

Properties of recycled ceramic aggregates specified in *WT-1 2014 Aggregates – Technical Requirements*

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Abstract. The article presents the results of research on primary recycling properties of ceramic aggregates conducted following the procedures outlined in *WT-1 2014 Aggregates – Technical Requirements*. The material for the tests was obtained from a company producing sanitary ceramic products. Damaged ceramic products, coming from the factory waste heaps, were transported to the laboratory and crushed. This enabled producing aggregate that was later subjected to tests carried out on the aggregates commonly used in the production of mineral-asphalt mixes applied in making road surfaces. The factors that were examined include the following: the flow rate of fine aggregates (angularity of fine aggregate), fine particles content - methylene blue test, light-weight impurities content, frost resistance, bulk density of grains as well as water absorption determined by pycnometric method. The test results showed that the properties of the recycled aggregates are similar to those included in traditional aggregates used for the production of mineral-asphalt mixes. On the basis of the conducted analyses, the waste ceramic aggregate was recommended for use.

1 Introduction

The Polish ceramic industry has a long tradition. Further, it has become a significant technical and research base for the development of the ceramics industry as, in many cases, it provides a basis for the operation of other sectors of the economy and their development. For example, products from the refractory materials industry contribute to the proper functioning of the steel industry and ceramic products are used in power engineering (electrical insulators), without which transmission lines would not be able to function. Such dependencies impact a well-developed network of companies producing a wide range of ceramic products in the country. An indirect cause of the described situation is also the fact that in the country there are high quality raw materials for the production of ceramic

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materials. Their domestic deposits can satisfy not only the local market's demands the ceramic products produced in Poland are often exported to those countries which lack resources of raw materials used for such type of production.

The core of the domestic ceramic industry produces household products such as tableware, sanitary ware and ceramics commonly called glazing, which include ceramic floor and wall tiles. The analysis of the Polish ceramic industry market shows a continuous development and, despite large-scale production, the market demand remains higher than production. The high demand for these types of goods can be linked to the development of new areas of the economy, such as residential and commercial construction, as well as a growing standard of living. In addition, the high quality and functionality of the Polish ceramic products also directly affects the demand.

The most significant Polish manufacturer producing sanitary ceramics is Cersanit in Krasnystaw (Lublin Province). This plant can produce over 2 million pieces of a fill and varied hygienic range. The other major plants are Sanitec Koło Ltd. (Greater Poland Province), Roca Polska Ltd. (Silesian Province), Hybner S.A. (Greater Poland Province). Despite equipping the companies with new production nodes, a large part of ceramic goods are classified as waste. It is due to high-quality control requirements as well as production difficulties. The products that are damaged, i.e. even the ones with slight damage to enamel, for instance with cracks or scratches, end up in the company's waste piles. Considering that about 20% of the produced items are not classified as proper for sale as well as the scale of the domestic production itself, more and more attention is drawn to the problem of unwanted stored ceramic goods.

Due to the above-presented factors, many research institutes have attempted to develop some rational methods for managing ceramic waste. The leading solution proposed is the use of crushed ceramic waste as aggregates for concrete. Such a solution could be a useful method of managing all ceramic products. However, one should pay particular attention to the fact that not all types of ceramics have the same technical properties, and this solution is not useful in all cases that might seem beneficial from the technical point of view. For example, the research findings presented in [1–16] indicate the potential for using red ceramics for the production of cement concretes. Further, although it has been proven that the substitute for traditional gravel aggregate in the form of broken bricks [1, 3, 6, 9, 12] has less favourable properties, there are several ecological benefits of new solutions. The research on cement composites in which the waste of fine white ceramics was found was different [17–26]. The analysis of the features of these composites proves that the addition of ceramic aggregate improves the properties of concretes prepared in this way. Besides, particular attention is paid to ceramic aggregates derived from sanitary ceramics waste [17, 19, 24–26]. The characteristics of these aggregates are similar to the ones of traditional aggregates, and their structure is similar to dolomite aggregates [25] popularly used in road engineering. Other works [25–26] show that considering the specific features of ceramic aggregates allows for obtaining concretes with particular characteristics. These include high temperature resistant concretes [25], those resistant to abrasion [25] and high strength concretes [26].

The results of the conducted research allowed for putting forward a hypothesis that ceramic aggregates obtained from the crushed ceramic goods can become an appropriate aggregate for mineral-asphalt mixes. As the requirements and tests of aggregates for mineral-asphalt mixes are very specific and the results of such works carried out on recyclable aggregate were not found in the literature, the authors performed several necessary tests following the procedures outlined in *WT-1 2014 Aggregates – Technical Requirements* [27] for aggregate with successive grain size up to $D \leq 8$ mm for the wearing course made of asphalt concrete. The following factors were examined: the flow rate of fine aggregates (angularity of fine aggregate), fine particles content - methylene blue test, light-

weight impurities content, frost resistance, bulk density of grains and water absorption checked by the pycnometric method. The test findings showed that the properties of the recyclable aggregates are similar to those of traditional aggregates used for the production of mineral-asphalt mixes. On the basis of the conducted analyses, it was recommended that waste ceramic aggregate should be used for the mentioned application.

2 Materials

The research material was taken from a company that produces sanitary goods. Items such as washbasins, bidets, toilet seats and shell tanks with manufacturing defects were stored on the factory's waste heap. They were pre-crushed while being transported to the site. Their dimensions ranged from 10 to 40 cm. Fragments of damaged ceramics are shown in Fig. 1.



Fig. 1. Fragments of damaged ceramics. Source: own source.

The aggregate obtained from the site was then transported to the laboratory and crushed in a jaw crusher. The machine's operation allowed segregation of the recyclate into two-grain sizes, i.e. a fine grain size with diameters ranging from 0 to 4 mm and a thick grain size with diameters ranging from 4 to 8 mm. The thicker grains were returned to the crusher again. The thick ceramic grains are presented in Fig. 2.



Fig. 2. Ceramic aggregate grains of 4–8 mm diameter.

3 Research methodology

The first of the conducted tests was the evaluation of the E_{CS} fine aggregate flow index, also marked as the angularity of the fine aggregate. This index is determined for fine aggregates with a grain size smaller than 4 mm and, according to the definition, it is the time expressed in seconds in which the specified volume of a given aggregate will flow through the given hole under special conditions with the use of an appropriate apparatus. The test stand is equipped with research sieves, a dryer with a thermostat, a scale, a stopper, funnels, a cylinder with an inner diameter of 90 mm and height of 125 mm, which is fitted to the wider end of the funnel and the stand in which the cylinder and funnel are together with the attached cap. The funnel with a properly selected cylinder was placed on the stand next to the closed hole. The sample was put into in the device, limiting at the same time its dropping height. The device's latch was opened and the stopwatch was switched on as well. The total aggregate flow time was recorded as E_{CSi} with an accuracy of 0.1 s. The test was repeated five times using the same sample. The final E_{CSi} flow rate of the tested aggregate is an average of the five separate E_{CSi} values that have been rounded to a second.

The purpose of the methylene blue indicator study was to determine the content of various clay minerals that swell under the influence of water. The methylene blue value of mineral powder (a filler) refers to the amount of methylene blue adsorbed in 100 g of powder. This method consists of successive adding of a portion of a methyl-blue solution to the analytical sample of the aggregate powder in water. After each addition of a portion of methylene blue, the adsorption of the dye was controlled by an analytical sample with the so-called stain test on the filter paper to detect the presence of a non-adsorbed dye. When the presence of the non-adsorbed dye was confirmed, the methylene blue index was calculated as the mass expressed in grams of the dye adsorbed by the filler.

Another test was to determine the content of light pollutants. The analytical sample was spread on a tray and placed in a dryer at 110–115°C. The weight of the dried sample m_{ϕ} was recorded. The aggregate was separated on a 300 μm sieve and the finer fraction was discarded. Next, the aggregate was poured into the beaker with approximately 1 l of the zinc chloride solution and gently mixed. Then, the solution was poured over the surface into the second flask through a 250 μm sieve so that the floating grains were collected from the sieves. The solution was poured into the first beaker and stirred again until the next grains were discharged to the surface. The solution above the surface was poured into a second flask, and this process was repeated until all the grains were collected on the sieve. The sieve was then washed and dried with the contents. The contents were poured into the evaporator, dried and the light-weight aggregate, i.e. m_{10} , was weighed. The content of light-weight particles in the m_{10} was weighed. The content of light-weight particles in the m_{LPC} aggregate was expressed as a percentage and calculated as the ratio of the mass of the dried analytical sample and the mass of dried light-weight grains separated from the analytical ones.

The next tests concerned the assessment of the density and absorbability of aggregates [28]. To perform the test, the analytical sample was immersed in water (in the pycnometer). The air was removed from the pycnometer by turning and shaking it in an inclined position. Then, the pycnometer was inserted into a water bath and the sample was measured by a thermostat at $22 \pm 3^{\circ}\text{C}$ for 24 h. After these activities, the aggregate was removed from the water, dried for five minutes and the pycnometer re-filled with water. The specific gravity of the aggregate was determined as the ratio of the mass of crushed aggregate without pores to its volume expressed as a percentage. The volume density of the aggregate was determined as the ratio of the aggregate mass to its volume with pores expressed as a percentage. The absorbability was determined as the ratio of the mass of water that could absorb the aggregate into the mass of the dry analytical sample in percentage.

The last conducted test was the one of freeze-resistance of aggregates. The chosen method consisted in determining the loss of masses of aggregate grains when the moistened aggregate sample was subjected to a specific number of freezing cycles and thawing, which was expressed as a percentage. The sample of the aggregate was soaked in water under atmospheric pressure and then subjected to 10 cycles of freezing and thawing. The sample was frozen at (-17.5°C) and thawed in a water bath at the temperature of about 20°C.

After 10 cycles, the contents were transferred to the research sieve with square mesh dimensions equal to half the size of the sieve used while preparing the test sample. The grains which were left behind on the sieve were dried at 115°C to a constant weight, cooled to ambient temperature and weighed. This allowed for determining the weight loss, which was expressed in percentage.

4 Test results

The findings of the conducted tests are presented in Table 1.

Table 1. Results of the laboratory tests.

TYPE OF RESEARCH TEST	TEST RESULT		TESTING METHOD	REQUIREMENTS acc. WT-1 2014 Aggregates (KR1÷KR2)
Fine aggregate flow indicator E_{CS} (angularity of fine aggregate), s	38		PN-EN 933-6:2014-07	Declared E_{CS}
Fine particle content - methylene blue test, MB (MB dye value per kilogram of 0/2 mm aggregate)	0,2		PN-EN 933-9+A1:2013-07	category not higher than MB_{F10}
The content of light-weight pollutants, %	< 0,1		PN-EN 1744-1+A1:2013-05 p.14.2	category not higher $m_{LPC0,1}$
Frost resistance F,% (tested fraction 4/8 mm)	weight loss of the aggregate,%	0,2	PN-EN 1367-1:2007	not higher than 10
	macroscopic description of aggregate	no changes in the appearance of aggregate		
Sizes of the aggregate fraction, mm	0/4	4/8	PN-EN 1097-6:2013-11	declared by the manufacturer
Bulk density of grains, Mg/m ³	2,44	2,42		
Water absorption, %	1,3	1,5		

The test results showed that the properties of the recycled aggregates are similar to those included in traditional aggregates used for the production of mineral-asphalt mixes. The examined parameters presented in Table 1, such as the flow rate of fine aggregates (angularity of fine aggregate), the presence of fine particles, light contamination, frost resistance, grain bulk density and water absorption, are similar to those typical of traditional aggregates used for the production of mineral-asphalt mixes and these characteristics meet the requirements set by *WT-1 2014 Aggregates – Technical Requirements*.

5 Conclusions

Basing on the conducted analyzes, it was found that due to the scale of the production of ceramic goods and a large percentage of production waste resulting from this process, new methods of recycling ceramic materials should be introduced. The results of own research have proven that ceramic waste can potentially be used for the production of composites as fillers, and it is possible to produce aggregate from waste sanitary ceramics by crushing them in jaw crushers.

Having conducted the analyses, we recommend further research on mineral-asphalt mixes that use waste ceramic aggregates left after crushing the post-production waste of sanitary ware.

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