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CONCRETE WITH COPPER SLAG AS A PARTIAL REPLACEMENT OF THE NATURAL AGGREGATE

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Abstract

Copper slag, a by-product of the pyrometallurgical process, used for obtaining copper from the copper ore in Bor, is disposed on the landfills. Despite favorable technical properties, the copper slag aggregates possess such resistance to the crushing (12.76 %) and higher particle density (3.33Mg/m^3); its use in the construction industry is not sufficiently examined. The experiments included tests on three concrete mixtures with a partial replacement of coarse natural aggregate with the copper slag. Replacement of the RA particle size 8/16 mm and 16/31.5 mm, with the CSA in the amount of 2 0+20% and 20+50%, resulted in an increase in the compressive strength of 10.2% and 12.6%, respectively. Increase of the CSA content in the amount of 20+20% and 20+50%, led to increase in tensile strength by 6.2% and 22.1%, respectively.

Keywords: *copper slag, recycled aggregate, natural aggregate, concrete, compressive strength, tensile strength*

1. INTRODUCTION

The growing needs of the construction industry cannot be met with the available resources. An example of this is the fact that the current rate of extraction the river aggregate can meet only 9% of the total annual need in China [1]. Taking into account that for every ton of copper produced in the world, about 2.2 t of copper slag is generated, it comes to the fact that about 24.6×106 t of copper slag is generated every year, which is deposited on the landfills as the waste material [2]. The industrial processing of smelter slag within the Bor Mining and Smelting Basin (RTB Bor), which has been carried out in the Bor Flotation Plant since 2001, resulted in a large amount of deposited copper slag amounting to 16-18×106 t. These industrial by-products, which are generated in huge quantities worldwide, lead to the serious challenges related to their disposal [3]. Due to this reason, it is necessary to find the alternative solutions to this problem, which would be acceptable from an environmental point of view. One of such solutions is the use of copper slag aggregate as a substitute for the natural aggregate in concrete [4]. Due to the fact that copper slag is made of the non-hazardous chemical materials, it can be used as a mineral raw material in various manufacturing industries [5]. According to the studied physical and chemical characteristics of copper slag, its use is possible in the production of concrete, where it is successfully used as a substitute for the common types of aggregates. Due to its high volumetric mass, it is suitable for use primarily in the massive concrete, concrete foundation slabs or as a material for building layers of the rigid pavement structures [6], [7]. By replacing the natural aggregate with the copper slag aggregate, the certain concrete properties such as the compressive strength, flexural strength, volumetric mass, workability and durability of concrete can be improved [8].

The subject of this research are concretes with the copper slag aggregate (CSA) in a naturally granulated state, from the Mining and Smelting Basin Bor, as a substitute for large fractions of the natural aggregate (RA), and special emphasis is placed on the analysis of some of the most significant physical and mechanical properties of fresh and hardened concrete, which are important both from the aspect of designing the composition of concrete mixtures and the aspect of designing the concrete structures. When designing the composition of concrete mixtures, in order to achieve the optimal properties of hardened concrete, different types of fine and coarse aggregate are often combined. In this research, the natural river aggregate (fractions 0/4 mm, 4/8 mm) was used as the fine aggregate in all concrete mixes, while the coarse fractions of natural aggregate (fractions 8/16 mm and 16/31.5 mm) replaced with the copper slag aggregate in combinations of content 20% and 50% (in percentage by volume).

The subject tests were performed primarily with the aim of comparing the behavior of ordinary concrete and concrete made with the copper slag aggregate, as an innovative solution for application the green concrete on the basis of this industrial by-product.

2. EXPERIMENTAL

The natural aggregate used in this research was taken from the "New Separation", originating from the Velika Morava river near Paraćin. Four standard fractions of this river aggregate were used in the test - 0/4 mm, 4/8 mm, 8/16 mm and 16/31.5 mm.

On the previously prepared samples of both aggregates (CSA and RA), the grain shape was determined according to the SRPS EN 933-4 and volumetric mass was determined according to the SRPS EN 1097-6. Aggregate tests were performed in accordance with the valid standards, shown in Figure 1.

As a part of the subject research, the tests of the physical and mechanical characteristics of three groups of concrete mixtures were performed, according to the standards shown in Figure 1. The first group consists of a control concrete (standard), based on the natural river aggregate (RA); the second group consists of a concrete mixture in which 20% of natural aggregate in fractions III (8/16 mm) and IV (16/31.5 mm) is replaced by the appropriate copper slag aggregate fractions (20% III + 20% IV), while in the third group, 20% of the 8/16mm fraction and 50% of the 16/31.5mm fraction (20% III + 50% IV) were replaced.

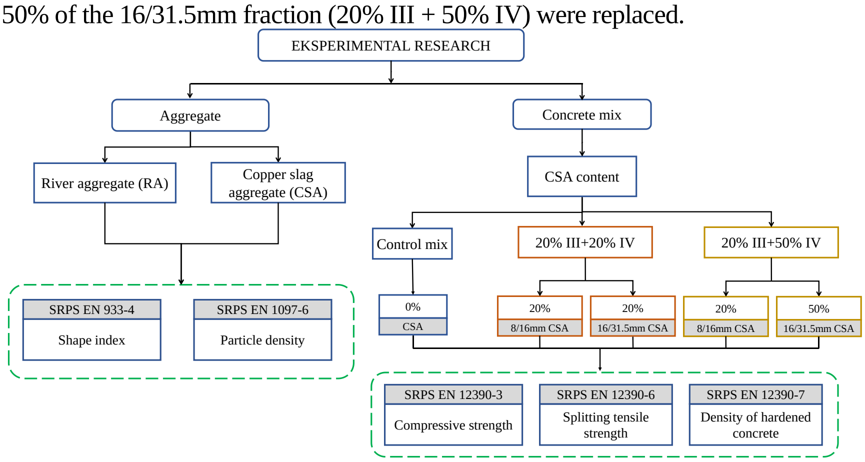

Figure 1. *Test matrix of aggregates and concrete mixtures*

3. RESULTS AND DISCUSSION

The copper slag aggregate grains are predominantly the cube-shaped and oblong, with the sharp edges, while the appearance of the grain surface is smooth to vitreous (Figures 1b and 1c). The average content of grains with a bad (flat) shape is low and amounts to only 5%. The grain shape of the natural river aggregate is mostly oblong and cube-shaped, and due to the different mineral origin, the grains are smooth, fine-coarse and sandy-coarse with a slightly higher average percentage of grains of an unfavorable shape of 16%. The most important physical and mechanical characteristics of both types of aggregates are shown in Table 1.

Table 1. *Physical and mechanical characteristics of aggregate*

Property	Standard	Fractions (mm)	Values CSA	Values RA
Shape index 3:1 (%)	SRPS EN 933-4	8/11	5	
		10/14		16
Bulk mass (Mg/m^3)	SRPS EN 1097-6	8/11	ρ_a 3.40 ρ_{rd} 3.33 ρ_{ssd} 3.36	
		10/14		ρ_a 2.66 ρ_{rd} 2.58 ρ_{ssd} 2.61

The volumetric mass of hardened concrete and compressive strength were determined on concrete samples tested according to the SRPS EN 12390-7 and SRPS EN 12390-3 standards. The results of these tests are shown in Table 2.

Table 2. *Test results of compressive strength, splitting tensile strength and volumetric mass of concrete*

	Compressive strength (MPa)			Splitting tensile strength (MPa)	Volumetric mass (kg/m^3)
mixture / age	1 day	7 days	28 days	28 days	28 days
Standard	16.7	28.0	36.3	7.25	2303
20% III+20% IV	17.6	27.2	40.0	7.70	2355
20% III+50% IV	20.1	34.1	40.8	8.85	2360

The test results showed that the concrete mixtures of the second group (20% III+20% IV) and the third group (20% III+50% IV) showed the higher compressive strengths by 10% and 12%, respectively, at the age of concrete of 28 days. The reason for an increase in strength is the higher strength of the CSA grains and the better interaction between the grains, given their pronounced roughness and sharpness.

The results of the tensile splitting strength tests showed that, compared to the control mixture, the copper slag aggregate (CSA) concretes had the higher tensile splitting strengths. Namely, at the age of 28 days, the mixtures of the second (20% III+20% IV) and third (20% III+50% IV) groups achieved an increase in strength of 6.2% and 22.1%, respectively, compared to the control mixture.

4. CONCLUSION

The experimental research presented in this paper included testing of the physical and mechanical characteristics of the concrete mixtures made with a partial replacement of the coarse natural aggregate (RA) with the copper slag aggregate (CSA). The conclusions obtained from tests, aimed at understanding and expanding the possibility of applying the mentioned aggregates in concrete, are as follows: With an increase in the CSA content, the volumetric mass of concrete increases, which recommends it for use primarily in massive concrete structures. Replacing 8/16 mm and 16/31.5 mm RA with the CSA aggregate in the amount of 20+20% and 20+50%, respectively, led to an increase in compressive strength of 10.2% and 12.6%, respectively. With an increase in the content of CSA in concrete, as a partial substitute for large fractions of the natural aggregate, the tensile strength increases by 6% and 22%, respectively.

Based on the conclusions of the subject experimental research, an increase in compressive and tensile strength was observed as a consequence of higher strength of the copper slag aggregate (CSA). The purpose of designing the concrete mixtures is to determine the optimal content of copper slag aggregates in order to improve the characteristics of concrete mixture. The addition of CSA to the concrete mixture does not significantly improve the quality of concrete, but on the other hand, it has the benefit of reducing the exploitation of natural aggregate, as well as reducing the environmental pollution through the copper slag landfills.

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