Analysis of applicability of porous concrete containing recycled ceramic aggregates for communication pedestrian routes forming surface rainwater drainage

Paweł Ogrodnik[1], Bartosz Zegardło[2]

[1] Main School of Fire Service, Faculty of Fire Safety Engineering, 52/54 Słowackiego Str., 01-629 Warszawa, pogrodnik@sgsp.edu.pl; [2] Siedlce University of Natural Sciences and Humanities, Faculty of Natural Sciences, 2 Konarskiego Str., 08-110 Siedlce

This work is a continuation of the authors' research conducted to develop innovative concrete mixtures containing recycled ceramic aggregates formed after crushing of waste ceramic sanitary elements. The article presents the problem of utilization of ceramic waste, there are listed factors of waste generating and the main characteristics of the waste material. Based on available literature, there are presented the results of research work on successfully using ceramic waste aggregates in the production of concrete composites.

The main aim of this work was to design innovative concrete containing sanitary waste which would be permeable to water. The composite presented in the work showed total water permeability. The tested strength parameters allowed us to propose using it for the communication substrates carrying the load from pedestrian traffic. In this type of communication substrates the authors see a remedy for the problem of utilizing rainwater. Especially in urban areas where is no rain water sewer system this solution would have a legitimate benefit. Totally permeable communication routes could directly transfer water to the substrate under their surface which would effectively increase the chance of natural rainwater absorption.

Key words: recycled aggregate, utilization, pedestrian routes, concrete

Introduction

Recent research on reuse of waste materials resulted in numerous industrial applications. Recycling starts with waste segregation, a process which concerns both households and enterprises. The current state of the art allows for the majority of waste substances in various forms to be reused for secondary production of raw materials. Several waste substances, especially those which storage is neutral to the environment, remain unrecycled. Therefore, the success of recycling is not the domain of all existing waste materials.

One of current research issues concerns rational construction waste management. Despite the fact that these wastes are generally biologically neutral to the environment, research of recycling of these materials draws interest of growing numbers of scientists. This issue also applies to ceramic materials. Although ceramics are ecologically neutral, the scale of growth of waste poses a significant environmental issue.

The word ceramics originated in greek keramos (clay). This term is commonly used to describe all products that are made of heat treated mineral materials. Customarily all forms made of heat treated mineral materials are described with this term.

Manufacture of ceramic is one of the oldest crafts. According to archaeological research, its origins date back to fifteen thousand BC. It is believed that the process of clay hardening under the influence of high temperature was discovered together with ability to control fire and the beginning of settled life. During the burning of campfire, it was noted that the soft clay substrate became hard and cohesive. Man took advantage of this discovery to make dishes out of the clay which were later burned in the fire. Various clays, recipes and firing methods were used over the years. The original pottery industry advanced and burnt clay products began to find new uses, including construction materials.

The industry of producing fine ceramics, depending on the method of preparation, differences in composition and properties of raw material, produces many types of porcelain and porcelain-like products. Among them are hard porcelain, soft, semi-porcelain, low temperature porcelain, zirconium, lithium, beryllium, faience, majolica, etc. They are made of tableware, medical supplies and a wide range of construction materials [1,2,3]: sanitary ceramics, electrical insulators, interior trim elements.

Apart from the described products of common and fine clays, ceramics include products made from mixtures of these clays as well as clays mixed with other components.

Positive features of ceramics include [4,5,6]: resistant to high temperatures, high resistance to chemical agents, good mechanical properties (compressive strength up to 600MPa), dielectric and insulating properties, high hardness, and abrasion resistance. Negative features include: low tensile and flexural strength, impact susceptibility, brittleness and low resistance to mechanical and thermal

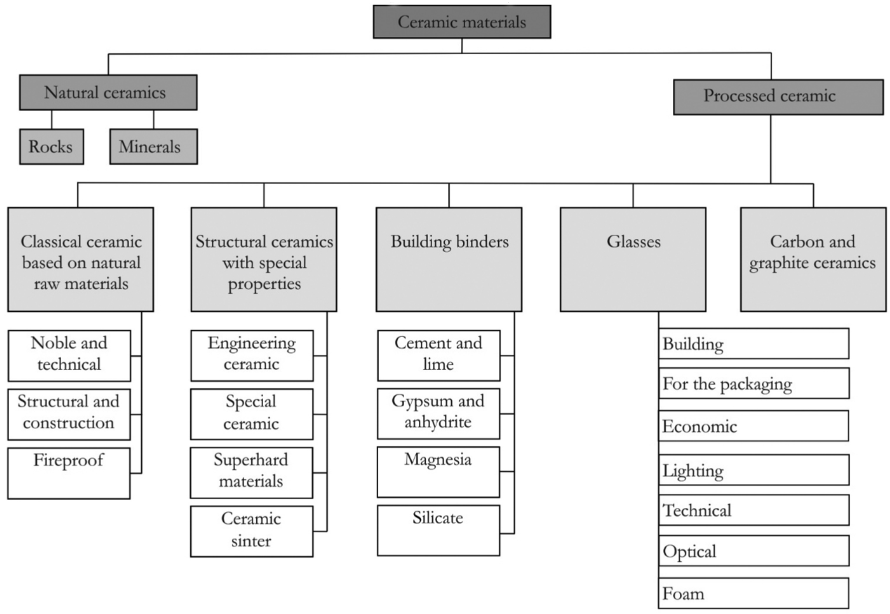

Fig. 1. General classification of ceramic materials [7]

shocks. Fragility hinders the mechanical processing of articles and the bonding of ceramic materials with each other or with other materials. General classification of ceramic materials [7] is presented in figure 1.

Production of concrete on waste ceramic aggregates

Thanks to the intensive development of concrete technology and construction chemistry it is possible to compose concrete with specific characteristics that differ from those of ordinary concrete. This applies to the characteristics, parameters and properties of both physical, mechanical and chemical. Compositions of concrete mixtures are modified by the choice of cement, aggregate and the use of additives or admixtures. Modification is usually aimed at achieving one or more related parameters. Due to their specific characteristics, such concrete are called special. Their applications are also special, depending on the leading characteristics of the concrete. There are waterproof, self-compacting, frost-proof, corrosion resistant (e.g. acid resistant or sulphate resistant), high value, radiation protection, insulating concrete and geobeton (geopolymer concrete). Special concrete also includes high-temperature concrete and abrasion resistant concrete. One of the new specialties in the concrete market is the so-called green concrete i.e. green concrete which is produced on recycled aggregates. The interest in such composites is increasing because of the demand for organic products.

The use of ceramic waste as a modifier and additive to concrete dates back to ancient times. In the area distant from the volcanoes as a binder was used worn, finely ground tiles. This fact remains forgotten for many years

Nowadays aggregate from crushed ceramic construction elements was reused after the Second World War for concrete production due to the large amount of demolition material. The current research on the application of red ceramic focuses mainly on the ecological effect [8,9]. The results of this study show that this type of additive, irrespective of the form in which it is incorporated into the concrete mix (powder or aggregate), substantially deteriorates the strength characteristics of the concrete. Other research results show the work carried out on concrete to which noble ceramic was used [10,11]. This type of material, which is extracted from waste ceramic or technical ceramics (e.g. electrical insulators), has a number of properties that are beneficial to the concrete. The results show that the higher amount of ceramic aggregates, the higher strength of concrete.

The characteristics of concrete produced with the aggregate from the sanitary cullet are presented in [12]. The authors of the article to give an economic sense of their work are looking for special applications of this type of concrete. The results show that this type of concrete can be successfully used in conditions where concrete is exposed to high temperatures or where high abrasion resistance is required. Although there is no comprehensive experimental research on components made of concrete prepared using recycled ceramic aggregates, this direction is perceived as possible to be implemented in the industry.

Design of porous concrete – own research

The main assumption of the designed concrete mix according to [13,14] was to obtain optimum strength characteristics of fully porous concrete which is produced of commonly used in concrete ingredients. Those interesting components will be commonly used in concrete plants. The aggregate

Table 1. Physicochemical parameters of concrete CEM I 42,5N – SR 3/NA

Feature	Average results	Requirements
Beginning of setting, [min]	233	> 60
End of setting, [min]	291	
Water demand [%]	27,5	
Volume stability, [mm]	1,1	< 10
Specific surface area, [cm^2/g]	3688	
Compression strength: after 2 days, [MPa]	23,9	<10
Compression strength: after 28 days, [MPa]	55,9	> 42,5 < 62,5
Chemical analysis: SO_3, [%]	2,77	< 3,0
Chemical analysis: Cl, [%]	0,070	< 0,10
Chemical analysis: Na_2O_{eq}, [%]	0,53	<0,6

Table 2. Basic composition and physical properties of used microsilic0a

Substances	Average values	Extreme values	
		Minimum	Maksimum
SiO_2 (%)	97.6	96.5	98.8
CaO (%)	0.5	0.3	0.8
Al_2O_3 (%)	<0.1	<0.1	0.2
Fe_2O_3 (%)	<0.1	<0.1	<0.1
MgO (%)	<0.1	<0.1	<0.1
Na_2O (%)	0.15	0.1	0.25
K_2O (%)	0.2	0.15	0.25
SO_3 (%)	0.1	0.05	0.15
Si (%)	0.2	0.08	0.4
Loss on ignition (950°C, 1 hour) (%)	0.8	0.3	1.4
C (%)	0.6	0.2	1
H_2O (%)	0.3	0.08	0.8
pH	7.1	6.8	7.5
Specific surface area (m^2/g)	25	22	30
Bulk density (kg/m^3)	400	350	500
> 45 μm (%)	0.8	0.2	1.5

as a whole will be formed as crushed post-production ceramic sanitary waste. The output data for the design of the concrete mix was the concrete formula prepared by the concrete plant for the production of C45 / 55 class. CEM I 42,5N-SR 3/NA was used as a cement for the mix, which has stable physicochemical parameters with suitable bonding time, high parameters of early and final strength, low alkalinity and high resistance to aggressive chemicals, which is commonly used in producing service concrete mix. Detailed values of physicochemical parameters of cement are presented in table 1. As a concrete admixtures was used ISOFLEX 7130 which, besides strong liquefying effect, also remains at the correct consistency as well as improves the early strength of the concrete composite.

Features of concrete admixture

The recipe for the concrete mix established use of a silica-based concrete additive obtained by the process of gas purification of furnaces for the production of silicon-containing alloys. Microsilica, due to its relatively low price and simple access, is one of the components used in the production of commercial concrete for the production of concrete with special requirements such as high strength, frost-resistant and concrete resistant to aggressive environmental factors. Basic composition and physical properties of microsilica are shown in Table 2.

Presented selection of ingredients guaranteed obtaining very strong leaven which would form the basis of the skeleton carrying the load in the porous concrete. The aggregate used to make the concrete mix was completely crushed post-production waste of sanitary ceramic. Ceramic wastes in forms of damaged washbasins, toilets, bidets and urinals were taken from the production company and crushed in jaw crushers. The machine's operating system allowed separation of the two grains obtained in the crushing process. Fine particle grain of size of 0-4 mm and coarse grain size of 4-8 mm. Grains more than 8mm in diameter were returned to the crusher. In designing the particle size, the proportions were based on the experience presented in the paper [12] where the optimum ratio of fine to coarse grains size was obtained as 1: 0.4. It was assumed that in order to obtain the total permeability of the concrete it would be made without aggregate fine grains which would fill the space between coarse grains as it is made in conventional concrete. When choosing grains first grains less than 2 mm were sifted and then left both 2-4 mm grains and 4-8 mm of which it was obtained aggregate mix.

When designing the concrete, the starting point was to maintain the grain composition ratio, and change of mass

Table 3. The composition of the porous concrete mixture prepared on the basis of aggregate from the sanitary ceramic waste

Ingredient name	Recipe
Concrete CEM I 42,5N – SR 3/NA, [kg]	245.18
Aggregate: Ceramic waste 2/4mm, [kg]	817.22
Aggregate: Ceramic waste 4/8mm, [kg]	326.89
Water, [kg]	162.22
Admixture ISOFLEX 7130, [kg]	8.81
Additive microsilica, [kg]	67.50

proportion of aggregate and leaven. Design was conducted by experimental method - known leaven. During attempt of ingredients mixing were made corrections of composition due to the inability to obtain the desired concrete mix form. Addition of small amount of water resulted in the separation of the mixture into spherical forms of the wet cement mixture with fine aggregate and isolation of aggregate coarse grains. Adding too much water resulted in falling of leaven at the mould bottom. Finally, the desired composition of the mixture in which the coarse grains were surrounded by a layer of leaven combined with fine grains was obtained by the untypical dosage of the components. Firstly, the solids were mixed together, while the water with the additive was added by dispersion to dry mixture with a high-speed mechanical stirrer. The final composition of the concrete is shown in Table 3. The total volume of components calculated on the basis of the composition was 0.9 m^3. This result assumed that 10% of the concrete is free space.

Study of porous concrete containing waste ceramic aggregate in its composition

Test samples were prepared in the form of 4x4x16cm cuboid. After forming samples were placed in a climatic chamber with high humidity. Three days after forming, samples were removed and left in the chamber for another 25 days. After 28 days, they were tested for strength. There were used universal strength testing machine of Controls company. First samples were subjected to a bending tensile strength test in a three-point pattern and the resulting half-beams were subjected to a compression strength test. The medium strength of the concrete was 1.33MPa. The medium compressive strength was 9.79MPa. The strength test results are shown in Table 4.

There were made test of other features of presented composite material such as density, absorbability and watertightness. Volumetric density of concrete was tested on 100x100x100mm cube samples. There were tested six samples. The test was carried out in dry condition by measuring the weight and volume of the sample according to standard PN-EN 12390-7 [15].

Concrete absorbability was tested on samples with volume of 1dm^3 with dimension 100x100x100mm. There were used six samples. Samples were soaked gradually by flooding them to the height ½ of sample, then to the height 1.1of sample and it was maintained in water till the mass was determined. Absorbability was defined as maximum amount of water which concrete is able to absorb.

Watertightness rate according to [14] was tested on cubic samples with dimension 150x150x150mm. There were applied water with the diameter of 100mm to the upper surface of the sample. Samples without changing water pressure showed total permeability assumed in designing. As it was assume water poured into the surface diffuse throughout the sample. Results of the selected features are presented in Table 5.

Table 4. Results of strength tests

Sample number	Strength i-th sample, [MPa]	Medium strength, [MPa]	Standard deviation, [MPa]	Volatility index, [%]
Bending tensile strength				
1	1.30	1.33	0.04	3.35
2	1.28			
3	1.43			
4	1.36			
5	1.29			
6	1.31			
Compression strength				
1	9.75	9.79	0.40	4.11
2	8.64			
3	10.15			
4	9.45			
5	9.86			
6	9.90			
7	10.04			
8	9.69			
9	10.04			
10	10.52			
11	9.01			
12	10.44			

Tabe 5. Results of selected tests of porous concrete whose composition was based on ceramic aggregate

Ingredient name	Recipe
Concrete CEM I 42,5N – SR 3/NA, [kg]	245.18
Aggregate: Ceramic waste 2/4mm, [kg]	817.22
Aggregate: Ceramic waste 4/8mm, [kg]	326.89
Water, [kg]	162.22
Admixture ISOFLEX 7130, [kg]	8.81
Additive microsilica, [kg]	67.50

Conclusions

The designed concrete was characterized by not very high strength parameters, which disqualify it as construction material. Similarly, its porous structure would prevent the adhesion of steel in the reinforced concrete structure. When looking for possible uses for the presented composite, it was offered to use it to carry light loads such as in pedestrian traffic. Strength of the composite is sufficient for such type of application. Its basic feature is the total permeability, which allows for the total penetration of rainwater into such surface. This type of pedestrian routes can be made in heavily urbanized areas where the use of green areas for absorbing precipitation is limited. In such places pedestrian routes made of the presented material can collect rainwater and transfer it to underground substrates, which would be a way of surface drainage. The use of the presented composite can also have positive influence on the environment. Thanks to the use of waste in the form of crushed sanitary ceramics as concrete aggregates, the amount of residual waste will decrease.

References

[1] Kielski A., „*Ogólna technologia ceramiki*" Skrypty uczelniane Politechniki Koszlińskiej

[2] Maksymiuk J.: *Aparaty elektryczne w pytaniach i odpowiedziach*. Warszawa: Wydawnictwa Naukowo-Techniczne, 1997, s. 88-95.

[3] PN-IEC 60050-151:2003 Międzynarodowy słownik terminologiczny elektryki - Część 151: Urządzenia elektryczne i magnetyczne

[4] Bieriensztejn P. I., ,,Intensifikacija obszyga izdielij stroitielnoj kieramiki, (Tiechn. Informacija CNII TESTROM MPSM) 1968

[5] Haase T., „*Keramik*" 2 Aufl. VEB Deutsch. Verlag fur Grundstoffindustire, Leipzig, 1961

[6] Węgrowski W., Przezdziecka K., „*Szkło i ceramika*" Państwowe Zakłady Wydawnictw Szkolnych Warszawa 1979

[7] Awgustinik A. J., „*Ceramika*" Arkady Warszawa 1980

[8] De Brito A., Pereira J., Correia R., Oliviera C., 2005: *Mechanical behavior of non-structural concrete made with recycled ceramic aggregates*, Cement and Concrete Composites 27, 429-433

[9] Senthamarai RM., Devadas M., Manoharan P., Gobinath D., 2011: *Concrete made from ceramic industry waste: Durability propertis*, Construction and Building Materials 25, 2413-2419

[10] Lopez V., Llamas B., Juan A., Moran J., 2007: *Eco-efficient Concretes: Impact of the Use of White Ceramic Powder on the Mechanical Properties of Concrete*, Biosystems Engineering 96(4), 559-564

[11] Guerra I., Vivar I., Liamas B., Juan A., Moran J., 2009: Eco-efficient concretes: *The efffect of using recycled ceramic material from sanitary installations on the mechanical properties of concrete*, Waste management 29, 643-646

[12] Halicka A., Ogrodnik P., Zegardło B., *Using ceramic sanitary ware waste as concrete aggregate*, Construction and Building Materials 2013, vol. 48, s. 295-305

[13] Neville A.M. *Właściwości betonu*. Polski Cement 2012

[14] Jamrozy Z. *Beton i jego technologie*. PWN Warszawa 2006

[15] PN-EN 12390-7 Badania betonu - Część 7: Gęstość betonu