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APPLICATION OF WASTE FROM UTILITARIAN CERAMICS FOR PRODUCTION OF CEMENT MORTAR AND CONCRETE

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Abstract: Preliminary results of utilization of ceramic waste for the produce of ceramic mortars and concrete have been presented. Currently, ceramic wastes from the production of ceramic flower pots and covers are not used in any form. The chemical composition of this waste materials was determined using X-ray fluorescence (spectrometer ARL Advant 'XP). Cement mortar and concrete were made using CEM I 42.5 R. The results showed that the compressive strength (after 28 days) of cement mortar increased with the increase of size reduction of the ceramic waste. The highest compressive strength (increased by 5.0% compared to the control sample) was found for cement mortars in which waste pottery with fragmentation of less than 0.2 mm were used. These mortars also showed the highest frost resistance (after 150 freeze and unfreeze cycles), whereas the largest decrease the compressive strength (over 17%) after the frost resistance test showed samples of the cement mortar with the ceramics waste fragmentation in range 1.0–3.0 mm. Studies have also shown that the compressive strength of concretes increase with added the ceramic waste (10–30%) instead of natural aggregate. The highest compressive strength (approximately 12.3%) compared with the sample control show the concrete in which 30% of the natural aggregates were replaced by the ceramics waste. Furthermore, using up to 30% of ground ceramic in the concrete reduces its water absorption capacity.

Keywords: *ceramics waste, cement mortar, concrete, mineral processing*

Introduction

Intensive industrial production growth and consumption causes a rapid increase in the amount of produced production waste and post-consumer waste. One of the sectors that produce significant amounts of waste is the sector of the ceramic industry. Only in Europe, every year more than 85 Tg of ceramic products (including 0.5 Tg tableware and decorative products) is produced, 5–10% of which are rejected due to manufacturing defects (European Commission, 2007). At present, this fraction of

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rejects is not reused in the production process, but shipped directly to landfills, thereby posing a risk for the environment.

Currently, ceramic utilitarian wastes that are durable, tough and highly resistant to physical, biological and chemical degradation are not used in any form. A literature review (Binici, 2007; Federico and Chidiac, 2009; Medina et al., 2012, 2012b, 2013, 2013b; Halicka et al., 2011, 2013; Mustafa et al., 2013; Sekar et al. 2011) indicates that, on a laboratory scale, attempts were undertaken to use a sanitary ceramics, bricks and glass as an aggregate for concrete production. Concrete with the addition of aggregate of red ceramics indicates lower strength properties compared with concretes on conventional aggregates (Akhtaruzzaman and Hasnat, 1983; De Brito et al., 2005). While concretes made with the addition of ceramic sanitary ware, i.e. used sinks or lavatory pans, have similar or slightly better properties (compression strength and tensile strength) than concrete made on the basis of the traditional aggregate (Guerra et al., 2009, Medina et al., 2012a). For the production of concretes in the laboratory tests were also used waste materials i.e. stone flour (Reddy, 2013), bottom ash and waste sand from foundry (Khatib and Ellis, 2001; Aggarwal and Siddique, 2014), rice hulls (Chao-Lung et al., 2011; Van Tuan et al., 2011), stopper (Panesar and Shindman, 2012) and fly ash from co-firing process of coal and biomass (Wang et al., 2008). Unfortunately, so far the results of laboratory tests (in micro scale) were not confirmed in larger scale (quarter-scale or semi-technical).

Quantity and physical-chemical properties of used waste materials determines the quality of produced product (Nowicka-Skowron and Ulewicz, 2015). The purpose of this paper is to investigate the possibility of using waste of utilitarian ceramics for the production of cement mortar and concrete. Up to now, no developed methods of practical application of this waste exist (pots, casings, decorative products) and so the performed research in this direction is the novelty of this work and is particularly important for the protection of the environment.

Experimental

In this study, pottery wastes formed during the manufacture of ceramic flower pots and casings in one of the ceramics plants from province of Silesia were used. Post-production wastes, in accordance with strict quality control requirements are ceramics which have defects, i.e. cracks, nicks, or damage to the enamel (Fig. 1). In the experiment, the multicolour ceramic wastes with a predominance of wastes covered by red and brown enamel were used. Ceramic wastes were crushed with the use of laboratory jaw crusher and disintegrator and then put under granulometric analysis. The chemical composition (Table 1) of the material was determined by using X-ray fluorescence (ARL Advant'XP spectrometer).

a) b)

Fig. 1. Post-production ceramic waste (a) crushed ceramics – fractions as in Table 2 (b)

Table 1. Chemical composition of utilitarian ceramics waste

Component	Contents, %	Component	Contents,%
Al_2O_3	20.0	Fe_2O_3	1.43
SiO_2	64.2	MnO	0.04
K_2O	2.64	ZnO	0.06
CaO	9.55	SrO	0.04
TiO_2	1.47	ZrO_2	0.38
V_2O_5	0.07	BaO	0.12

For the preparation of cement mortars waste fractions of ceramic materials with a grain size 0.0–3.0 mm were selected. The composition of the tested mortars are shown in Table 2. Bars with the following dimensions: 4×4×16 cm were made in accordance with PN-EN196-1 standards. In this research municipal water from the intake of the city of Czestochowa with a pH of 7.7 and the content of nitrate and chloride ions equal to 34.3 and 30.9 mg/dm^3 was used. Electrical conductivity of water was 480 μS/m. In the experiment Portland cement CEM I 42.5 R (Cemex) was used. The water–cement ratio (the ratio of the weight of water to the weight of cement used in a mix) in the cement mortars was equal to 0.50. Ceramic products after 24 hours were disassembled and placed in a water bath with temperature 20 ± 1°C, where they remained for 27 days. The obtained mortars were subjected to microscopic examination (LEO Electron Microscopy Ltd.) and their compressive strength (PN-EN-196-1) and absorbability (PN-85/B-04500) were identified.

Table 2. Composition of the studied cement mortar

Components	Mixture number				
	M1*	M2	M3	M4	M5
Cement, g	450	450	450	450	450
Water, cm^3	225	225	225	225	225
Naturally moulding sand, g	1350.0	1282.5	1282.5	1282.5	1282.5
W/C	0.50	0.50	0.50	0.50	0.50
Waste of utilitarian ceramics, g	–	67.5	67.5	67.5	67.5
Degree of fineness of ceramics, mm	–	0–0.2	0.2–0.5	0.5–1.0	1.0–3.0

M1*– standardized PN-EN 196-1:2006 cement mortar (control sample)

In the next stage of the research the influence of pottery waste addition (10 – 30 %) on the concrete samples with cubic dimensions of 150x150x150 mm was studied. The concrete was designed using computational-experimental method. The composition of tested concretes are shown in Table 3. The water–cement ratio (the ratio of the weight of water to the weight of cement used in a mix) in the concrete was equal 0.48. The consistency of the concrete mix was determined in accordance with standard PN-EN 12350-2, the average absorbability of samples with norm PN-88/B-06250, and the penetration depth with water with PN-EN12390-8. Also there was specified concrete compressive strength (PN-EN12390-3 and PN-EN206) and frost resistance (PN-88/B-06250).

Table 3. Composition of tested concretes

Components	C00*	C10	C20	C30
Cement CEM I 42.5 R, kg/m^3	332	332	332	332
Water, dm^3/m^3	158	158	158	158
W/C	0.48	0.48	0.48	0.48
Natural aggregates (size 0-16 mm), kg/m^3	1933.0	1899.8	1866.6	1833.4
Waste of utilitarian ceramics, kg/m^3 (percentage of the weight of cement)	–	33.2 (10%)	66.4 (20%)	99.6 (30%)
Polycarboxylate superplasticizer (Sika ViscCrete EPL-4), dm^3/m^3	6.64	6.64	6.64	6.64

C00*– control sample of concrete

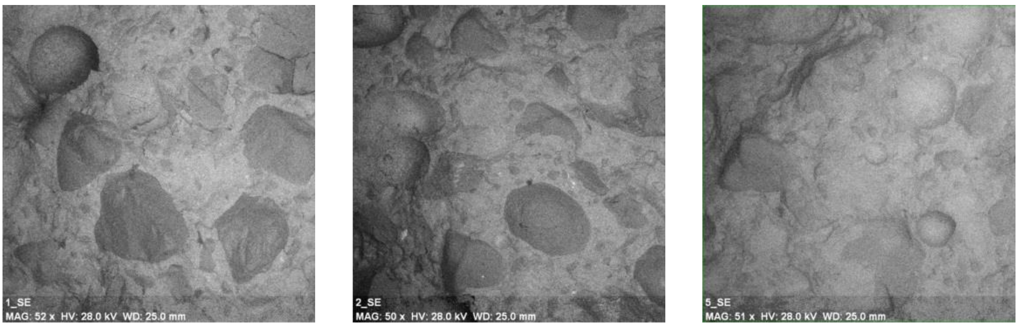
Results and discussion

The main ingredient of ceramic masses used for the preparation of pottery is kaolinite. The properties of clay, especially the diverse composition of the ceramic masses and different technological parameters of the used production processes affect the physio-chemical properties of manufactured ceramic products, and hence the properties of post-production ceramic wastes. The tests of the post production wastes of the pottery used in this paper, are shown in Table 1. The samples contained more than 60% SiO_2 and 20% Al_2O_3 and small amounts of other metals oxides. Higher compactness of two basic metal oxides in the ceramic wastes compared to the content in a typical basalt (45–55% SiO_2 and approx. 14% Al_2O_3) or granite (20–60% SiO_2) suggests that this material can be successfully used as replacement of natural aggregates.

In the first stage of research, the influence of the degree of fineness of ceramic wastes on selected properties of cement mortars was defined. As can be seen from Table 4, together with an increased degree of fineness of the ceramic waste increases the compressive strength of cement mortar. The highest compressive strength (increased by 5.0% compared to the control sample) showed cement mortars in which waste pottery with fragmentation of less than 0.2 mm were used. In contrast, the addition of wastes pottery with fragmentation of 1.0–3.0 mm caused a decline in the strength of cement mortars by 6.1% compared to the control sample. With the increase in degree of fineness of ceramic wastes added to cement mortars there was observed increase of frost resistance (after 150 cycles) and decrease in absorbability of tested samples. Cement mortars with addition of finest fraction (less than 0.2 mm) showed an increase in frost resistance of 16.7% and a decrease in absorbability of 12.7% compared with the control sample. Whereas, the addition of wastes pottery with fragmentation of 1.0–3.0 mm caused a decline in the strength of cement mortars after testing frost resistance by 15.7% compared to control sample.

Table 4. Properties of the studied cement mortar

Properties	M1	M2	M3	M4	M5
Compressive strength, MPa	70.3	73.8	70.0	69.3	66.1
Absorbability, %	7.27	6.35	6.09	6.04	6.06
Compressive strength after testing frost resistance, MPa	64.5	61.7	58.1	57.4	54.4



a) b) c)

Fig. 2. SEM micrographs of cement mortar M0 (a), M1 (b), and M5 (c)

Microstructural studies of cement mortars (Fig. 2) showed their heterogeneous microstructure, particularly in the contact area of ceramic aggregate with cement grout. The addition of finely divided ceramic waste and low water-cement ratio (w/c) of 0.5 has caused the creation of tight structure of cement mortar and consequently not only increase in mechanical properties of the cement mortars but also decrease in absorbability of mortar and increase in frost resistance. In contrast, cement mortars containing the thickest fractions of recycled pottery (1.0–3.0 mm), with a high proportion of particles of irregular and flattened shape, show a more heterogeneous structure, which caused a reduction in the compression strength, but does not affect the absorbability and frost resistance.

The next stage of the study included the production of concretes with the addition of 10, 20 and 30% of waste pottery as a substitute for natural aggregate and the determination of selected properties of these concretes. The composition of the ceramic on concrete aggregate was designed by computational-experimental method, assuming a ratio w/c equal to 0.48 to obtain a homogeneous, non-porous concrete. The consistency of obtained concrete mixtures, or the degree of fluidity of these mixtures (blends ability to flow) was determined by the settling cone (according to PN-EN 12350-2). As is apparent from the data presented in Table 5, the results obtained for concretes made from blended waste pottery are in the range of 15–38 mm and belong to a class S1 (moist consistency), while the control concrete mix can be classified as a class S1/S2 (settling of the cone 44 mm). The obtained concretes, together with increasing amounts of waste of ceramic, were characterized by a lower absorbability and a slightly lower depth of penetration of water compared to the control concrete. Taking into account the fact that the plain concrete has an absorbability n_w = 5–8%, the addition of up to 30% of waste pottery does not deteriorate the properties of the concrete mix. The increase in the amount of added ceramic waste also caused increase in the compression strength of investigated concretes. Control concrete received an average compressive strength f_{cm} equal to 54.5 MPa and concrete with addition of 20 and 30% of waste, respectively, 7.3 and 12.3% higher. Also, higher values of the compressive strength were obtained by Medina et al. (2012a, 2013a) for the concrete containing 20 and 25% sanitary ceramic wastes. The authors observed increase compressive strength for concrete containing waste by 7 and 12%. A similar effect was also observed by Pecheco-Torgal and Jalali (2011) for concrete containing a mixture of ceramic floor tiles and sanitary wastes. On the other hand, Brito et al. (2005) observed decrease of the compressive strength of the concrete containing the ceramic construction waste (brick, tile). The strength decreases as the quantity of ceramic aggregates in concrete increases. The highest decrease (44.2%) was observed when the coarse aggregate were replaced with ceramic waste. While Akhtaruzzaman and Hasnat (1983) used of crushed brick as a 100% replacement for coarse natural aggregates in concrete and found that the tensile strength of the brick concrete was about 11% higher than that of normal concrete.

In the study of frost resistance for all series of concretes were not observed weight loss after 150 cycles of freezes and defrosts. Concrete with addition of 20 and 30% of pottery waste obtained after 150 cycles of freezes and defrosts, the loss of strength, respectively by 10.5 and 10.1% compared to the control samples. The most resistant concrete on cycles of freezing and defrosting was concrete with the addition of aggregate fraction below 0.2 mm, for which the strength loss was only 2.4%. Favourable results of mechanical tests and greater resistance to operation of external physical factors of examined concretes with the addition of waste can be explained by the fact that fine ceramic waste of aggregate are arranged strictly between the grains of thicker natural aggregate and sharp edges of aggregate grain help grains to wedge between them. High tightness and uniformity of the structure determines the durability of concrete.

Table 5. Properties of tested concrete

Properties	C00	C10	C20	C30
Slump test, mm	44	38	35	15
Slump class	S1/S2	S1	S1	S1
Absorbability, %	4.8	4.7	4.6	4.0
Penetration depth of water, mm	88	88	86	84
Compressive strength, MPa	54.5	55.9	58.5	61.2
Mean percentage reduction of compressive strength, %	12.3	12.0	10.5	10.1
Mass loss after 150 cycles, %	0.01	0.01	0.0	0.0

Conclusions

Concrete is the most extensively used material for construction of different types of structures such as buildings and bridges as well as for precast products such as poles, columns and sleepers. During the concrete production large amounts of natural aggregates are used. The replacement of the natural aggregates by a post-production waste will reduce consumption of raw materials and will have a good influence on the environment.

Based on experimental studies, we can conclude that it is possible to use waste from utilitarian ceramics for the production of cement mortar and concrete. Studies shown that, the compressive strength of cement mortar containing ceramic wastes increases with the degree of fragmentation of this waste. The use of fractions of fragmentation less than 0.2 mm allows to obtain cement mortar having good tensile strength and low absorbability. The highest compressive strength (increased by 5% compared to the control sample) showed cement mortars in which were used waste pottery with fragmentation of less than 0.2 mm. Cement mortars with this fraction of waste showed an increase in frost resistance of 30.2% and a decrease in absorbability of 12.7% compared with the control sample. Also, the increase in the amount of added ceramic waste caused increase in the compression strength of investigated concretes. The highest compressive strength (increased by 12.3% compared to the control sample) showed concretes containing 30% of ceramic waste. This concrete after 150 cycles freezing and defrosting showed strength loss of 10% compared to the control samples. Using the post-production ceramic wastes for production of concrete will give a good results (a higher compressive strength) and made economic concrete (production of 1 m^3 of concrete containing the ceramic waste allow to save 5% of natural aggregate and 20% of cement).

The use of waste from the production of ceramic flower pots and covers, which until now not being used is an important issue and novelty of this work. This research work provides a basis for future experiments related to the potential for using utilitarian ceramic waste as sand for cement mortar and as aggregates for concrete. The replacement of traditional raw material in building materials by ceramic waste leads to relevant environmental benefits. It avoids the extraction of large quantities of raw materials from the earth, reduces energy costs and also prevents landfill problems.

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