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SURFACE BLAST-CLEANING WASTE AS A REPLACEMENT OF FINE AGGREGATE IN CONCRETE

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Abstract
In the article the possibility of using a surface blast-cleaning waste as a replacement of fine aggregate in concrete manufacturing was presented. Concretes with w/c ratio 0.6 and 300 kg/m^3 dosage of cements: CEM I 32.5R and CEM II/B-V 32.5N were tested. The quite high value of the w/c ratio resulted in good compactibility of the mixtures without use of plasticizer. The replacement rate of the fine aggregate (0–2 mm) with copper slag (CS) was 33%, 66% and 100% respectively. Concretes of the same composition served for reference except for with river sand as fine aggregate instead of slag. The performed tests focused on: compressive and tensile strength (both after 28 days), sorptivity, free water absorption capacity and abrasion resistance. The obtained results showed that the strength and some other tested properties of concretes with copper slag as sand replacement were similar or even better than that of the control mixtures.

Streszczenie
W artykule zaprezentowano badania na temat możliwości zastąpienia całości lub części drobnego kruszywa w betonie żużlem pomiedziowym – odpadem z piaskowania. Badano beton z w/c = 0.6 i zawartością cementów CEM I 32.5 R i CEM II/B-V 32.5N 300 kg/m^3. Stosunkowo wysoka wartość współczynnika w/c pozwoliła na dobre zagęszczenia mieszanek bez użycia plastyfikatora. Stopień zastąpienia drobnego kruszywa (0–2 mm), żużlem pomiedziowym wyniósł odpowiednio 33%, 66% i 100%. Beton o tym samym składzie ze 100% piasku rzecznego jako kruszywa drobnego służył jako referencyjny. Przeprowadzone badania koncentrowały się na: wytrzymałości na ściskanie i rozciąganie (po 28 dniach), sorpcyjności, nasiąkliwości i odporności na ścieranie. Uzyskane wyniki wykazały, że wytrzymałość i niektóre inne badane właściwości betonów z odpadem jako zamiennikiem piasku były podobne lub nawet lepsze niż właściwości betonu referencyjnego.

Keywords: **Sustainable development, Waste utilization, Fine aggregate, Copper slag, Concrete, Recycled materials.**

1. INTRODUCTION

Recycling of waste materials, reducing greenhouse gas emission and frugal natural resources management became necessary. This is caused by both climate changes and necessity of the transition to an energy-efficient, low-carbon economy [1, 2]. Copper slag is a by-product, produced besides mill tailing, during the process of copper extraction by smelting. It is an inert material and its physical properties are similar to natural sand [3]. It is used, among others, as an abradant in the surface blast-cleaning process but after this usage it is considered to be a waste. Despite increasing the rate of reusing copper slag, the huge amount of its annual production is still disposed in landfills or stockpiles. Potential applications were described already [4, 5]. One of the most promising potential application for reusing copper slag is concrete production [6, 7, 8]. It is possible to use copper slag for the production of high-quality concrete, improving its properties compared to concrete, which is mixed with sand [9, 10].

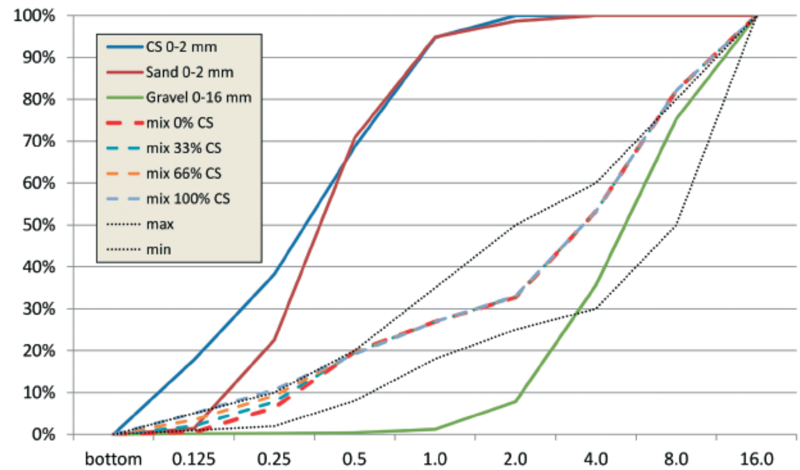

Figure 1.
Grading curves of aggregate fractions and mixtures

The usage of copper slag in concrete production provides potential benefits both environmentally and economically for all related industries, particularly in such areas where considerable amount of copper slag is produced. Using copper slag with gravel improves the consistency of the mixture [7, 11]. It has been found that the usage of copper slag instead of sand, without changing the amount of tap water, significantly improves consistency and compressive strength [9]. However it is possible to reduce the amount of water by 22% and obtain the same consistency. In this case the compressive strength increases up to 20%. No negative impact of copper slag on concrete contraction was found [6]. Copper slag is also used as an abrasive in blast-cleaning processes during corrosion protection. The copper slag particle size after this process is smoother. The content of 0–0.125 mm and 0.125–0.25 mm fractions is significantly increased. The waste also contains a small amount of corrosion products and corrosion protection coatings [12]. The use of blast-cleaning waste as a substitute for sand was tested and described in the article. Since the tested concrete can be used in the production of prefabricated elements, part of the research and evaluation of the results were carried out according to the PN-EN 1340:2004 "Concrete kerb units – Requirements and test methods" standard.

2. MATERIALS AND METHODS

Portland cement CEM I 32.5R and Portland-composite cement CEM II/B-V 32.5N from Ożarów Cement Plant as per PN-EN 197 were used. All concrete mixes contained 300 kg/m^3 of cement by 0.6 w/c ratio. Fractions of River sand 0–2 mm and natural gravel of 0.5–16 mm were used. Aggregates were at laboratory air-dry condition. Copper slag waste from blast cleaning was used as a partial replacement of sand. The ratio of substitution was 33%, 66% and 100% of sand amount by volume. Regular tap water was used as mixing water.

Grading curves of the used aggregates and the waste is shown in Figure 1. Boundary grading curves were adopted according to PN-B-06250:1988. Grading of all mixes of the aggregates were similar. They differed mainly in the amount of finest fractions 0–0.125 mm. If only sand and natural gravel were used, the portion of this fraction was about 0.5% while after replacing 100% of the sand with CS it increased to about 5.0%.

Eight concrete mixtures were prepared. Mix IDs and proportions are presented in Table 1. The consistency of fresh concrete was measured by slump test, in accordance with PN-EN 12350-2. In the case of mixes CI100 and CII100 also test mixes were prepared with using superplasticizer for concrete with an extended workability Ha-Be PANTARHIT® RC540 (FM) according to PN-EN 934-2. For these mixtures only the consistency of the mixture was determined to find the right amount of the necessary amount of plasticizer to provide such a consistency as that of the reference concrete.

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Table 1.
Proportions of concrete mixtures [kg/m^3].

Material	Mixture ID							
	CI0	CI33	CI66	CI100	CII0	CII33	CII66	CII100
CEM I 32.5	300	300	300	300	0	0	0	0
CEM II/B-V 32.5	0	0	0	0	300	300	300	300
natural sand 0–2	519	346	173	0	524	349	175	0
natural gravel 0–16	1375	1375	1375	1375	1388	1388	1388	1388
copper slag	0	195	390	586	0	197	394	591
water	180	180	180	180	180	180	180	180
W/C	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60

according to PN-EN 934-2. For these mixtures only the consistency of the mixture was determined to find the right amount of the necessary amount of plasticizer to provide such a consistency as that of the reference concrete.

Specimens were prepared and cured as per PN-EN 12390-2. They were cast in plastic moulds and compacted by double vibration (half and full) on a vibrating table. After 2 days they were stripped and then water cured in the laboratory for 28 days.

2.1. Compressive and tensile strength test

The compressive strength test was conducted on 100 mm cube specimens on the 28 day of hardening. The test were carried out in accordance with PN-EN 12390-3. The splitting tensile strength test was conducted on the same type of specimens in accordance with PN-EN 12390-6. The strength tests were performed by using a Matest instrument, having 3000 kN compression force capacity. The rate of loading was maintained at 0.5 MPa/s for compressive strength test and 0.05 MPa/s for splitting tensile strength test.

2.2. Free water absorption and sorptivity test

The free water absorption test was conducted on the halves of cubic specimens of 100 mm edge by means of mass method. Specimens after splitting were stored 12 hours in water. Then the surface-dry mass of the specimens ms were determined. Prior to the sorptivity test, the specimens had been oven-dried to the stable mass at a temperature of 105°C. The measurements were conducted at the temperature of approximately 20°C. The specimens were weighed (to determine mass md for calculation of free water absorption) and then arranged in a water containing vessel. The specimens were immersed up to the height of 3 mm. In the specific time intervals from the beginning of the test the specimens were weighed again to define their weight gain resulting from water sorption. Subsequent weight measurements were conducted for 6 hours. Sorptivity S in g/(cm^2·h$^{0.5}$) was defined as a slope of the linear function expressing the dependence of the mass of the water absorbed Δm by the area F on the time root $t^{0.5}$ [13]:

$$\frac{\Delta m}{F} = S \cdot t^{0.5} \tag{1}$$

Free water absorption has been calculated using formula 2:

$$n = \frac{m_s - m_d}{m_d} \tag{2}$$

where:

n – free water absorption [%],

m_s – mass of the fully soaked specimen [g],

m_d – mass of the specimen dried to stable mass [g].

Mass of a specimen dried to stable mass has been the same value as the starting mass in sorptivity test.

2.3. Bohme abrasion test

The abrasion resistance is important to evaluate the durability of concrete produced with waste used as aggregates, especially in cases of such structural elements as pavement slabs or kerb units, which are subjected to abrasion degradation. The test was performed according to PN-EN 1340. For each concrete mix, four 70×70×70 mm specimens were tested. Specimens were obtained by sawing the 150 mm cubes, and the tests were carried out between 40 and 45 days after concreting. Just before the test the specimens were dried in an oven at 105°C to stable mass. The specimens were then weighed with 0.1 g accuracy and the thickness in four points was measured.

Table 2.
Test results

Test	ID of mixture							
	CI0	CI33	CI66	CI100	CII0	CII33	CII66	CII100
Flow [mm]	140	80	40	20	130	50	20	20
Compressive strength 28d [MPa]	34.82	37.60	38.08	40.20	28.04	31.58	34.40	35.24
Compressive strength 90d [MPa]	38.12	41.77	48.83	50.01	35.21	41.17	43.95	45.59
Tensile strength 28d [MPa]	3.11	3.27	3.46	3.41	2.72	3.16	3.20	3.16
Water absorption [%]	5.88	5.81	5.87	5.89	6.53	6.74	6.60	6.21
Sorptivity [$cm^3/(cm^2 \cdot h^{0.5})$]	0.133	0.129	0.123	0.107	0.136	0.121	0.122	0.121
Bohme abrasion [$cm^3/50\ cm^2$]	17.08	17.49	15.86	17.52	18.05	19.10	19.26	18.32

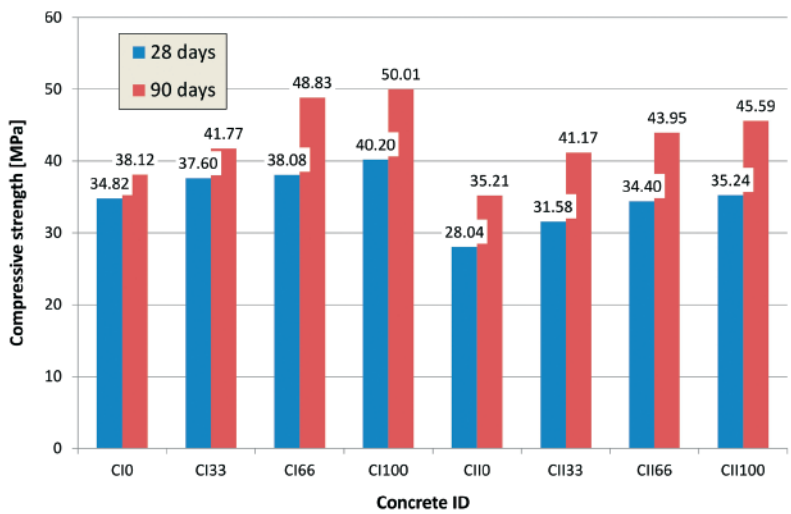

Figure 2.
Presentation of compressive strength test results

3. RESEARCH RESULTS

Research results are presented in the Table 2. Each value in the table is an average of six measurements expect abrasion test result which is an average of four measurements and fresh concrete slump which is an average of three measurements. Due to paper content limitations we can only represent some of the obtained data in figures.

3.1. Consistency of concrete

Particle size, finer than in the copper slag is not used for sandblasting and high dust content results in increased water demand of aggregate and lowers the consistency of the mixture. There was a change in the consistency class from S3 to S1 for both cements used when replacing 100% of sand with the waste. There were no problems with compaction and specimen preparation. Obtaining the same consistency like of reference concrete, the ones mixed with the waste required the usage of plasticizer. For concrete with a 100% replacement ratio it was necessary to add up to 1% of plasticizer on cement base to achieve a consistency such as of the reference concrete.

3.2. Compressive and tensile strength

The compressive strength after 28 days increased as the replacement ratio increased. The difference for 100% replacement rate was 25.7% for CEM I cement and 15.4% for CEM II/B-V one. The compressive strength after 90 days also increased with the increase replacement ratio (Fig. 2.). The maximum increase was 31.2% and 29.5% respectively for CEMI100 and CEMII100 concrete. The difference in compressive strength after 28 and 90 days was 9.5% and 11.1% in the CEMI0 and CEMI33 series respectively. In the remaining series, the increase was higher and ranged from 24.4% for CEMI66 to 30.4% for CEMII33. The

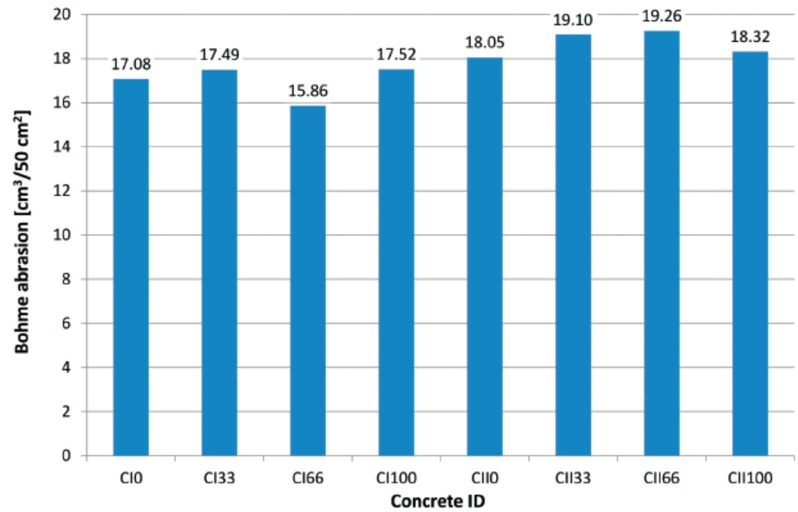

Figure 3.
Presentation of abrasion test results

tensile strength after 28 days for CEM I cement concrete increased with increasing replacement ratio. The difference in comparison with reference concrete was, respectively 5.1%, 11.3% and 9.6% in case of concrete CEMI33, CEMI66 and CEMI100. For concrete with CEM II/B-V all mixes with the waste added had the tensile strength higher by approximately 16.5% compared to the result of the reference mix. The increase in compressive strength and tensile strength was probably due to the higher content of fine particles that could fill the space between the larger aggregate grains.

3.3. Free water absorption and sorptivity

The water absorption of concrete with a given type of cement was similar regardless of the degree of substitution of sand with the waste. The average water absorption of concrete with cement CEM II/B-V was 11.2% higher than that of CEM I. Concrete with CEM I cement fulfilled the water absorption requirements of class 2 according to EN 1340:2004, whereas concrete with CEM II/B-V had water absorption > 6% and did not meet the requirements for prefabricated elements.

The addition of waste reduced the sorptivity of concrete. In the case of concrete with CEM I cement a gradual decline of sorptivity with increasing replacement ratio was found. Sorptivity of concrete CEMI100 is 19.5% lower if compared to the reference concrete. The concrete with CEM II/B-V cement, independently of the replacement ratio, had a similar sorptivity of approximately 11% lower than the sorptivity of the reference concrete.

3.4. Bohme abrasion

In the case of concrete with CEM I cement, no significant impact of sand substitution on abrasion was found. The abrasion of concrete with CEM II/B-V cement and replacement ratios 33% and 66% of sand was 5.8% and 6.7% higher than the reference concrete. At 100% replacement the abrasion was 1.5% higher than the abrasion of CII0. The abrasion resistance of all CEM II/B-V concrete meets the requirements of EN 1340: 2004 for abrasion resistance class H. Concrete with CEM I have met the requirements of wear class I.

4. CONCLUSIONS

- Replacing a part or all of the sand with blast-cleaning waste does not aggravate any of the tested properties of concrete.
- The compressive of the concrete with the waste is higher than that of the reference concrete and the higher the slag content is, the higher is the increase in the strength. The reference value for compressive strength is 34.8 MPa for CI*n* series and 28.4 for CII*n* series and for the concrete with the slag the values are 37.6–40.2 MPa and 31.6–35.2 MPa respectively.
- The tensile splitting strength of the concrete with the slag is higher than that of the reference concrete. The reference tensile strength is 3.11 MPa for CI*n* series and 2.72 for CII*n* series. Concrete with the waste achieved values 3.27–3.46 MPa and 3.16–3.20 MPa respectively.

- Greater content of fine particles in the waste if compared to sand changes the consistency. In the case of 100% sand replacement it changed from S3 to S1.
- Achieving for the concrete with 100% replacement the consistency class such as of the reference concrete requires superplasticizer in an amount of about 1% of cement mass.
- Concrete with 100% of sand replaced with the waste can be used for the production of precast elements. It is possible to properly compact the mixture without the addition of plasticizer. Concrete meets the requirements of abrasion and water absorption.

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