

Article

# The Assessment of Possibility of Using Sanitary Ceramic Waste as Concrete Aggregate—Determination of the Basic Material Characteristics

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**Abstract:** This article presents the possibilities of using soft clay pottery waste as concrete aggregate. There is shown a new approach of complete exchange natural aggregate in concrete with recycled aggregate, i.e., crushed ceramic of two fractions 0–4 and 4–8 mm. Basic characteristics of aggregate were evaluated, i.e., phase composition and crush strength. Drawing on past experiences, two concrete mixes were designed that were based on Portland cement 32.5 R used for ordinary concrete and aluminous Górkal 70, which is characterized by high initial strength and the fact that Al<sub>2</sub>O<sub>3</sub> is the binding factor. The prepared concrete samples were subjected to maintenance for the next 28 days, and then tests started. A series of tests were performed on the properties of concrete obtained, including a compressive strength and bending strength, an abrasion resistance, frost resistance, water absorption, depth of penetration of water under pressure, and bulk density of concrete. The research confirmed assumptions that it is possible to completely replace the natural aggregate with aggregate made of soft clay pottery waste. Both designed concretes showed high compressive and bending strength, as well as low absorbatibility and abrasiveness. It was also found that soaking in water, as well as its duration, adversely affects the strength properties of the designed concretes. Regarding concrete based on Portland cement, it was also demonstrated that the concrete has a high frost resistance and resistance to penetration of water under pressure.

**Keywords:** sanitary ceramic; concrete; recycled aggregate

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## 1. Introduction

The growth of the European and world economy is based on the intensive use of natural resources. It results in the generation of waste in which a larger part of it is landfilled. The Europe 2020 strategy [1] with a flagship initiative on a resource-efficient Europe shows a number of initiatives supporting the efficient use of natural resources, minimizing their impact on the environment. At the same time, in the communication [2] by 2020, waste is managed as a resource that emphasizes that the highest priority must be given to recycling and re-use of waste. One of the fundamental directions of the conducted research is the use as concrete aggregate of the waste received from construction works and demolition. However, many problems are connected with the use of this type of aggregate such as the necessity of selective demolition and the existence of old cement mortar and impurities [3]. The works made such a claim that there is increased absorbatibility and lower specific gravity of this kind of aggregate, and thus the concrete mixes of this type are less practical. In order to achieve similar workability as in concrete

with NA aggregate, concrete produced from RCA requires about 5% to 15% additional mixing water in the mixture, assuming that RCA is used in the dry state. It was confirmed in works [4,5]. At the same time, researchers show that in relation to recycling aggregates, similar specific weight as in natural aggregates is characterized by aggregate from crushed sanitary ceramics [6–8]. The re-use of concrete and ceramic waste as aggregates in the production of concrete (recycled concrete aggregate—RCA) has been the subject of many studies. It has been generally verified that the mechanical properties of concrete made from this kind of recycled aggregate depend mainly on the percentage of its use in the concrete mixture [9–11] crushing resistance, porosity, crushing index, density, geometric properties, and a number of other factors [12–14]. If these parameters are properly selected, it is possible to produce concrete of a quality similar to that produced with the use of natural aggregates (NA). The latest research carried out by [15] has confirmed the possibility of using broken bricks as a concrete aggregate in reinforced concrete structures. The tests were carried out on 24 beams 2100 mm long and cross-sectional dimension 200 × 250 mm. The research [16] used recycled ceramic aggregate obtained from prefabricated pipe remains with a compressive strength of 20 MPa. In addition, the researchers attempted to replace some of the cement (0–15%) with ceramic brick powder. All these elements were combined to analyze the impact of both factors on the mechanical properties of concrete, such as compressive strength, resistance to bending, and the determination of modulus of elasticity. The results indicate that when no RCA recycled aggregates are used, cement can be replaced with up to 15% waste brick without significantly affecting the parameters of the resulting concrete. In the case in which both components are combined, the recommended amount of waste brick powder, which will not cause significant losses in the properties of the material, must be limited to 5%. Other research is also carried on other concrete features based on recycled aggregate in the form of bricks. A comprehensive experimental program on the use of recycled aggregates produced by crushing refractory bricks was carried out [17]. For this purpose, ten blend patterns were used to prepare 210 samples with 0%, 25%, 50%, 75%, and 100% refractory brick aggregate replacements instead of natural sand. The samples were prepared on the basis of Portland and clay cement. Prior to performing strength tests, they were heated at temperatures in the range of 110–1000 °C. The results showed that refractory brick aggregate and aluminous cement improve the residual strength of concrete in relation to the natural aggregate. The authors of [18,19] proved the great potential of using waste ceramic aggregate for non-structural concretes for which there are no high strength requirements, including the production of pavement slabs. The authors of [20] conducted tests to determine the possibility of using waste from floor and wall tiles as aggregates for the production of concrete. There were determined physical and chemical properties of the aggregate. The properties of the achieved concrete are compared with the properties of concrete made of limestone aggregates. It was found that the concrete produced using aggregate from crushed floor tiles has similar mechanical properties as limestone aggregate; on the other hand, concretes made of recycled aggregate from wall tiles have lower mechanical properties than limestone. The authors of [21] made samples using Portland cement and recycled aggregate from new and used wall and floor tiles.

The huge number of parameters were examined including the shape of aggregate grains, the crushing index, and other parameters. There was percentage testing of natural recyclable aggregate recycling at 0% (reference concrete), 20%, 35%, 50%, 65%, 80%, and up to 100%. The compressive strength and bending strength, as well as the modulus of elasticity, were tested for the prepared samples. The obtained test results are ambiguous, however; the authors confirm that the use of recycling aggregates from wall and floor tiles for concrete is possible. In work [22], it reviews the impact on the recovered ceramic aggregate from floor and wall tiles as an aggregate for concrete. The highest compressive and tensile strength was achieved by replacing 100% of the natural aggregate with a fine ceramic aggregate. In summary, it should be emphasized that the addition of red ceramics into concrete as aggregate can be achieved primarily by replacing a coarse aggregate [23–28] or exchanging small aggregates [29–31]. Some researchers have also investigated the possibility of using ceramic dust as a mineral supplement to concrete [32,33]. Due to a number of factors, the obtained test

results were ambiguous. In some cases, researchers even managed to increase the strength of concrete with a different percentage of natural aggregate exchange for recycling in the form of ceramics. In the study [23], researchers managed to achieve an increase in strength by about 9% when replacing with ceramic aggregate only in 9%. In the study [29], an increase in compressive strength of about 7% was achieved with 5% replacement. In other studies [30,31], an increase in strength by 8–9% was also noted but with the complete replacement of the aggregate with RCA ceramic material. There is also carried out research on the use of waste of soft clay pottery products in the form of broken elements of sanitary equipment. Research conducted by [23,34] showed that the concrete made entirely on aggregate made of sanitary ceramics does not deviate from physical and mechanical properties of concrete on natural aggregates. In the research carried out by [35], 15–25% of the aggregate was replaced with a crushed ceramic cullet. The achieved concretes showed similar features to the basis of gravel aggregate. It was also noticed that as the amount of ceramic material increases, the compressive strength of the concrete increases as well.

In research [36], 25% of natural coarse aggregate was replaced with sanitary ceramic waste in order to make concrete that will be in direct contact with water available for human consumption. Researchers have proved that the inclusion of ceramic aggregate slightly increases the concentration (Na and K) and reduces the concentration of other elements (B, Si, Cl, and Mg) in water. It has been found that the levels of all elements are lower than limit values laid down in current legislation on water intended for human consumption. The authors of [31] have also confirmed the positive effect of using RCA aggregate in the form of sanitary ceramics, in which 20% and then 25% of the coarse aggregate NA was replaced with crushed sanitary ceramics. It has been found that electrical resistance increases with the use of recovered aggregate due to the intrinsic properties of this material. The new concretes have proved to be as durable as conventional materials and are effective over the whole lifetime of the concrete. The use of sanitary ceramics as concrete aggregate has also proved beneficial in relation to special concrete resistant to fire conditions. There are also attempts to use finely crushed sanitary waste in mortar. The authors of [37] have stated that 0–20% of the aggregate was replaced with crushed sanitary ceramics. It was shown that mortars with 20% content of waste aggregate have significantly higher bending strength than mortars with natural aggregate. These differences reached up to 250% with reference to the reference mortar. The results of these tests were also confirmed in studies [38] in which the change of aggregates in mortar ranged from 0–100%. In the studies conducted by [6,39], the authors compared the use of finely ground aggregate from bricks and sanitary ceramics for concretes. Increased water absorption of mixtures with recycled aggregates was shown to occur, along with increased porosity in the case of using sanitary ceramics, concurrently demonstrating that with appropriate use, they can be an effective alternative to the sand used for concrete. The authors of [40–42] examined the material properties of aluminous cement with ceramic aggregate compared to concrete on natural aggregate. The samples were heated at 1000 °C. In contrast to samples of concrete with traditional aggregate, samples with ceramic aggregate have retained their shape and consistency, and there were not any cracks or defects. Despite a decrease in strength, these samples still showed high compressive and tensile strength after heating. The tests have shown that for aluminous cement with sanitary ceramics aggregate, it is possible to eliminate the thermal effect of concrete particles' chipping off using air entraining admixture. The admixture also caused an increase in the strength of the concrete in relation to those without it, as well as a decrease in the strength drop in the case of heating samples to high temperatures in accordance with the assumed temperature-time distribution. Previous research has confirmed that the recycle aggregate derived from waste sanitary fittings may be an alternative to the natural aggregate, but there is no comprehensive study on the basic characteristics of the concrete to fully determine its suitability.

## 2. Materials and Methods

For the research was used sanitary waste obtained from waste products of one of the Polish sanitary fittings factory. Ceramic waste was ground into two 0–4 mm and 4–8 mm fractions and

subjected to sieving analysis according to [43]. Ceramic cullet before and after crushing is shown in Figure 1.

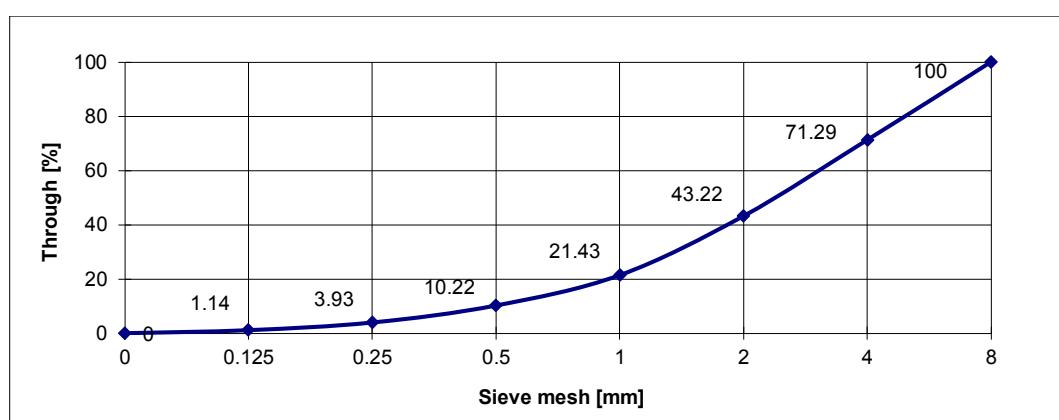


**Figure 1.** Ceramic cullet: (a) before crushing; (b) after crushing, fraction 4–8 mm.

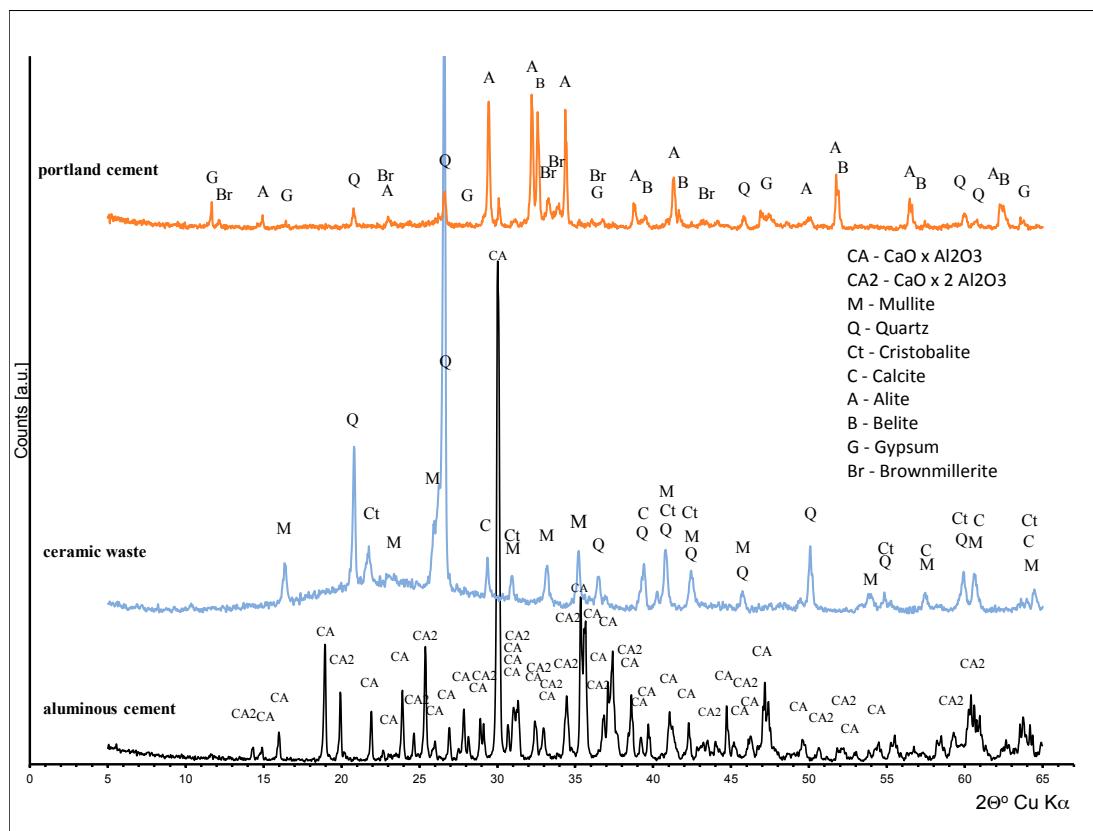
It allowed to obtain the following results of individual fractions  $0 \div 0.125$  mm – 1.14%,  $0.125 \div 0.25$  mm – 2.79%,  $0.25 \div 0.5$  mm – 6.29%,  $0.5 \div 1.0$  mm – 11.21%,  $1.0 \div 2.0$  mm – 21.79%,  $2.0 \div 4.0$  mm – 28.07% and  $4.0 \div 8.0$  mm – 28.57%. The grain-size distribution curve of the studied aggregate is shown in Figure 2.

As part of the aggregate tests performed, its crushing strength based on [44] was determined. The test was carried out on an aggregate of  $4 \div 8$  mm. The average crushing index was 6.75%, which means that the aggregate from sanitary ceramic waste is resistant to crushing.

The mineral content of ceramic aggregate used to the designed concrete mixes was also studied method using X-ray diffractometer Panalytical X'pertPRO MPD with goniometer PW 3020. The diffractogram of phase content of aggregate is shown in Figure 3. The main mineral content of ceramic aggregate constitutes multil recognized by characteristic interplanar distances  $d_{hkl} = 5.376$ ; 3.425; 3.390; 2.882; 2.427; 2.294; 2.208 Å. In addition, quartz occurs collaterally recognized by  $d_{hkl} = 4.255$ ; 3.344; 2.456; 2.283; 2.237; 2.128 1.981 Å and cristobalite  $d_{hkl} = 4.055$ ; 3.140; 2.847; 2.486 Å and calcite  $d_{hkl} = 3.861$ ; 3.040; 2.283; 2.096 Å. Together with crystal phases in the used aggregate, there was also an amorphous substance (aluminosilicate glaze) whose occurrence on diffractograms is visible by the increase of their background within the scope of angles from 15 to 35 ( $2\theta$ ).



**Figure 2.** The grain-size distribution curve of aggregate.



**Figure 3.** Diffractograms of mineral content of ceramic aggregate.

#### Characteristics of Concrete Mix

Under the iterative method of designing a concrete mixture with assuming the limitation of the substrates of the mix to the popularly used cements, there were designed 2 concrete mixtures, which differed only in the applied cement. The first series was based on the “Górkal 70” aluminous cement, while the second series, based on the Portland cement 32.5R.

In each series, only aggregate from sanitary ceramic waste was used, it was crushed to the two previously described fractions. Below, in Table 1 is presented the composition of concrete mixtures referred to 1 m<sup>3</sup>. All prepared samples have been treated in accordance with the standard requirements.

**Table 1.** The comparison of the composition of concrete mixtures.

Sample Determination	SG	SP
Aluminous cement “Górkal 70” (kg)	488	-
Portland cement 32.5R (kg)	-	488
Aggregate 0 ÷ 4 mm (kg)	997.14	997.14
Aggregate 4 ÷ 8 mm (kg)	398.86	398.86
Water (L)	199	199

### 3. Results

#### 3.1. Compressive and Bending Strength

The compressive strength test was carried out on cubes with side 100 mm in accordance with the standard [45]. The compressive strength of the samples was determined depending on their moisture content. In total, 18 samples were used in the study (9 on the basis of Portland cement designated as SP and aluminous SG). In addition, the samples were divided into three groups. The first group consists

of dry samples. The second group of samples was placed in water for 1 h prior to strength tests and the third group was immersed in water for 24 h. After samples initial drying the strength test started.

Compression strength test of cubic samples according to [45] and bending strength test of beam samples according to [46] were carried out in the Construction Laboratory in Civil Engineering and Architecture Faculty of the Lublin University of Technology with using the advanced system for tests on concrete and mortar Advantest made by Controls company compliant with [47]. Figure 4 shows an example of a beam and cubic sample during the test. The samples were made of SG concrete.

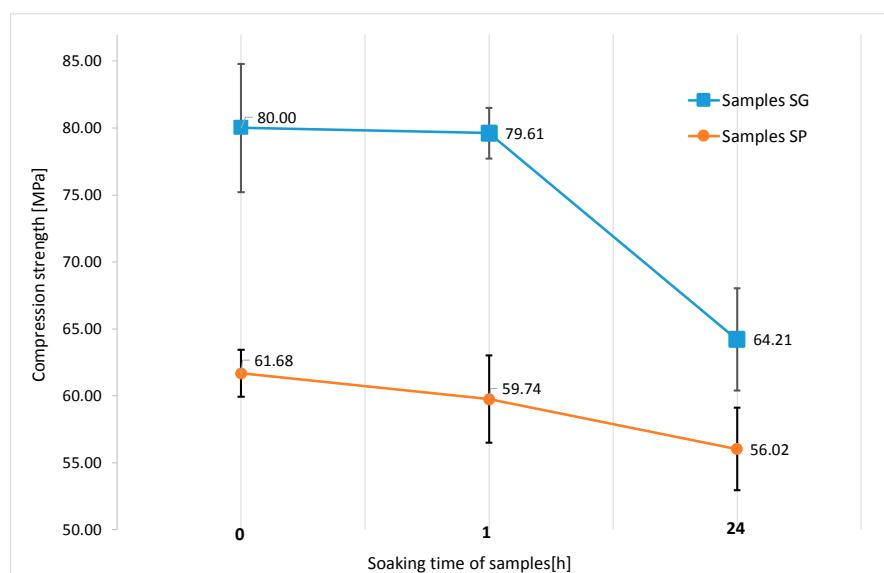


**Figure 4.** Example samples used in the research: (a) beam sample; (b) cubic sample.

The strength machine itself is equipped with three frames:

- frame with pressure up to 3000 kN for testing the compressive strength of concrete elements with maximum dimensions of  $200 \times 200 \times 200$  mm
- frame with pressure up to 250 kN for testing the strength of mortars for bending (samples  $40 \times 40 \times 160$  mm),
- frame with pressure up to 250 kN for testing the compressive strength of mortars, as well as elements with maximum dimensions of  $100 \times 100 \times 100$  mm (e.g., standard samples of cellular concrete).

Additional inserts allow testing the tensile strength of concrete elements, e.g., standard cylindrical or cubic samples, or finished products in the form of paving stones. Obtained results of compressive strength tests are presented in Figure 5. The graph compares the average compressive strength of SP and SG concrete with the standard deviation including the soaking time in water at  $20^{\circ}\text{C}$ .

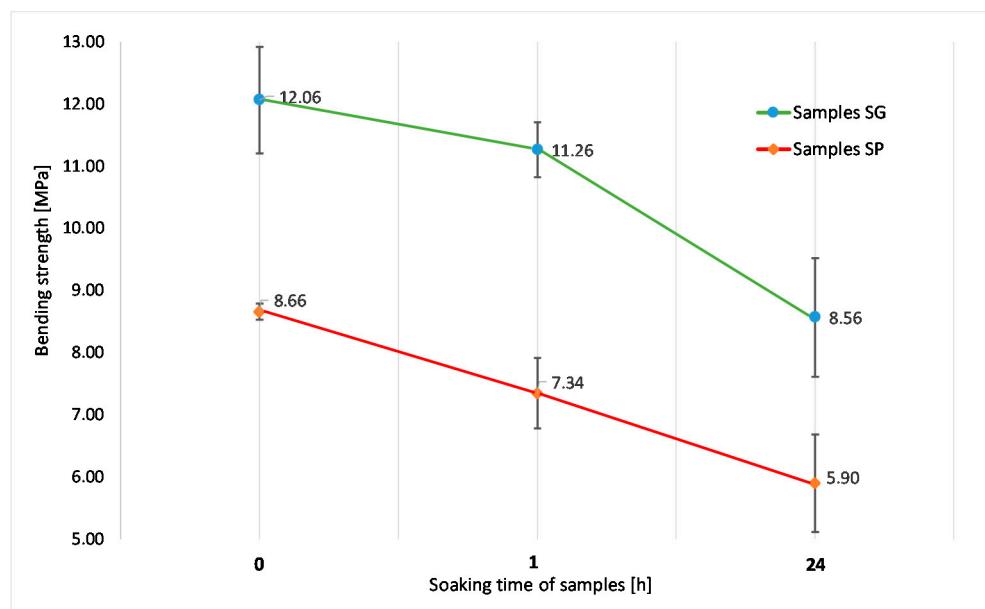


**Figure 5.** Compressive strength of cubic samples with standard deviations.

The obtained test results showed that greater compressive strength obtained samples made on the basis of aluminous cement. The largest average difference concerns dry samples and those pre-moistened for one hour. The average strength of the samples was greater by about 30%. A much smaller difference occurs in the case of samples that were immersed for 24 h. In this case the average compressive strength of the aluminous cement samples was higher by about 15%.

In the case of concrete made on Portland cement, the drop in strength caused by moisture was significantly lower than for aluminous cement. In this case, also the lowest average strength obtained samples that were immersed in water for 24 h. The maximum standard deviation in the SG group was 4.78% and in the SP group 3.26%. The described behaviour of the samples is consistent with the suggestion described in the literature [48] that the loss of strength due to moisturizing the samples is caused by the swelling of the cement gel due to the presence of adsorbed water: the cohesive force of solid particles is then reduced. This is also confirmed by the fact that the drop in strength is affected by the length of the sample saturation in water.

The bending strength test was performed according to the standard [46]. In this case, 18 samples were also divided into three groups the same as in the case of compressive strength. The obtained test results are presented in Figure 6. The graph shows the values of the average compressive strength of SP and SG concrete with the standard deviation including the soaking time in water at 20 °C.



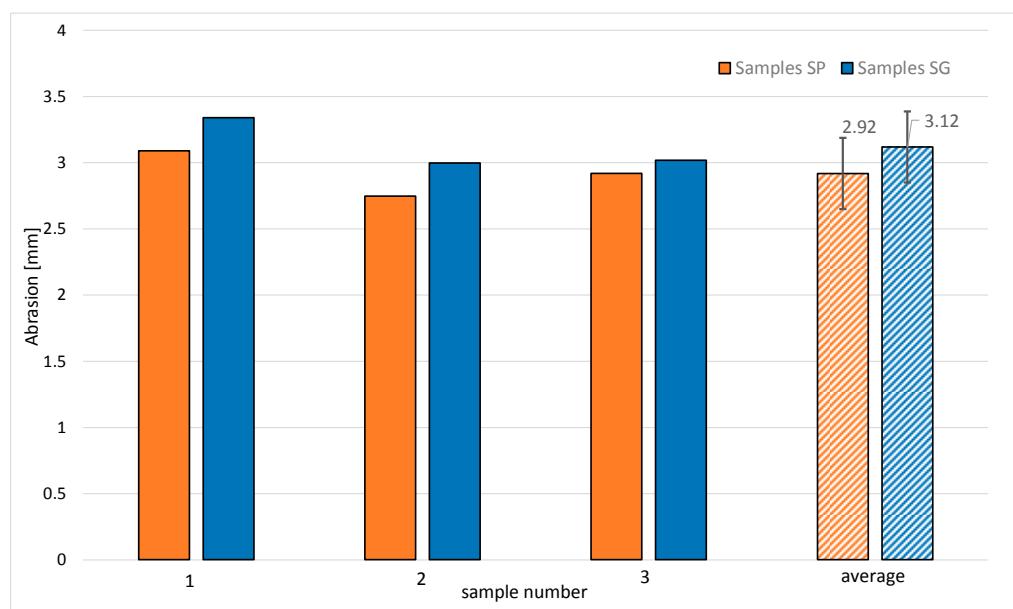
**Figure 6.** Bending strength of beam samples with standard deviations.

Similarly as in the case of compressive strength, the samples on aluminous cement obtained greater strength in this test. With increasing the time the samples were in the water, their bending strength decreases. Within the complete range of performer tests the bending strength of samples on aluminous cement is greater in the range of about 39–54%. The biggest difference is occurs the case of samples immersed in water for 1 hour. However it should be emphasized that the differences in average strength are much greater in the case of bending tests compared to compressive strength tests.

### 3.2. Resistance to Abrasion

Abrasion resistance tests were carried out to determine the possibility of using the designed concrete on the basis of waste ceramic aggregate. The tests were performed in accordance with [49] and the Appendix H. Three 3 cubic samples were prepared for the test, Portland and aluminous cement lengths ( $71.0 \pm 1.5$ ) mm which were pre-cut to size on a circular saw with cubes with a side length of

100 mm. Before the test on the abrasion machine based on Böhme, the samples were dried at 105 °C until a constant weight was obtained. During the tests, the disc was sprinkled with 20 g of corundum powder. The sample was then loaded with a force of  $294 \pm 3$  N and subjected to 16 abrasion cycles. Each abrasion cycle consisted of 22 disc rotations. Then the sample is rotated by 90°. In total, 16 cycles (352 revolutions) were performed according to the standard requirements. The result of the losses is shown in Figure 7. The graph shows the comparison between the results of individual tests and the average value of SP and SG concretes.



**Figure 7.** Abrasion resistance of SP and SG concrete with standard deviations.

The test results show that despite the fact that the compression strength of SG concrete samples is higher than those of SP concrete, the average abrasiveness of aluminous cement samples is higher than samples prepared on the basis of Portland cement. The difference is only around 7%. It is also worth emphasizing that during the test, the obtained results for all individual samples from the group were similar.

### 3.3. Frost Resistance of Concrete

The frost resistance test was performed on 20 cubic samples with 150 mm side where 10 was made on aluminous and 10 on Portland cement with so-called “ordinary method”. The test was performed on the basis of the standard [50]. The aim of the study was to determine the effect of frost taking into account the degree of concrete damage as its compressive strength and external destruction determined by the mass loss of the sample. Five samples from each group were placed in a bathtub with water at a temperature of  $18 \pm 2$  °C for the test duration. The rest was placed in the chamber, where they underwent freeze-thaw cycles. The freezing period at  $-18 \pm 2$  °C was at least for 4 h. Then, defrosting in water at  $+18 \pm 2$  °C lasted from 2 to 4 h. There were performed 150 cycles for Portland cement and 56 for aluminous: 56. The obtained test results are presented in Table 2.

In the case of SP concrete samples, the total mass loss after 150 cycles was 0.1% and the average strength drop was 2.2%. It is also worth adding that the tested samples did not show any cracks. According to the requirements of the standard [51], it can be qualified to the degree of frost resistance F150. Regarding concrete SG, after 56 cycles, cracks were visible and after strength tests, the strength drop of samples was as high as 29%. This means that this concrete should not be exposed to freezing temperatures.

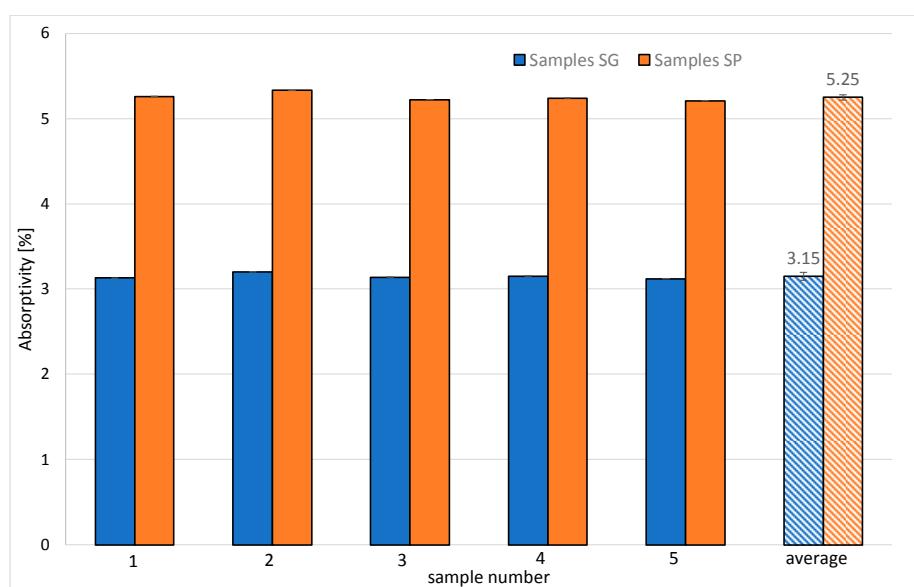
**Table 2.** Test results for frost resistance of SP and SG concrete specified on cubic samples.

No.	Mass before Freezing (g)	Mass after Freezing (g)	Average Mass Loss (%)	Stress (MPa)	Stress–Samples from Water (MPa)	Average Drop in Strength (%)
Aluminous cement						
1	7645.0	7645.0		47.56	51.60	
2	7573.5	7503.0		44.25	59.08	
3	7519.0	7453.5	0.4	19.77	56.71	29.2
4	7674.0	7673.0		42.31	46.83	
5	7613.5	7603.0		36.26	54.33	
Portland cement						
1	7220.5	7214.0		65.44	62.89	
2	7227.5	7225.5		51.92	61.32	
3	7386.5	7364.0	0.1	64.45	62.98	2.2
4	7378.0	7380.5		68.77	60.97	
5	7269.0	7265.5		49.15	58.40	

### 3.4. Water Absorption of Concrete

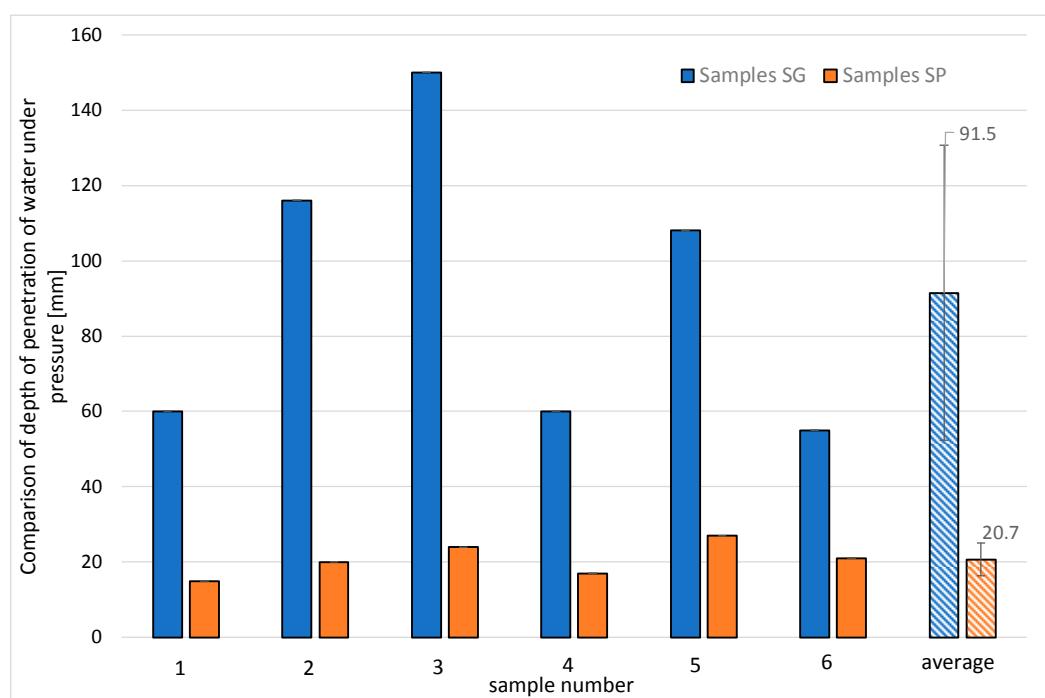
The test of concrete absorbability was made on the basis of the standard [50] on cubic samples with a side of 150 mm. The tests were carried out after 28 days of sample maturation on 5 samples on aluminous and Portland cement. The test cubes were placed in a tub in the way that distance between the samples was at least 15 mm and their base was not in contact with the bottom of the vessel. The samples were filled with water at a temperature of  $18 \pm 2$  °C up to half of their height. Then, after 24 h, the water was topped up so that its level was more than 20 mm above the upper surface of the sample. Then samples were removed from the tub every 24 h and then weighed with an accuracy of 0.2%. The study itself lasted until two further tests showed no differences. Saturated samples were placed in an oven at 105–110 °C and dried until constant weight. The mass absorption of the samples was determined on the basis of the mass measurement.

The obtained results are very similar in different groups (Figure 8). The average water absorption of concrete on aluminous cement is 3.15% and samples on Portland cement 5.25%. When comparing the obtained results, the mass absorption of SP concrete is greater of about 67% of SG concrete. However, it should be emphasized that for both concrete mixtures the values obtained are relatively small. For SG concrete, the value obtained meets the criterion described in the literature, not exceeding 4% of water absorption [52,53].

**Figure 8.** Comparison of mass absorption of SP and SG concrete with standard deviations.

### 3.5. Depth of Penetration of Water under Pressure

The study of the depth of water penetration under pressure was carried out on cubic samples with a side of 150 mm in accordance with the requirements of the standard [54]. There were prepared for the tests six samples for aluminous and Portland cement. The samples after maturation period were placed in the device and then were treated for 72 h with water pressure equal to  $(500 \pm 50)$  kPa. During the test, the surface appearance of samples that were not treated with water was periodically observed. After the time foreseen by the standard, the sample was removed and dried. Then the samples were split in half in a direction perpendicular to the surface treated with water. During the splitting and during the crunch examination the sample was set in a way that the surface of the water's operation was at the bottom. The penetration depth was measured rounded to 1 mm. The obtained test results are presented in Figure 9. The graph shows the results of six tests carried out for SP and SG concretes and the average value.



**Figure 9.** Comparison of depth of penetration of water under pressure for SP and SG concrete with standard deviations.

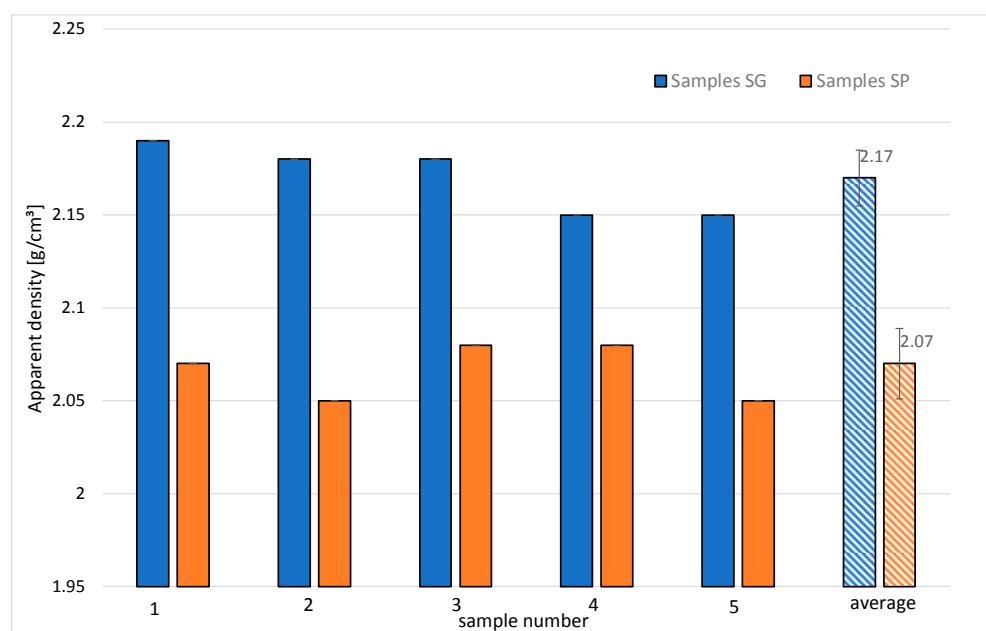
In this case, the SG concrete obtained a much greater depth of penetration and its average value is 91.5 mm. It is also important that the obtained test results are inhomogeneous. For three of the tested samples, the depth does not exceed 60 mm, while the others significantly exceed 100 mm. It is completely different for SP samples. The obtained results are much more homogeneous and the average penetration depth is 20.7 mm.

### 3.6. Determination of Bulk Density

The apparent density test was carried out in accordance with [53]. According to the standard requirements, the minimum volume of the sample used in the test should not be less than 0.785 L, therefore 5 samples were prepared on aluminous and Portland cement with a side length of 100 mm. The test was carried out using the hydrostatic method. First, the samples were weighed in their natural state with mass accuracy of 0.01. Then samples were then immersed in water at a temperature of  $(20 \pm 2)$  °C until the moment when the changes in mass were less than 0.2% within 24 h. Then their mass was determined in water according to the procedure described in the standard. The next stage of

the test was drying the samples in the oven at a temperature of  $(105 \pm 5)^\circ\text{C}$ , up to the point where the weight change was less than 0.2% within 24 h. Before the next weighing the samples were cooled to ambient temperature in a hermetic dry vessel and then weighed again. The obtained test results are presented in Figure 10. The graph shows the results for individual tests carried out for SP and SG concretes as well as average values.

The tests carried out showed that the volume density of SP and SG concretes is relatively similar. The SG concrete achieved a slightly higher value, however, the difference is less than 5% in comparison to SP concrete.



**Figure 10.** Comparison of bulk density of SP and SG concrete with standard deviations.

#### 4. Conclusions

In Poland in 2017, the production of ready-mix concrete will amount to 23 million cubic meters and is comparable with the record-breaking year 2011 with an upward trend in the year 2018. It is therefore very important to use recycling materials for the production of concrete commonly referred to as “green concrete”. Green concrete promotes sustainable and innovative use of waste materials and unconventional alternative materials in concrete, as well as circular economy. In the presented article, only recycled aggregate in the form of crushed sanitary ceramics of fraction 0–4 and 4–8 mm was used in the preparation and design of the concrete mixture. This is a new approach to the design of concrete from soft clay pottery waste. So far, the authors replaced natural aggregate with aggregate of soft clay pottery in the amount of 15–25% [36–42]. It was used as coarse aggregate. Most importantly, the authors used only Portland cement. From the work of authors [40–42], it appeared that the concrete bases on soft clay pottery and aluminous cement are resistant to high temperatures, but their other material features were not determined. Therefore, the verification of other material features was necessary to determine the application possibilities of using new concrete. The article presents a number of basic tests of two designed concretes based on Portland cement (SP) and aluminous cement (SG).

The results of compressive and bending strength tests confirmed preliminary assumptions for the exchange of natural aggregate with RCA aggregate from ceramics of two fractions 0–4 and 4–8 mm. Designed concrete based on Górkal 70 SG aluminous cement was characterized by higher compressive strength by about 30% and, in the case of bending strength, by as much as 40% in relation to concrete on Portland cement SP. However, it is worth noting that concrete on aluminous cement SG, which

was in water for 24 h and dropped in strength compared to dry samples, was as much as about 25%, and for SP samples the difference was only 10%. Even greater strength drops of 40–45% for both SG and SP samples were noted when beams were bended, which were in water for 24 h compared to dry samples.

Conducted abrasion tests showed that SP is less susceptible, but the difference is small compared to SG samples. Due to the fact that for SP concrete the average loss in height does not exceed 3 mm, it can be used as a surface for the forecasted medium traffic. In the case of the frost resistance test, samples made of SP concrete after 150 freeze-thaw cycles do not show any changes in appearance, and on the basis of tests they can be classified can be qualified to the degree of frost resistance F150. Significantly worse results were obtained for SG concrete. After 56 cycles, significant changes in the appearance of the samples take place; moreover, the conducted tests confirmed a drop in strength by as much as 29.2%. The research shows that SG concrete shows a lower water absorption by about 65% in relation to SP concrete. Importantly, the obtained results for individual tests in the study were homogeneous for both tested concretes. It is also worth noting that the obtained results for individual test samples were homogeneous for both concrete mixtures. As part of the work, the depth of penetration of water under pressure was also tested. The results showed that on average more than four times less depth of penetration of water under pressure was obtained for SP samples, and the obtained individual results were homogeneous, which was in contrast to SG concrete samples for which a large fluctuation of individual results was received.

The obtained test results confirmed the possibility of completely replacing the natural aggregate with aggregate made of soft clay pottery waste. Using the iterative concrete design method, concrete mixes have a number of advantageous features such as high compressive strength and bending strength, low water absorption and abrasion, and, in the case of Portland cement-based concrete, high frost resistance and resistance to water penetration under pressure. Considering the fact that ceramics is a material that is biodegradable for over 4000 years, this direction should be promoted and further developed.

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