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THE POSSIBILITY OF USING COPPER SLAG AGGREGATE IN CONCRETE

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Abstract
Copper slag, produced as a by-product of the pyrometallurgical process of obtaining copper from copper ore in Bor, is disposed as waste in landfills. Despite the favorable physical and mechanical properties of concrete made with copper slag aggregate, such as higher compressive strength (40.8 MPa), higher tensile splitting strength (10.3 MPa), higher pull-off strength (3.1 MPa) and lower water permeability, its use in the construction industry has not been sufficiently investigated. The paper shows the possibility of using copper slag aggregate (CSA) in concrete as a potential replacement for natural river aggregate (RA).

***Keywords**: Copper slag; natural aggregate; concrete; compressive strength; tensile strength.*

1. INTRODUCTION

Copper slag, being derived from non-hazardous chemical constituents, offers potential as a mineral raw material across a variety of manufacturing industries [1]. Bipra Gorai et al. [2] reviewed prior research on its potential applications and concluded that, due to its favorable physical and mechanical properties, copper slag can be widely employed in the production of cement, abrasives, cutting tools, aggregates, roofing materials, glass, tiles, and other products. Among the most promising reuse pathways is its incorporation in cement and concrete production. Utilizing copper slag aggregate as a partial cement replacement can yield substantial energy savings in binder manufacturing, since the process requires only grinding of the slag. Furthermore, significant quantities of copper slag can serve as fine and coarse aggregates in concrete (CSA), given that aggregates account for more than 70% of the concrete volume. A critical review of the literature reveals a notable scarcity of studies investigating the effects of coarse CSA fractions as substitutes for equivalent fractions of river aggregate (RA), as well as the performance characteristics and potential applications of such concretes.

Fine-grained copper slag can be used as a substitute for sand in concrete production, serving either as an aggregate or as a binding agent that helps bond larger gravel particles within the concrete matrix. When applied in this manner, copper slag generally enhances the performance characteristics of concrete [3]. Moreover, such concrete exhibits improved fire resistance, as copper slag slows down the transfer of heat and the spread of flames. This material is also a popular alternative to sand as a medium for industrial abrasive blasting. Through blasting or high-pressure spraying techniques, copper slag is employed to clean large smelting furnaces and other equipment. Slag blasting is also used to remove rust, paint, and other materials from metal, concrete, or stone surfaces, thereby facilitating surface preparation for painting or simply removing unwanted coatings or deposits. Certain properties of copper slag also indicate its potential application in pavement construction. The most effective use of CSA is in ways that take advantage of its favorable physico-mechanical characteristics. Such applications not only utilize its beneficial properties but also address the issue of slag disposal. Consequently, the use of copper slag aggregate holds significance in the waste management industry [2].

Ravindra et al. [4] investigated the geotechnical properties of copper slag and found that it is a non-plastic material with greater compressibility compared to sand. The internal friction angle of copper slag is similar to that of sand, and its use as backfill behind retaining structures reduces active lateral earth pressure. Furthermore, copper slag is suitable for use in construction as a fill material. Since it has no harmful environmental impact, it can be incorporated into soil as a load-bearing layer in pavement structures, railway tracks, as a subbase layer in building foundations, or in other types of civil engineering works.

C. Shi, C. Meyer, and A. Behnood [5] examined the potential of copper slag as a raw material in clinker production and concluded that its use improves clinker grindability, acting as a grinding intensifier. When used as a substitute for cement or aggregate, concrete (or mortar) containing various forms of copper slag generally exhibits equal or greater strength compared to concrete made with ordinary Portland cement. Such studies are increasingly important given that Portland cement production is an energy-intensive process that releases substantial amounts of CO_2. In recent years, copper slag has been used as a replacement for cement [5,6]. It has also been evaluated as a pozzolanic substitute for cement, as 70% of the world’s copper slag contains a favorable combination of $SiO_2 + Al_2O_3 + Fe_2O_3$ [7,8]. However, due to its large specific surface area in raw form (approximately 400 m^2/kg) and high hardness, the grinding and comminution of copper slag require a significant energy input [9].

2. MATERIALS AND METHODS

The copper slag used in this study originated from a landfill, formed by the rapid cooling of molten copper matte. In addition to loose fine material, this process also produces large chunks unsuitable for direct use in concrete; however, their potential application can be realized through further crushing and grinding. The copper slag aggregate samples used in the present research were sieved through a series of standard sieves and separated into two size fractions: 8/16 mm and 16/31.5 mm, as shown in Figures 1a and 1b.

(a) (b)

Figure 1. Macroscopic appearance of copper slag aggregate: fraction III (a) and fraction IV (b).

The natural aggregate used in this study was sourced from the “Nova separacija” plant and originates from the Velika Morava River, near Paraćin (Figure 2). Four standard fractions of this river aggregate were used in the investigation: I (0/4 mm), II (4/8 mm), III (8/16 mm), and IV (16/31.5 mm).

Figure 2. Natural aggregate from the “Nova separacija” plant near Paraćin.

Table 1. Mix designs of concrete mixtures.

Mixture	RA (kg/m^3)		CSA (kg/m^3)	Water (kg/m^3)	Portland cement (PC) (kg/m3)	v/c
	0/4 mm	4/31.5 mm	8/31.5 mm			
ETALON	732	1045	/	212	398	0.533
20% III+20% IV	732	753	394			
20% III+50% IV	732	659	529			

The cement used in this study was a composite Portland cement (PC) designated as CEM II/A-L 42.5R, with a specific gravity of 3.15 Mg/m^3. Cement classification was carried out in accordance with the European standard SRPS EN 197-1.

The baseline for designing the concrete mixtures used in these experiments was an existing mix design from a local concrete plant in Bor, corresponding to concrete grade MB40. The quantities of materials required for producing 1 m^3 of the tested concrete mixtures are presented in Table 1. The purpose of using an existing mix design in this investigation was to modify a formulation already applied in practice by incorporating copper slag [10].

3. RESULTS OF TESTING CONCRETE MIXTURES

The results of compressive strength testing indicated that, compared to the control mixture, mixtures containing copper slag aggregate (CSA) exhibited higher compressive strengths at all concrete ages. For example, at 28 days, the mixtures with 20% III + 20% IV and 20% III + 50% IV substitutions achieved strength increases of 10.2% and 12.6%, respectively, compared to the control mix. A similar trend was observed in the hardened concrete bulk density, which increased by 2.3% and 2.5%, respectively [11].

The splitting tensile strength test results showed that, compared to the control mixture, concretes with CSA also achieved higher splitting tensile strengths. At 28 days, the mixtures with 20% III + 20% IV and 20% III + 50% IV substitutions recorded strength increases of 6.2% and 22.1%, respectively, relative to the control mix.

The pull-off tensile strength test results demonstrated that, at 28 days, the mixtures with 20% III + 20% IV and 20% III + 50% IV substitutions exhibited increases in tensile strength of 13.8% and 11.2%, respectively, compared to the control mixture [12].

Table 2. Physical and mechanical properties of concrete mixtures.

Property	Standard	Concrete mixture		
		Etalon	20% III + 20% IV	20% III + 50% IV
Compressive strength	SRPS EN 933-4	36.3	40.0	40.8
Splitting tensile strength	SRPS EN 1097-6	7.25	8.49	10.26
Pull-off tensile strength	SRPS EN 1097-6	2.69	3.06	2.99

An increase in water penetration depth was also observed in concretes with a percentage replacement of aggregate by CSA compared to the control mixture. The recorded maximum water penetration for the 20% III + 20% IV and 20% III + 50% IV mixtures was 12% and 55% higher, respectively, than that of the control mix.

Table 3. Results of water permeability testing of concrete mixtures.

Concrete mixture	Water penetration depth (mm)
Etalon	83
20% III+20% IV	93
20% III+50% IV	129

4. CONCLUSION

This study examined the potential use of copper slag aggregate as a replacement for natural river aggregate in concrete production, as well as the possibilities for applying such concretes. The conclusions drawn from these tests, aimed at evaluating and expanding the potential applications of the aforementioned concretes in construction, are as follows:

- Replacing RA fractions of 8/16 mm and 16/31.5 mm with CSA aggregate in amounts of 20% III + 20% IV and 20% III + 50% IV resulted in an increase in compressive strength of 10.2% and 12.6%, respectively.
- Increasing the CSA content in concrete, as a partial replacement for coarse fractions of natural aggregate, led to an increase in splitting tensile strength of 6% and 22%, respectively.
- A partial replacement of coarse aggregate with copper slag in 28-day-old concretes resulted in a pull-off tensile strength increase of 13.8% for the second group mixture (20% III + 20% IV) and 11.2% for the third group mixture (20% III + 50% IV).
- The use of CSA aggregate as a replacement for RA reduces the water impermeability of concrete due to increased porosity of the cement paste.

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