

Mechanical Properties of Mortars Containing Waste Glass Powder

Elżbieta Horszczaruk^{1*}, Piotr Brzozowski¹

¹ Department of Concrete Structures and Concrete Technology, Faculty of Civil Engineering and Architecture, West Pomeranian University of Technology Szczecin, al. Piastów 50, 70-311 Szczecin, Poland

* Corresponding author, e-mail: elzbieta.horszczaruk@zut.edu.pl

Received: 25 June 2018, Accepted: 06 February 2019, Published online: 01 April 2019

Abstract

The utilization of solid waste materials or industrial waste as partial substitution of cement is growing in construction industry all around world. Less cement consumption causes consequently reduction in CO₂ emission into the atmosphere and reduction in energy consumption. This paper examines the possibility of using finely ground waste glass as a partial replacement for cement and as a sealing admixture. Glass powder used in the research was prepared from the glass waste obtained from a local recycling company. 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. This paper is the revised version of the paper that has been published in the Proceedings of the Creative Construction Conference 2018 (Horszczaruk and Brzozowski, 2018).

Keywords

cement composites, waste glass powder, 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 recycle. 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 (Kuśnierz, 2010). 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 (Najduchowska et al., 2014).

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 (Ganjian et al., 2015; Isa, 2008; Liu, 2011; Rashad, 2014; Sahmenko et al., 2014; Sikora et al., 2015).

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 (Byars et al., 2004; Park et al., 2004). The use of waste glass as coarse aggregate in concrete does not have a significant impact on the workability. However, it significantly influences its mechanical properties. According to tests described in the papers (Keerio et al., 2017; Topçu and Canbaz, 2004) compressive strength decreases in proportion to the increase in the amount of glass cullet in concrete.

Research (Sérifou et al., 2013) has shown that the use of the waste glass as a coarse aggregate may decrease the mechanical properties of cementitious composites due to

the cracking of the larger grains. The use of waste glass as a substitute for fine aggregate in mortar and concrete results in reduced workability of the composite with the increase of the content of waste glass (Schwarz et al., 2008).

A significant increase in mechanical properties and durability of concrete was observed when very finely grounded glass was used as a cement substitute (Carsana et al., 2014; Idir et al., 2010; Matos and Sousa-Coutinho, 2012; Shi et al., 2005). Moreover, another research (Shao et al., 2000) showed that the smaller size of glass particles leads to higher reactivity with lime, which results in higher compressive strength of concrete and smaller expansion related to the alkali–silica reaction.

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 125 μm . The glass powder, prepared this way, was used in the tested mortars as a sealing admixture and a cement replacement.

Based on the interesting results of previous experiments (Horszczaruk and Brzozowski, 2018), the study was extended to investigate the properties of mortars after 56 days of hardening. What is more, pozzolanic effect of waste glass powder was determined.

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 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 photography of the waste glass after milling process.

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



Fig. 1 Photography of the waste glass after milling process (25 \times)

Table 1 Chemical composition of the waste glass

Component	SiO ₂	M ₂ O ₃	Fe ₂ O ₃	CaO	MgO
Content [%]	71.51	1.67	1.66	10.24	1.64
Component	SO ₃	K ₂ O	Na ₂ O	P ₂ O ₅	TiO ₂
Content [%]	0.07	0.55	12.35	0.02	0.21
Component	Mn ₂ O ₃	BaO	SrO		
Content [%]	0.05	0.56	0.02		

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 $^{\circ}\text{C} \pm 2$ $^{\circ}\text{C}$ and relative humidity $RH > 95$ % for 28 days.

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 and 56 days of curing. Six prisms in size of 40 \times 40 \times 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 \times 40 \times 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

Table 2 Mixture compositions and consistency of fresh cement mortars designation

Sample	R0	R3	R5	M10	M20
Cement [kg/m ³]	519	519	519	467	415
Water [kg/m ³]	257	257	257	257	239
Sand [kg/m ³]	1546	1546	1546	1546	1546
Glass powder [kg/m ³]	-	15.5	26.0	52.0	104.0
Consistency, mean diameter [mm]	165	150	147	155	163

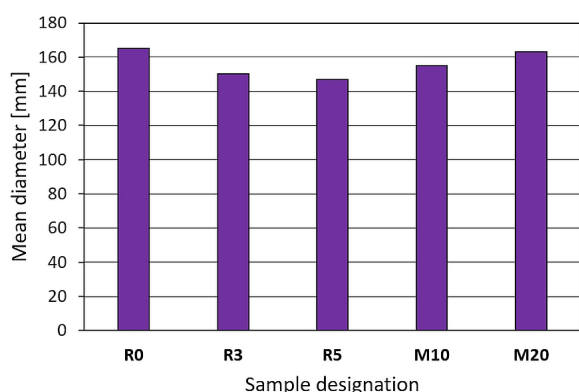


Fig. 2 Consistency of fresh cement mortar

consistency obtained was similar to the consistency of the reference mortar R0.

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. 4 presents flexural strength after 28 and 56 days of curing. The use of 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 glass flour. The use of waste glass as a cement replacement resulted in a reduction in the flexural strength of mortars by about 9 % and 14 % for mortar M10 and M20 respectively.

After 28 days, the compressive strength of the tested mortars decreased with the increase of the content of the waste glass in the mortar (Fig. 5). The use of the glass powder as an admixture caused a slight decrease in 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

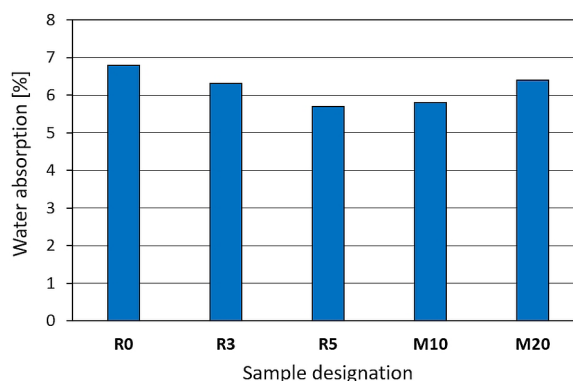


Fig. 3 Water absorption of cement mortars

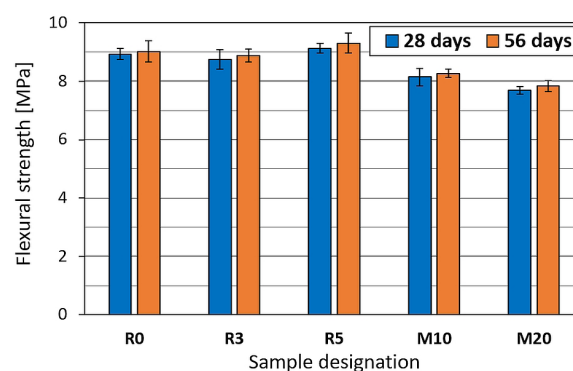


Fig. 4 Flexural strength of cement mortars after 28 and 56 days of curing

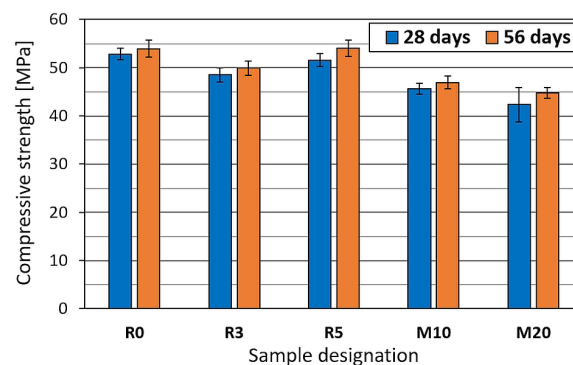


Fig. 5 Compressive strength of cement mortars after 28 and 56 days of curing

(Matos and Sousa-Coutinho, 2012), 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.

After 56 days of curing mortars containing waste glass performed higher increments of their compressive strength compared to mortar R0. The biggest increment was observed for mortars R5 and M20.

The pozzolanic effect of waste glass powder was assessed with the Activity Index (*AI*) (Fig. 6) which is the ratio between compressive strength of mortar containing waste glass powder and strength of equivalent control mortar (*R0*) at the same age.

For all mortars containing waste glass the increase of *AI* in time was observed. Moreover, after 56 days of curing for *R5* mortar Activity Index greater than 100 % was achieved.

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*.

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 μm . 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 and 56 days of curing.

References

- Byars, E. A., Morales-Hernandez, B., Zhu, H. Y. (2004) "Waste glass as concrete aggregate and pozzolan Laboratory and industrial projects", *Concrete*, 38(1), pp. 41–44.
- Carsana, M., Frassoni, M., Bertolini, L. (2014) "Comparison of ground waste glass with other supplementary cementitious materials", *Cement and Concrete Composites*, 45, pp. 39–45.
<https://doi.org/10.1016/j.cemconcomp.2013.09.005>
- Ganjian, E., Jalull, G., Sadeghi-Pouya, H. (2015) "Using waste materials and by-products to produce concrete paving blocks", *Construction and Building Materials*, 77, pp. 270–275.
<https://doi.org/10.1016/j.conbuildmat.2014.12.048>
- Horszczaruk, E., Brzozowski, P. (2018) "A study of the possibility of using ground waste glass as a replacement for cement in cement composites", In: *Creative Construction Conference 2018, CCC 2018*, Ljubljana, Slovenia, pp. 115–120.
<https://doi.org/10.3311/CCC2018-016>
- Idir, R., Cyr, M., Tagnit-Hamou, A. (2010) "Use of fine glass as ASR inhibitor in glass aggregate mortars", *Construction and Building Materials*, 24(7), pp. 1309–1312.
<https://doi.org/10.1016/j.conbuildmat.2009.12.030>
- Isa, H. (2008) "The need for waste management in the glass industries: A review", *Scientific Research and Essay*, 3(7), pp. 276–279.

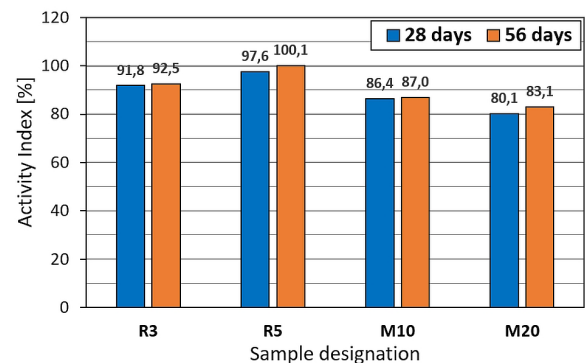


Fig. 6 Activity Index at 28 and 56 days of curing

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 (Matos and Sousa-Coutinho, 2012).

Acknowledgement

This research was funded by the National Centre for Research and Development within SEFIRCAOM 2/ KONNECT/2016 (KONNECT Joint Call).

- Keerio, M. A., Khoso, S., Khan, J. S., Ansari, A. A., Bhatti, N. K. (2017) "The effect of Waste Glass as Partial Replacement of cement on Properties of Concrete", *Engineering Science and Technology International Research Journal*, 1(1), pp. 59–63.
- Kuśnierz, A. (2010) "Recykling szkła" (Glass recycling), *Scientific Works of Institute of Ceramics and Building Materials*, 3(6), pp. 22–33. (in Polish)
- Liu, M. (2011) "Incorporating ground glass in self-compacting concrete", *Construction and Building Materials*, 25(2), pp. 919–925.
<https://doi.org/10.1016/j.conbuildmat.2010.06.092>
- Matos, A. M., Sousa-Coutinho, J. (2012) "Durability of mortar using waste glass powder as cement replacement", *Construction and Building Materials*, 36, pp. 205–215.
<https://doi.org/10.1016/j.conbuildmat.2012.04.027>
- Najduchowska, M., Różycka, K., Rolka, G. (2014) "Ocena możliwości wykorzystania stłuczki szklanej w przemyśle budowlanym w aspekcie jej wpływu na środowisko naturalne" (Assessment of the glass cullet application in building industry in terms of its impacts on the environment), *Scientific Works of Institute of Ceramics and Building Materials*, 7(17), pp. 46–56. (in Polish)
- Park, S. B., Lee, B. C., Kim, J. H. (2004) "Studies on mechanical properties of concrete containing waste glass aggregate", *Cement and Concrete Research*, 34(12), pp. 2181–2189.
<https://doi.org/10.1016/j.cemconres.2004.02.006>

- Rashad, A. M. (2014) "Recycled waste glass as fine aggregate replacement in cementitious materials based on Portland cement", *Construction and Building Materials*, 72, pp. 340–357.
<https://doi.org/10.1016/j.conbuildmat.2014.08.092>
- Sahmenko, G., Toropovs, N., Sutinis, M., Justs, J. (2014) "Properties of High Performance Concrete Containing Waste Glass Micro-Filler", *Key Engineering Materials*, 604, pp. 161–164.
<https://doi.org/10.4028/www.scientific.net/KEM.604.161>
- Sérifou, M., Sbartai, Z. M., Yotte, S., Boffoué, M. O., Emeruwa, E., Bos, F. (2013) "A Study of Concrete Made with Fine and Coarse Aggregates Recycled from Fresh Concrete Waste", *Journal of Construction Engineering*, 2013, article ID: 317182.
<https://doi.org/10.1155/2013/317182>
- Schwarz, N., Cam, H., Neithalath, N. (2008) "Influence of a fine glass powder on the durability characteristics of concrete and its comparison to fly ash", *Cement and Concrete Composites*, 30(6), pp. 486–496.
<https://doi.org/10.1016/j.cemconcomp.2008.02.001>
- Shi, C., Wu, Y., Riefler, C., Wang, H. (2005) "Characteristics and pozzolanic reactivity of glass powders", *Cement and Concrete Research*, 35(5), pp. 987–993.
<https://doi.org/10.1016/j.cemconres.2004.05.015>
- Shao, Y., Lefort, T., Moras, S., Rodriguez, D. (2000) "Studies on concrete containing ground waste glass", *Cement and Concrete Research*, 30(1), pp. 91–100.
[https://doi.org/10.1016/S0008-8846\(99\)00213-6](https://doi.org/10.1016/S0008-8846(99)00213-6)
- Sikora, P., Horszczaruk, E., Rucinska, T. (2015) "The Effect of Nanosilica and Titanium Dioxide on the Mechanical and Self-Cleaning Properties of Waste-Glass Cement Mortar", *Procedia Engineering*, 108, pp. 146–153.
<https://doi.org/10.1016/j.proeng.2015.06.130>
- Topçu, İ. B., Canbaz, M. (2004) "Properties of concrete containing waste glass", *Cement and Concrete Research*, 34(2), pp. 267–274.
<https://doi.org/10.1016/j.cemconres.2003.07.003>