Mechanical Properties of Mortars Containing Waste Glass Powder

Elżbieta Horszczaruk†, Piotr Brzozowski

† 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 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 (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 incense 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 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.

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 × 40 × 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 × 40 × 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 1** Chemical composition of the waste glass

<table>
<thead>
<tr>
<th>Component</th>
<th>SiO₂</th>
<th>M₂O₃</th>
<th>Fe₂O₃</th>
<th>CaO</th>
<th>MgO</th>
</tr>
</thead>
<tbody>
<tr>
<td>Content [%]</td>
<td>71.51</td>
<td>1.67</td>
<td>1.66</td>
<td>10.24</td>
<td>1.64</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Component</th>
<th>SO₃</th>
<th>K₂O</th>
<th>Na₂O</th>
<th>P₂O₅</th>
<th>TiO₂</th>
</tr>
</thead>
<tbody>
<tr>
<td>Content [%]</td>
<td>0.07</td>
<td>0.55</td>
<td>12.35</td>
<td>0.02</td>
<td>0.21</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Component</th>
<th>MnO₂</th>
<th>BaO</th>
<th>SrO</th>
</tr>
</thead>
<tbody>
<tr>
<td>Content [%]</td>
<td>0.05</td>
<td>0.56</td>
<td>0.02</td>
</tr>
</tbody>
</table>
consistency obtained was similar to the consistency of the reference mortar \( R_0 \).

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 \( M_20 \) mortar, water absorption similar to the reference mortar \( R_0 \) 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 \( R_5 \) 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 \( M_{10} \) and \( M_{20} \) 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 \( M_{10} \) and \( M_{20} \), 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 (Matos and Sousa-Coutinho, 2012), when using 20 % glass powder (as the cement substitute) of fractions up to 40 \( \mu \)m, the mortars obtained compressive strength similar to the reference mortars. The use of the glass powder of fractions 80-100 \( \mu \)m 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 \( R_0 \). The biggest increment was observed for mortars \( R_5 \) and \( M_{20} \).
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 ($R_0$) 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 $R_5$ mortar Activity Index greater than 100% was achieved.

The best properties were obtained for $R_5$ 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 $R_0$.

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.

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).

References
https://doi.org/10.1016/j.cemconcomp.2013.09.005
https://doi.org/10.1016/j.conbuildmat.2014.12.048
https://doi.org/10.3311/CCC2018-016
Kusnierz, A. (2010) "Recyklung szkla" (Glass recycling), Scientific Works of Institute of Ceramics and Building Materials, 3(6), pp. 22–33. (in Polish)
https://doi.org/10.1016/j.conbuildmat.2010.06.092
https://doi.org/10.1016/j.conbuildmat.2012.04.027
Najduchowska, M., Różyczka, K., Rolka, G. (2014) "Ocena możliwości wykorzystania śluziczki szklanej w przemyśle budownictwem 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)
https://doi.org/10.1016/j.cemconres.2004.02.006


