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A study of the possibility of using ground waste glass as a replacement for cement in cement composites

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Abstract

The paper presents the results of tests of cement composites in which a glass substitute derived from municipal waste was used as a partial replacement for cement. The tests used a glass cullet made of brown glass, which after rinsing to remove sugars and other impurities, was dried and ground to a fraction below 125 μm. Cement mortar samples were made, in which cement was replaced with: 3, 5, 10 and 20% of glass powder. Heat of hydration of the paste and the consistency of fresh mortars and mechanical properties of mortars after 28 days of curing were analyzed. The best results were obtained for mortars with a 5% share of glass powder. The research shows that the binding properties of glass powder are closely related to the degree of grinding of the waste, and when significantly ground, they may exhibit pozzolanic properties.

Keywords: cement composites, ground waste glass, recycling, mechanical properties

1. Introduction

Glass, being an inert material, is commonly used for the production of packaging. Glass recycling in Europe is among the most advanced in the world. In some European countries, nearly 85 % of glass packaging, especially bottles and jars, are made from recyclate. Glass that is made of sand, a commonly occurring raw material, can be melted many times without losing its value. Unfortunately, these advantageous features of glass packaging, especially in the terms of used packaging and glass cullet formed from them, are not rationally used in Poland. Industrial cullet associated with the technological process of glassware production in Poland is about 28 % of the total amount of cullet possible to re-use [1]. Cullet, which comes from car windows, from "safe" glass or from CRT glass is a particularly serious problem. These types of cullet are not used by glassworks and other ways of their utilization have to be found.

When assessing the possibility of using waste glass in the construction industry in terms of its impact on the natural environment, some benefits can be observed. Primarily the reduction of the storage of waste material can be mentioned. There is also the possibility of the use of the waste glass as a substitute of materials derived from natural resources. The waste glass used for concretes does not significantly affect the level of environmental impact of the obtained material. An exception may be glass cullet coming from CRT glass, containing significant amounts of heavy metals [2].

Waste glass in the construction industry is used, for example, for the production of mats and insulation boards, grits for plaster, as an addition to ceramic masses, mortars and cement concretes [3-8].

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In the case of the use of waste glass in cement composites, the replacement of natural fine aggregate with fine ground glass cullet has proved to be the most effective so far [9-10]. Research [11] has shown that the use of the waste glass as a coarse aggregate may worsen the mechanical properties of cementitious composites due to the cracking of the larger grains.

The paper presents the results of cement mortar tests, in which the waste glass from brown glass was used. The waste glass was ground to a fraction with a maximum grain size of 125 μm. The glass powder, prepared this way, was used in the tested mortars as a sealing admixture and a cement replacement.

2. Materials and methods

2.1. Materials

Cement mortar was made using Portland cement CEM I 42.5R (according to PN-EN 197-1), fine aggregate and tap water. The fine aggregate was CEN standard quartz sand with a grain size compliant with the requirements of PN-EN 196-1. Glass powder was prepared from the glass waste obtained from a local recycling company. Prior incorporation to cement mortars, the waste glass was washed in water (in order to remove contaminants), dried and ground to obtain a glass powder with a maximum grain size of 125 μm. The gradation curve was conforming to PN-EN 196-1. Table 1 presents the chemical composition of waste glass used. Fig. 1 shows a SEM photography of the waste glass after milling process.

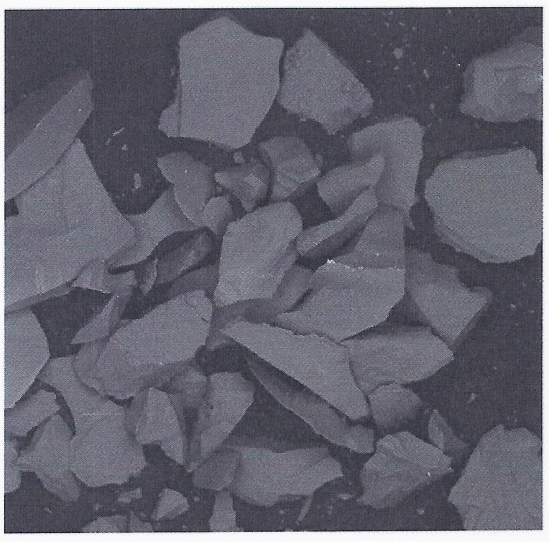

Fig. 1. SEM photography of the waste glass after milling process.

Table 1. Chemical composition of the waste glass.

Component	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	K_2O
Content [%]	71.51	1.69	1.66	10.24	1.64	0.07	0.55
Component	Na_2O	P_2O_5	TiO_2	Mn_2O_3	SrO	BaO	
Content [%]	12.35	0.02	0.21	0.05	0.02	0.56	

2.2. Mixture composition and mortar preparation

Cement mortars with the constant aggregate to cement to water ratio 3:1:0.5 were prepared according to the PN-EN 196-1. Two groups of cement mortars were prepared. The first group of cement mortars was designed as R (reference mortar). Digits 0, 3 and 5 next to the name of the mortar indicated the percentage content of the glass powder, in relation to the cement mass. The second group of mortars were marked as M10 and M20. In these mortars 10 % and 20 % of the mass of the cement was replaced with glass powder, respectively. The composition of the tested mortars is presented in Table 2. After demoulding, the mortars were stored at 20°C ± 2°C and relative humidity RH ≥ 95 % for 28 days.

Table 2. Mixture compositions and consistency of fresh cement mortars.

Sample designation	Unit weight [kg/m³] Cement	Water	Sand	Glass powder	Consistency Mean diameter [mm]
R0	519	257	1546	-	165
R1	519	257	1546	15.5	150
R3	519	257	1546	26.0	147
M10	467	257	1546	52.0	155
M20	415	239	1546	104.0	163

2.3. Test methods

The consistency of cement mortars was tested by a flow table according to PN-EN 1015-3. Flexural strength and compressive strength of mortars were determined in accordance with PN-EN 197-1 after 28 days of curing. Six prisms in size of 40 x 40 x 160 mm were prepared for each type of mortar for the determination of strength. Water absorption test, by soaking, was conducted in accordance with PN-B-04500:1985. For this test 3 prisms of each type of mortar in size of 40 x 40 x 160 mm were used.

3. Results and discussion

Table 2 and Fig. 2 present the consistency of fresh cement mortars determined by the flow table method. The addition of the glass powder had a slight effect on the deterioration of the consistency of R3 and R5 mortars, and both mortars maintained their workability. The use of glass powder as a cement replacement did not significantly affect the consistency of the mortars, and in the case of M20 mortar, the consistency obtained was similar to the consistency of the reference mortar R0.

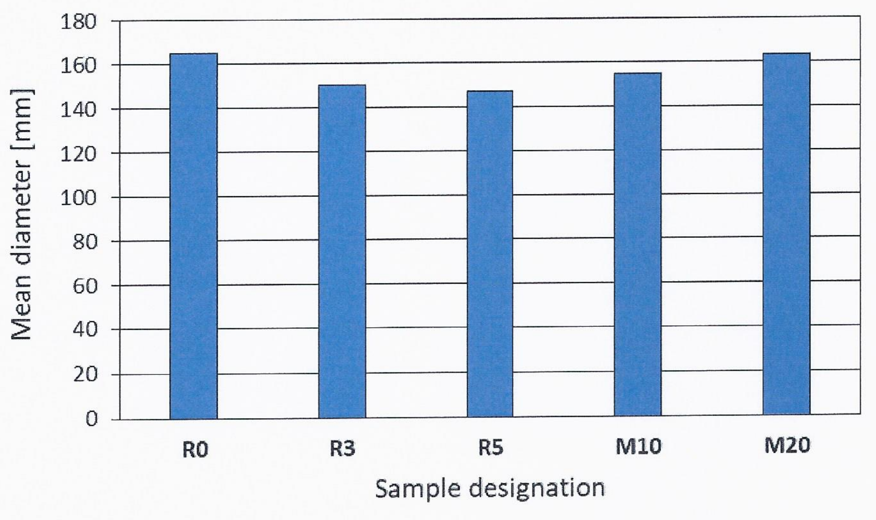

Fig. 2. Consistency of fresh cement mortar.

Fig. 3 presents the results of the mass absorption testing of mortar samples. Addition of the glass powder slightly improves the absorption resistance of the tested mortars. However, for the M20 mortar, water absorption similar to the reference mortar R0 was obtained.

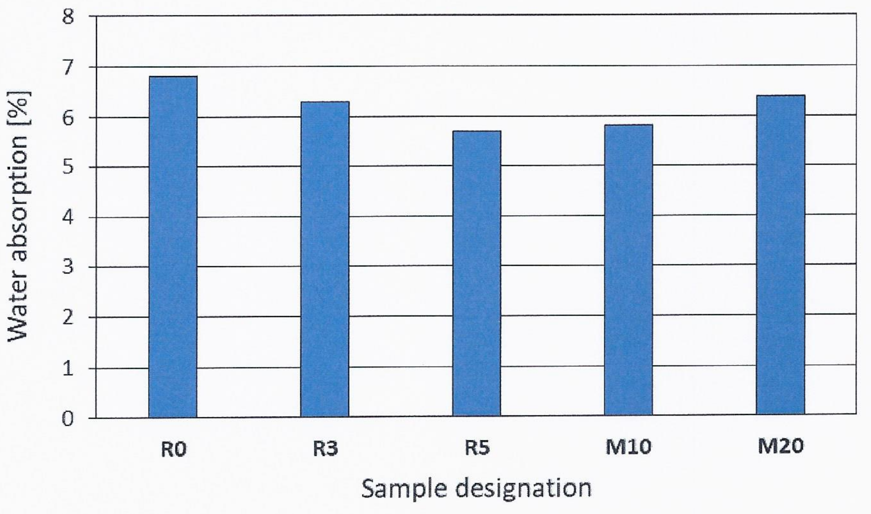

Fig. 3. Water absorption of cement mortars.

Fig. 4 and 5 present flexural and compressive strength after 28 days of curing, respectively. The use of the waste glass did not significantly affect the flexural strength of the tested mortars. For R5 mortar, a slight increase in flexural strength by 1.5 % was observed. This may be related to the sealing of the composite structure by the glass powder. The use of the waste glass as a cement replacement resulted in a reduction of the flexural strength of the mortars by 9 % and 14 % for mortar M10 and M20, respectively.

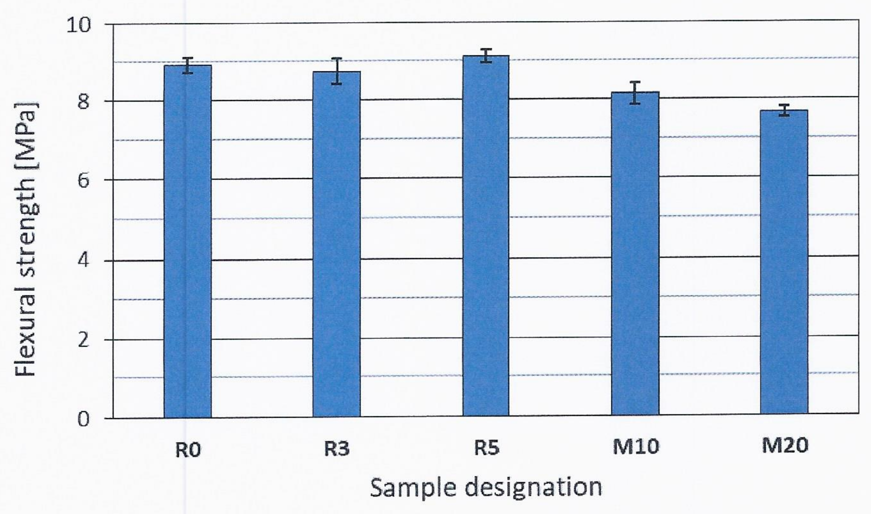

Fig. 4. Flexural strength of cement mortars after 28 days of curing.

The compressive strength of the tested mortars decreased with the increase of the content of the waste glass in the mortar. The use of the glass powder as an admixture caused a slight decrease ~~in~~ of strength by 3.7 % and 2.5 %. However, for mortars M10 and M20, the decrease of compressive strength was 14 % and 20 %, respectively. The low grinding degree of the glass powder could be the reason for its negative effect on the compressive strength of the tested mortars. As shown by research [12], when using 20 % glass powder (as the cement substitute) of fractions up to 40 µm, the mortars obtained compressive strength similar to the reference mortars. The use of the glass powder of fractions 80-100 µm resulted in a compressive strength drop by 20-23 %, regardless of the color of the glass used.

The best properties were obtained for R5 mortar, with 5 % content of the glass powder. It had good workability, high flexural strength and slightly lower compressive strength in comparison to the reference mortar R0.

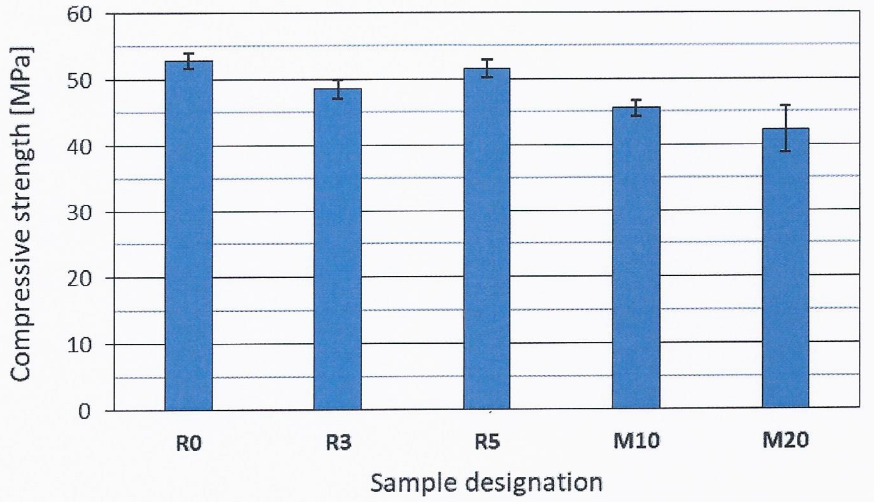

Fig. 5. Compressive strength of cement mortars after 28 days of curing.

4. Summary

The paper presents the experimental results of investigations of the cement mortars modified with a variable amount of the glass powder of fractions up to 125 um. Based on the obtained results, it was assessed that the idea of using the glass powder derived from the waste glass for the modification of the composition of cement mortars is promising. The addition of the glass powder in the amount of 5 % of the cement mass resulted in the structure sealing, smaller water absorption and the improvement of the workability of fresh mortar while maintaining its mechanical properties after 28 days of curing.

The use of the glass powder as a cement replacement in the amount of 10-20 % does not reduce mortar workability, however, it causes deterioration of the mechanical properties of the mortar. The improvement of mechanical properties can be obtained by using glass powder with a smaller diameter of the maximum fraction, which is confirmed by research [12].

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