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EXTRACTS OF CEMENT COMPOSITES BASED ON RECYCLED GLASS

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ABSTRACT

This article presents the results of extracts of recycled photovoltaic glass and cement composites, in which 100 % of natural aggregates were replaced with recycled photovoltaic glass in various fractions. Test specimens in the shape of a cylinder with a diameter and height of 40 x 40 mm were prepared according to the designed formulas R1 to R5. The R0 formula was a comparative one without the replacement of natural aggregates. The test specimens were stored in a water bath for 28 days. The test specimens together with the recycled glass fr. 0/10 mm were subsequently subjected to extract tests according to Decree No. 294/2005 Coll. The incorporation of photovoltaic glass into the cement matrix has significantly reduced the content of selenium, molybdenum and cadmium. The concentrations of these toxic metals were reduced by 98.5 % in case of selenium, by 88.9 % in case of cadmium, and by 97.5 % in case of molybdenum.

Keywords: Cement; Glass; Photovoltaic panel; Recycling; Secondary raw material.

1 INTRODUCTION

Photovoltaic panels are very important sources of renewable energy because they are friendly to the environment. This is the most frequently used energy production technology, right after the production of hydro and wind energy [1]. As the number of photovoltaic panels increases, so will the amount of waste. About 95 % of the panels can be recycled. The remaining 5 % is dust, which is trapped by filters after crushing [2, 3]. Because recycled photovoltaic glass is waste, it can be used as a secondary raw material as a substitute for natural aggregates in the production of concrete or cement [4]. Since natural aggregate is a non-renewable resource, it is necessary to find a suitable solution in order to make the most of the secondary raw materials to save the non-renewable ones [5]. It could become a sustainable building material. There are many research projects [6–10] where waste glass was used to replace natural aggregates or additives were used instead of cement. Photovoltaic glass cannot be reused as it would contaminate the glass charge. The remains of polymer film can also be found on the glass – the removal of this film is not economically profitable in case of recycled glass used as the secondary raw material. This is why it is very important to find a suitable use for recycled glass, which is beneficial from the energy and financial point of view, and especially to find out whether the composites made of recycled photovoltaic glass are safe for the environment, and whether they do not contain harmful or toxic substances [11].

2 MATERIALS AND METHODS

Recycled photovoltaic glass

Bambas Elektroodpady s.r.o. company supplied the recycled photovoltaic glass in four fractions: 0.0/0.5 mm; 0.5/1 mm; 1/4 mm; and 4/10 mm. The photovoltaic glass did not undergo any chemical treatment, it was only crushed. The glass was used as a 100% replacement for natural aggregates in the production of cement specimens.

Cement

Portland cement EN 197-1 – CEM I 52.5 R (commercial designation TOP-CEMENT), manufactured by Cement Hranice, a.s., was used for the production of the test specimens.

Mixing water

Water from the water supply system was used as mixing water in the production of the test specimens. The criteria for the quality of the mixing water are set out in the standard EN 1008 – Mixing water for concrete – Specifications for sampling, testing and assessment of the suitability of water, including water obtained during recycling in a concrete plant, as mixing water for concrete [12].

Designed formulas

A total of 5 formulas were designed with 100% replacement of natural aggregates with recycled photovoltaic glass. The individual formulas were designated as R1 to R5. Formula R0 was a comparative one with natural aggregates, and there was no replacement.

Formula R0 contained Portland cement CEM I 52.5 R, mixing water and natural standardized aggregate (PG1, PG2, PG3) in the cement: water: aggregate ratio of 1:0.5:3.

The same ratio was maintained for the designed formulas R1 to R5, the only difference was that 100% of natural aggregate was replaced with recycled photovoltaic glass. Table 1 shows the percentage of 4 test fractions of recycled glass.

Table 1. *Percentage of the individual glass fractions in formulas R1 to R5*

Recycled glass fraction [mm]				
Formula	**0.0/0.5**	**0.5/1**	**1/4**	**4/10**
R1	13 %	14 %	0 %	73 %
R2	15 %	14 %	0 %	71 %
R3	14 %	14 %	5 %	67 %
R4	9 %	8 %	0 %	83 %
R5	9 %	8 %	9 %	74 %

Preparation of the test specimens

The test specimens R1 to R5 were prepared according to the formulas [13]. The procedure of preparation of fresh cement mixture based on recycled glass was performed in accordance with ČSN EN 196-1 [14].

Methods of testing the recyclate properties

Aqueous extract from recycled glass from photovoltaic panels was obtained in accordance with Decree No. 294/2005 Coll. [15], which deals with the conditions for depositing waste in landfills and their use on the terrain surface. The determination of the individual analytes in the extract was carried out according to: ČSN EN ISO 11885 (757387) Water quality - Determination of 33 elements by inductively coupled plasma atomic emission spectrometry (ICP AES) [16], ČSN EN ISO 11969 (757403) Water quality – Determination of arsenic – Atomic absorption spectrometry method (hydride technique) [17], and ČSN EN 1483 (757439) Water quality – Determination of mercury – Atomic absorption spectrometry method [18].

Cement composites testing methods

The aqueous extract from the test cement composites was subjected to the same laboratory tests as the aqueous extract of recycled glass.

Test specimens

The test specimens for the extract tests were cylinders with a diameter and a height of 40 x 40 mm. The cylinders were drilled from cuboid-shaped cement composite with the dimensions of 160 x 140 x 40 mm, see Figure 1, 2. The age of the test specimens for the extract test was 28 days.

Figure 1. *Test specimens preparation process*

Figure 2 shows the structure of cylinders made according to formulas R1 to R5. The individual formulas differ from one another in the different percentages of the individual recycled glass fractions.

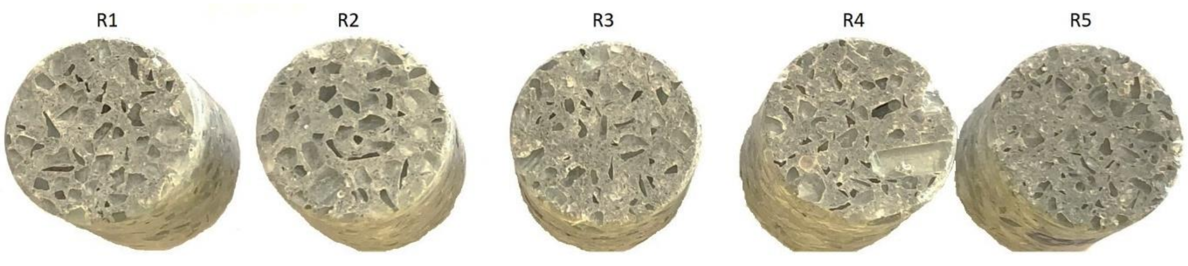

Figure 2. *Structure of the test specimens prepared according to formulas R1 to R5*

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3 RESULTS AND DISCUSSION

Laboratory tests of the extracts were performed on the test specimens prepared according to formulas R1 to R5 and on recycled glass prepared according to formula R3 (see Methods of testing the recyclate properties and Cement composites testing methods). The values of hazardous metals were determined from the aqueous extracts. Based on the obtained results, the individual metals were classified into extractability classes according to Decree No. 294/2005 Coll. [15]. Figure 3 shows a comparison of the aqueous extract of recycled glass according to formula R3 and the test cylinder according to formula R3. The results of the values of the individual metals from formulas R1 to R5 were very similar.

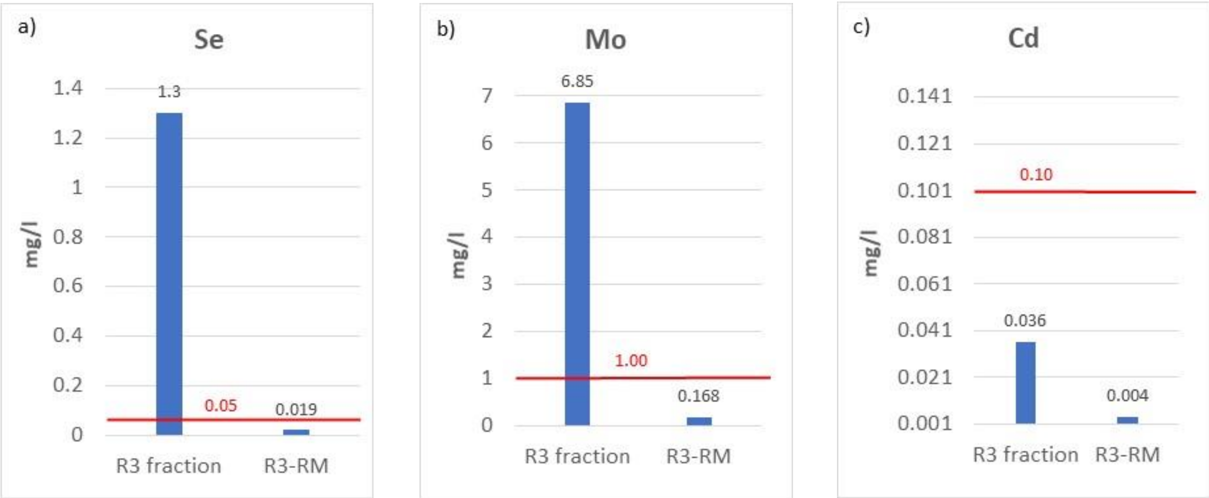

Figure 3. *Comparison of the values of Se, Mo a Cd from aqueous extract of recycled glass (R3 fraction) and cement composite according to formula R3 marked R3-RM (the limit value in mg/l of Se, Mo and Cd indicators for extractability class of IIb according to Decree 294/2005 Coll. is marked in red* [15]*)*

It can be seen from Figure 3 that selenium, molybdenum and cadmium were encapsulated when recycled glass from photovoltaic panels was incorporated into the cement matrix. The degree of solidification is 98.5 % for selenium, where the value decreased from 1.3 mg/l to 0.019 mg/l, and 97.5 % for molybdenum from the value of 6.85 mg/l to 0.168 mg/l, and 88.9 % for cadmium from the value of 0.036 mg/l to 0.004 mg/l. After the consolidation of these elements, only cadmium got into the first class of extractability according to Decree 294/2005 Coll. of Annex No. 2 [15]. Table 2 shows the maximum permissible values of indicators for the individual extractability classes. Selenium and molybdenum, when they were encapsulated in the cement matrix, still show values exceeding those of extractability class I, but meet the limit values of extractability class IIb.

Analyses of the aqueous extract from recycled glass of R3 formula and the test cylinder prepared according to formula R3 were also performed for the following elements listed in Table 2. Table 2 shows the same values both for the aqueous extract from recycled glass and the test cylinder prepared according to formula R3.

Table 2. *Measured values and maximum permissible values [mg/l] for selected elements*

Indicator	As	Sb	Hg	Ni	Cr	Ba	Pb
Measured value – extracts from experimental samples [mg/l]	<0.001	<0.001	<0.001	<0.001	<0.001	<0.020	<0.020
Maximum permissible value [mg/l] (for extractability class I) [15]	0.05	0.006	0.001	0.04	0.05	2	0.05

The values of the elements from Table 2 were also evaluated according to Decree 294/2005 Coll. [15]. According to this decree, the elements fall into the first class of extractability.

4 CONCLUSION

This article presents the results of an experiment based on the preparation of cement composites from waste recycled photovoltaic glass as a 100% substitute for natural aggregates. Because it was necessary to determine whether waste glass contains toxic metals, analyzes of the aqueous extract of the waste glass as well as of the test specimens were performed.

Based on the performed tests, we can draw the following conclusions:

1. waste glass from photovoltaic panels contained high concentrations of molybdenum, selenium and cadmium. Incorporating glass into the cement matrix reduced molybdenum concentrations by 97.5% to 0.168 mg/l, selenium concentrations by 98.5% to 0.019 mg/l and cadmium concentrations by 88.9% to 0.004 mg/l. The limit value according to Decree No. 294/2005 Coll. and extractability class IIb is 1 mg/l for molybdenum, 0.05 mg/l for selenium and 0.1 mg/l for cadmium,
2. other metals, such as As, Sb, Hg, Ni, Cr, Ba and Pb, were present both in the input material and in the cement matrix, but only in trace concentrations,
3. this type of recycling of waste glass from photovoltaic panels makes sense, but it is necessary to adjust the formulas in order to achieve the lowest possible concentrations of selenium and molybdenum up to the highest permissible value for the first extractability class.

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