great recognition of the value of this special type of concrete. The synergy of the chemical and construction materials industries and the development of a new generation of superplasticizers based on polycarboxylic ethers as the main constituent of SCC concrete should be emphasized here, which directly enabled the design of the concrete mix composition of required viscosity and yield strength.

The objective of this investigation was to evaluate SCC concrete made of recycled concrete aggregate at low temperatures in order to promote its wider utilization. In winter conditions, concrete requires special organizational, technical, and technological measures, because the impact of low temperatures on the properties and safety of structures must not be ignored. These measures must be applied if the average air temperature is not expected to be higher than 5°C for more than 3 days. In these circumstances, there is an accelerated cooling of young concrete and slowing down of hydration, which endangers the maturation and reaching the critical strength of concrete. The critical strength of concrete represents the strength of the material at the time of reaching the ambient temperature, i.e. the minimum strength that installed concrete must have at the time of freezing. The critical strength of concrete is a function of the type of cement and the curing conditions, and a strength of 5 MPa can be considered as the relevant value [7].

MATERIALS AND METHODS

Four types of SCC concrete mixtures were made (Table 1). The first type of concrete SCC A represented a standard, basic concrete mixture only with natural aggregate (NA). The standard was made for comparison of characteristics of ordinary SCC with the characteristics of SCC with different proportions of recycled concrete aggregates (RCA).

Concrete mixtures were prepared in a laboratory mixer brand "Beckel" (Germany) with a capacity of 20 L. All components were weighed by mass, including water and additive. Each mixture was prepared in one mixing cycle and their volumes were 6 L each. When preparing concrete with recycled aggregate, a mixing procedure according to TSMA (Two-Stage Mixing Approach) is proposed, as an improvement over NMA (Normal Mixing Approach) [8]. This procedure was applied to all four mixtures, including the standard.

***Table 1** Recipes of the subject mixtures in kg/m^3*

SCC	Cement	Filler	Additive	NA I(0/4)	NA II(4/8)	RCA II(4/8)	NA III(8/16)	RCA III(8/16)
A	380	250	5.7	860	530	0	310	0
B	380	250	5.7	860	265	265	310	0
C	380	250	5.7	860	530	0	155	155
D	380	250	5.7	860	265	265	155	155

*In all mixtures was added cca 200 kg/m^3 of water.

The procedure of mixing component materials lasted a total of 6 minutes and consisted of the following stages:

- dry mixing of all fractions of NA and RCA, and limestone filler for 60 s;
- adding 50% water without stopping the mixer and stirring for 30 s;
- adding cement and other 50% of water and mixing for 30 s;
- a superplasticizer is added over the next 30 s;
- stirring is continued for another 3.5 minutes.

All of the mixtures showed very good properties in terms of fluidity, workability, passing ability, and segregation resistance. Mixtures were cast into the molds only with the help of a fangle, trowel, and a small shovel without additional vibration. Prior to installation, the molds were cleaned, marked, and coated with a formwork release agent, to prevent adhesion of concrete and molds.

The shape and dimensions of the samples for compressive strength testing must meet the requirements of the standard SRPS EN 12390-3:2010 [9]. The test was performed on concrete cubes with edges of 10 cm, gradual loading to the breaking of the concrete sample, in the hydraulic press "Amsler" range up to 2500 kN and "Matest" range up to 2000 kN. The load application rate was 0.6 ± 0.4 MPa/s.

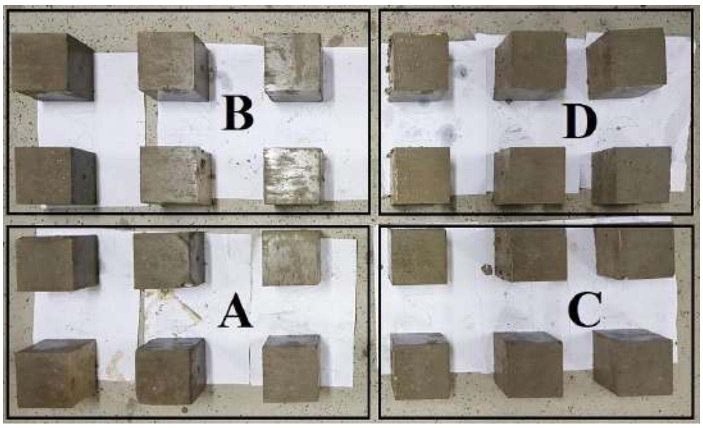

***Figure 1** Concrete samples after removal from the mold*

After production, the concrete molds were placed outside, where they were exposed to external conditions at early ages, at as low temperatures as 5°C to 10°C, and below zero afterward. After 2 hours, the samples were covered with plastic bags, in order to prevent the concrete from drying out quickly. After 24 hours from the moment of casting the concrete mixture in the molds, the mold was carefully detached from the samples (Figure 1), and compressive strength was tested for 8 selected samples (2 from each mixture).

RESULTS AND DISCUSSION

For similar values of the water to powder ratio, the compressive strength does not differ significantly between SCC and Normally Vibrated Concrete (NVC) [10]. However, the choice of aggregates (river, crushed, recycled) has a greater impact on compressive strengths in NVC than in SCC, due to a more homogeneous matrix in SCC and lower content of coarse aggregate, which reduces its impact [11]. Actually, SCC with the same water to cement or water to powder ratio usually has increased compressive strength values, as a result of a better bond between the aggregate and hardened paste due to the absence of vibration. In addition, SCC fills the formwork completely, ensuring reliable "packaging" of the concrete and eliminating segregation [12].

The compressive strength of concrete aged 1, 7, and 28 days was tested. The results are given in Table 2 and Figure 2. For compressive strength at the age of 28 days, the results were converted to a 15 cm edge cube (fp,28, k 15), in order to assess the strength class according to SRPS EN 206-1:2011 [13].

Table 2 *Average values of compressive strength of solid concrete at different ages [MPa]*

SCC	fp,1	fp,7	fp,28	fp,28, k 15	Concrete class according to EN 206
A	8.5	35.8	50.4	47.9	35/45
B	2.2	29.7	53.1	50.4	40/50
C	5.6	33.8	47.7	45.3	35/45
D	4.3	32.8	50.8	48.3	35/45

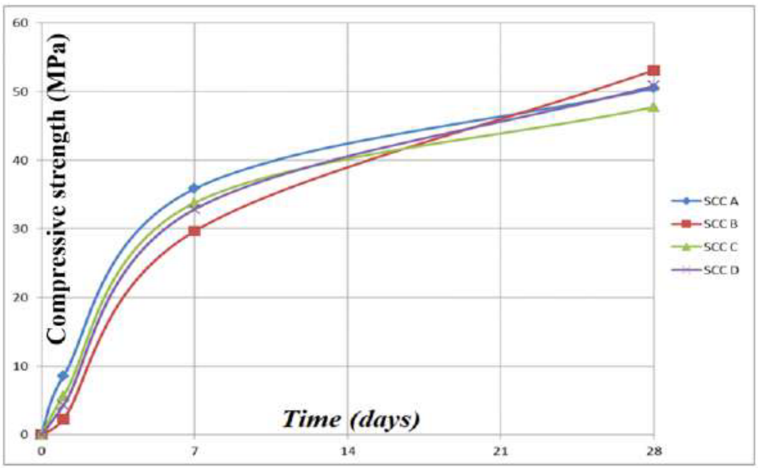

Figure 2 *Compressive strength diagram for all concrete mixtures at different ages*

The diagram shows the fastest increase in compressive strength in the first 7 days, despite low temperatures. Previous investigations of the same mixtures in laboratory temperature conditions have shown 75–80% higher values at the age of 1 day [14,15]. This is also the highest difference induced by the condition because at the older ages the compressive strength values were similar to the previous study [14], which can be attributed also to the significant increase in outdoor air temperatures in that period.

The ultimate strengths are not fully in line with expected values. Three mixtures (including the standard) belong to the concrete strength class C 35/45, while the mixture with recycled SCC B aggregate achieved strength class C 40/50. This is not in line with expectations, as reference mixture A (without recycled aggregate) is expected to have the highest compressive strength [15,16].

CONCLUSION

The results of the investigation of SCC mixtures made with recycled aggregate and cured in ambient conditions are shown in this paper. Fluidity, workability, passing ability, and segregation resistance of all mixtures were in line with the requirements for SCC.

The compressive strength of the investigated mixtures, as a proper quality indicator was monitored over the period of 28 days. It showed that the early age strengths were more influenced by the curing conditions. The concrete mixtures made with recycled aggregate had lower values of compressive strength at 1 day than the reference. The differences in the compressive strengths decreased with the age, which can be attributed both to the age and the higher ambient temperatures at that period.

The values of compressive strength of concrete mixtures with recycled aggregate were in line with the values for mixture with natural aggregate, paving the way for the industrial use of recycled aggregate in SCC in ambient conditions. Nevertheless, all of the principles of design, component investigation, and proportioning, as well as the mixing process have to be applied in order to provide the shown best effects.

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REFERENCES

[1] C. Lian, Y. Zhuge, Constr. Build. Mater; 24 (12) (2002) 2664–2671.

[2] V.A. Mymrin, K.P. Alekseev, R.E. Catai, *et al.*, Constr. Build. Mater; 79 (2015) 207–213.

[3] O. Zimbili, W. Salim, M.A. Ndambuki, Int. J. Civil Architect. Struct. Constr. Eng; 8 (2014) 91–95.

[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] H. Okamura, M. Ouchi, J. Adv. Concr. Technol; 1 (1) (2003) 5–15.

[7] H.T. Nam Le, L.H. Poh, S. Wang, *et al*., Cem. Concr. Compos; 82 (2017) 202–216.

[8] V.W.Y. Tam, C.M. Tam, Constr. Build. Mater; 22 (10) (2008) 2068–2077.

[9] SRPS EN 12390-3:2010, Testing hardened concrete – Part 3: Compressive strength of test specimen (2010).

[10] M.C.S. Nepomuceno, L.F.A. Bernardo, Appl. Sci; 9 (Y2019) 1–18.

[11] R. Martínez-García, P. Jagadesh, G. Búrdalo-Salcedo, *et al.*, Materials; 14 (13) (2021) 3480–3492.

[12] P. Dybel, M. Kucharska, Materials; 14 (19) (2021) 5685.

[13] SRPS EN 206-1:2011, Concrete – Part 1: Specification performance, production, and conformity, Withdrawal of Standard: Dec 25, 2017 (2011).

[14] B. Kovačević B., Testing of SCC concrete with partial replacement of natural aggregate with recycled aggregate, Faculty of Civil Engineering, University of Belgrade, Belgrade (2017).

[15] K.C. Panda, P.K. Bal, Procedia Eng; 51 (2013) 159–164.

[16] Z.J. Grdić, G.A. Topličić-Ćurčić, I.M. Despotović, *et al*., Constr. Build. Mater; 24 (7) (2010) 1129–1133.