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Possibilities of use of glass recyclate from photovoltaic panels for concrete masonry units

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Abstract. The paper deals with the possibilities of use of glass recyclate from photovoltaic panels for concrete masonry units. It compares different recipes and its physical and mechanical properties with the focus on the compressive strength, density. It then compares the values of these recipes with the values of commonly used composite materials for masonry units without recyclates. Recycling of materials from photovoltaic panels is a highly discussed topic nowadays. The paper presents possibility for secondary use of glass from these panels in building industry, namely the substitution of aggregate in concrete with glass recyclate.

1. Introduction

The Czech Republic is one of the best in Europe to sort waste and recycle. And it is great that this trend does not tend to cease [1]. However, regarding the recycling of industrial waste and its possible subsequent use, here we do have considerable space for improvement. This paper deals with the recycling of glass from photovoltaic panels and studies the possibilities of use of this glass for concrete masonry units.

Photovoltaic panels installed in Europe, including the Czech Republic, will begin to reach the limits of their lifetime in few years. Therefore, the topic of recycling of photovoltaic panels is more than actual and the possibilities as well as the limits of recycling are increasingly being discussed. Waste material from photovoltaic panels consists mostly of glass, for which we can find a wide range of secondary use. Here we focus of the usage in the building industry, specifically as a substitute for aggregates in concrete. The paper examines the mechanical properties of concrete samples made from glass recyclate, that has supplemented or completely replaced the aggregate in the concrete recipe.

2. Recycling of photovoltaic panels

Recently, the recycling of solar panels has been a major topic and it brings several serious questions and unsolved issues.

EU Directive on waste electrical and electronic equipment aims to contribute to sustainable production and consumption by the prevention of electrical waste and by the re-use, recycling and other forms of recovery of such wastes to reduce the disposal of waste and to contribute to the efficient use of resources. Since 2018, this EU Directive dealing with the disposal of solar panels requires recycling of at least 80 % of the panel and minimum of 85 % of waste recovery. Recycling means secondary material use; the waste recovery (use of waste) means both material and energy use. Table 1 shows the evolution of the quota over the time.

Table 1. EU quota for recycling of photovoltaic panels.

	2012–2015	2015–2018	Since 2018
Waste recovery of PV panels	75 %	80 %	85 %
Recycling of PV panels	65 %	70 %	80 %

source: https://www.resolar.cz/cs/co-nabizime

There are many types of photovoltaic panels – Monocrystalline (Mono-SI), Polycrystalline (Poly-SI), Thin-film (TFSC, CdTe, CIS, CIGS, a-Si), or Concentrated (CVP, HCVP). Various types from different manufacturers are installed in the Czech Republic. Classic solar panels of first and second generation are largely made up of glass (typically 70 %, up to 95 % in Thin-film PV panels) [3]. In order to meet the quotas, it is therefore necessary to ensure primarily the recycling of glass.

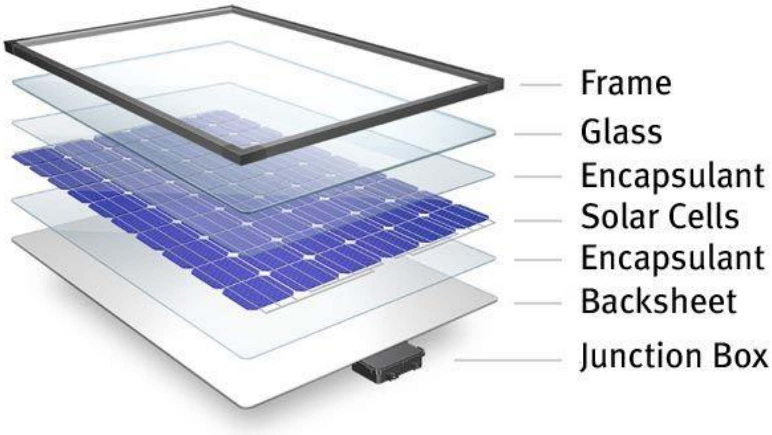

Figure 1. Structure of a photovoltaic panel.
source: http://www.dupont.com/

For the presented research, crushed glass from photovoltaic panels was used for production of glass recycled concrete samples. The glass we get from the PV panels is not a 100 % SiO_2. Table 2 shows the chemical composition of glass from the two types of panels commonly used in the Czech Republic.

Table 2. Chemical composition of PV panels glass.

	Loss on drying (105°C)	Loss by ignition 1100°C	SiO_2	Al_2O_3	Fe_2O_3	TiO_2	MnO	CaO
LDK SOLAR	0.23	1.08	69.5	1.230	0.172	0.023	0.005	10.20
QS SOLAR	0.22	0.50	71.0	0.499	0.110	0.023	0.006	8.45

	MgO	K_2O	Na_2O	Li_2O	Cr_2O_3	BaO	ZrO_2	SrO
LDK SOLAR	1.44	0.032	12.9	<0.002	0.005	0.005	0.008	0.008
QS SOLAR	4.04	0.171	12.4	<0.002	0.005	0.009	0.009	0.005

Figure 2. PV panels – producer QS Solar and LDK Solar Co.

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3. Concrete recipes

Glass recyclate from photovoltaic panels was obtained from BAMBAS Elektroodpady s.r.o., in two fractions, 1-2 mm and 4-8 mm.

By the sieving method (ČSN EN 933-1) we confirmed that in the case of fraction 1-2 mm 86 % of the recyclate falls into the indicated fraction, in the case of 4-8 mm 84 % falls into the indicated fraction [4].

Table 3. Results of sieving method for glass recyclate of fraction 1-2 mm.

Sieve Designation [mm]	Weight of the Partial Residue R_i [g]	Partial Residue on the Sieve [%]	Total Residue on the Sieve [%]	Total Sieve Drop [%]
16	0.00	0.00	0.00	100.00
8	0.00	0.00	0.00	100.00
4	0.00	0.00	0.00	100.00
2	1.09	0.05	0.05	99.95
1	1717.43	85.90	85.95	14.05
0.5	281.14	14.10	100.05	0.00
0.25	0.97	0.05	100.10	0.00
0.125	0.17	0.00	100.10	0.00
0.063	0.02	0.00	100.10	0.00
0	0.17	0.00	100.10	0.00

Table 4. Results of sieving method for glass recyclate of fraction 4-8 mm.

Sieve Designation [mm]	Weight of the Partial Residue R_i [g]	Partial Residue on the Sieve [%]	Total Residue on the Sieve [%]	Total Sieve Drop [%]
16	0.00	0.00	0.00	100.00
8	9.59	0.50	0.50	99.50
4	1685.24	84.30	84.80	15.20
2	269.32	13.50	98.30	1.70
1	31.26	1.60	99.90	0.10
0.5	3.83	0.20	100.10	0.00
0.25	0.23	0.00	100.10	0.00
0.125	0.38	0.00	100.10	0.00
0.063	0.00	0.00	100.10	0.00
0	0.57	0.00	100.10	0.00

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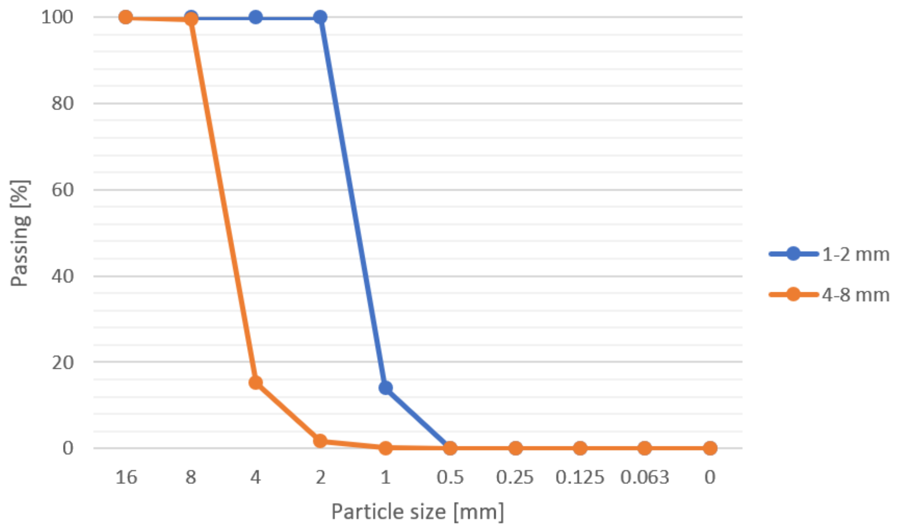

Figure 3. Grain size distribution curves of the glass recyclate fractions.

Two recipes were used to produce concrete samples with glass recyclate, that we used for further research. The first recipe (A) contained glass recyclate of both of mentioned fractions and the aggregate of fraction of 4-8 mm. The second one (B) contained only the glass recyclate of both fractions, without the addition of aggregate. A detailed description of both recipes is given in the Table 5.

Table 5. Recipes of concrete specimens with glass recyclate.

Recipe designation	Cement CEM II 32,5 R [kg.m^{-3}]	Glass		Aggregate	Water [kg.m^{-3}]
		1-2 mm [kg.m^{-3}]	4-8 mm [kg.m^{-3}]	4-8 mm [kg.m^{-3}]	
A	350	700	300	1000	150
B	350	950	1150	-	150

4. Performed tests

Specimens made from concrete with glass recyclate (both recipes A and B) and the recyclate itself were subjected to the following test:

- Tests for mechanical and physical properties of aggregates – Determination of loose bulk density and voids (ČSN EN 1097) [5]
- Determination of bulk density of fresh concrete – 48 hours old (ČSN EN 206+A1, ČSN EN 12350) [6],[7]
- Determination of bulk density of concrete – after 28 days (ČSN EN 206+A1, ČSN EN 12390) [6],[8]
- Determination of compressive strength of concrete (ČSN EN 206+A1, ČSN EN 12390-3) [6],[9]

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5. Results and discussion

According to the standard ČSN EN 1097, we determined the loose bulk density and voids of glass recyclate from PV panels [5]. Where the void content indicates the ration of grain gap volume to total volume of mass. The measured results of bulk density and void content is shown in the Table 6.

Table 6. Measured results of loose bulk density and voids of glass recyclate.

Bulk density	fraction 1-2 mm [kg.m^{-3}]	fraction 4-8 mm [kg.m^{-3}]
Loose recyclate	1086	1265
Compacted recyclate	1261	1413
Void content	fraction 1-2 mm [%]	fraction 4-8 mm [%]
Loose recyclate	60	53
Compacted recyclate	53	48

Figure 4. Determination of bulk density of glass recyclate of fractions of 4-8 mm and 1-2 mm.

The values of *fresh concrete density*, i.e. samples at the age of 48 hours, reached an average of 2160 kg.m^{-3} for the recipe A. For the recipe B, that contained only the glass recyclate, the average value was 1880 kg.m^{-3}.

Further test results are presented in the following Table 7. There are presented values for each specimen, as well as average values for *recipe A* and *B*. The compressive strength was determined after 28 days.

Table 7. Tests results and measured values.

Specimen	Weight [g]	Density [kg.m^{-3}]	Specimen Dimensions [mm]	Compressive Strength [MPa]
A1	7213.2	2137.2	150x150x150	20.9
A2	7227.0	-	150x150x150	22.6
A3	7243.6	-	150x150x150	22.0
A – average	7227.9	**2140**	150x150x150	**21.8**
B1	6220.4	1843.1	150x150x150	11.5
B2	6286.4	1862.6	150x150x150	11.9
B3	6198.6	1836.6	150x150x150	11.9
B4	6229.8	1845.9	150x150x150	11.3
B – average	6233.8	**1850**	150x150x150	**11.7**

The results of compressive strength, that we obtained from the measurements, show satisfactory values. For recipe A, with both glass recyclate and one fraction of aggregate, the average measured strength is 21.8 MPa. This value corresponds to the mean values of ordinary normal weight concrete. Recipe B, where all the aggregate is replaced by the recyclate from PV panels, reached the average value of 11.7 MPa. However, it also has a lower density and is therefore lighter. Both recipes, even the mix B with lower value of compressive strength, are suitable for load-bearing masonry units.

For illustrative comparison, we can take a short look at compressive strength and density of the widely used lightweight aerated concrete YTONG. See the data in the Table 8. We can see that the compressive strengths of different types of YTONG reach just half (or in some types quarter) of the value measured for the concrete with glass recyclate from PV panels. (This comparison only aims to illustrate differences in compressive strength and density, it does not seek to compare mentioned materials overall. More properties such as thermal conductivity and frost resistance need to be studied and compared.)

Table 8. Data and values for lightweight aerated concrete YTONG for peripheral and load-bearing walls.

Type	Density [kg.m^{-3}]	Compressive Strength [MPa]
Standard P2-400	400	2.7
Univerzal P3-450	450	3.5
Statik P4-550	550	5.0
Statik Plus P6-650	650	6.5

data source: data sheet of the producer, www.ytong.cz

6. Conclusion

The results obtained from measurement proved that strengths of concrete units with glass recyclate from photovoltaic panels are satisfactory for use in building foundations as well as for load-bearing structures of low-rise buildings.

The admixture of polymer fibres could bring further improvements in mechanical properties of the material. Combination of coarse concrete recyclate with fine glass recyclate comes into consideration when preparing new possible recipe.

One limitation will always be the smoothness of glass surface in connection with cement and possible reaction glass – calcium hydroxide. Several scientific studies have already addressed this issue [10], [11], [12], [13].

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