Photovoltaic Panels' Downcycling Method that Pushes the Transition to a Circular Economy

Student **Miruna-Andreea TOKAR[1]**, Student **Iuliu-Ioan LAZĂR[1]**,
Assist. Prof. PhD. Eng. **Dănuț TOKAR[1,*]**

[1] University Politehnica Timisoara, Romania

* danut.tokar@upt.ro

Abstract: *In the current context regarding energy sources' problems, it is estimated that a high percentage of waste will be produced from photovoltaic panels, that will put pressure on the environment. Thus, the study focuses on downcycling them by incorporating them into mortars by six new recipes (R1, R2, R3, R4, R5 and R6) that replace the sand by integrating photovoltaic panels' dust (PVd) and pieces of photovoltaic panels (PVp) (1/3 to 100% of the total amount). All samples were subjected to tensile bending, compression and an economic analysis and were compared with the control sample (R0). As a result of the experimental research, a change in the apparent density of the proposed samples was found, and a general improvement in all areas of testing. The obtained results show that used photovoltaic panels can constitute raw material for the creation of new construction materials.*

Keywords: *Environmental protection, mortars, new materials, PV downcycling*

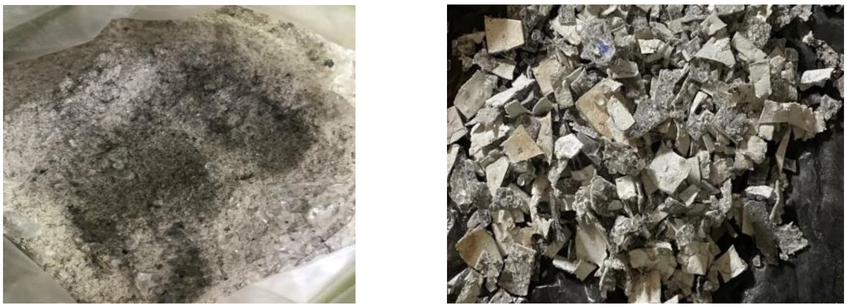
1. Introduction

The electrical context is based on the recent problems regarding the way we produce electricity. Photovoltaic panels seem to be the future regarding green energy production [1]. However, the lies with the waste generated after a period of 25-30 years of usage and the fact that current recycling methods are expensive and inefficient. This issue must be fixed through the use of new legislation and regulations regarding the recycling of photovoltaic panels for each country. It is known that photovoltaic panels, besides having precious metals (silver, aluminium, copper, steel, etc.), contain toxic materials such as lead [1], [2], [3], [4]. In the European Union the legislation forces the recycling of photovoltaic panels (PV), however, in most part only the materials in bulk are collected, such as the aluminium frames and glass, which represent 80% of the total mass of the siliceous panel. The remaining mass is usually incinerated even if it contains certain elements such as silver, copper, and silicon which together represent the two terms of economic value of the materials of a photovoltaic panel [2]. Similar measures are taken in Japan, India, and Australia that intervene through plans of recycling. The top countries, in 2022, regarding cumulative capacity of installed photovoltaic panels are China (414.5GW), the European Union (209.3GW), the USA (141.6GW), Japan (84.9GW), India (79.1GW), Germany (67.2GW), followed, at large differences, of Australia, Spain, Italy, Korea and Brazil [5]. In this paper we will discuss downcycling methods that are not only good for the environment but also bring an economic benefit. Given all of the above, this paper approaches new options of recycling, by integrating photovoltaic panel cells into construction materials. Similar recipes were proposed beforehand, and the result were positive [6]. This article proposes 4 new recipes from which 3 samples of each were created. All were tested for bending tensile strength, compressive strength, and thermal insulation.

2. Methods

In order to obtain the raw materials for this study we had to process the photovoltaic panels using equipment such as: ball mill and diamond disc cutting machine.
The basic materials used in all recipes are cement (CEM II A-LL 42.5R), sand (0.5/1-Sort 3), release agent (Master Finish RL 450) and water. For the proposed research, retired monocrystalline and polycrystalline photovoltaic panels were used. The used photovoltaic panels were cut into pieces using a diamond disc cutting machine.

The cut pieces of the panel were crushed with the help of an experimental grade ball mill, resulting in crushed glass and pieces of photovoltaic cells together with plastic material (supporting material for photovoltaic cells and for sealing) and residues from auxiliary material (adhesive, other unknown elements). The final products are shown in Fig.1.



a) b)

Fig. 1. The final materials obtained: a) PV dust (PVd), b) PV pieces (glass+plastic)-PVp

3. Procedures

After obtaining the materials necessary to study six recipes were made: R1trough R4 without additives, R5 (R0 + superplasticizer SikaPlast (SP)-331, 1% of cement mass) and R6 (R3+ superplasticizer SikaPlast (SP)-331, 1% of cement mass). The mixture R0 (control sample) was realized and tested in conformity with SR EN 196-1: 2016 [7]. Testing was done on four of the six samples (R0 through R4). They were tested after 4 months. The results of the new recipes were compared with R0's results.

The steps of this project are:

- determining the recipes for the control sample R0 (Table 1) and the series of probes R1 through R6 (Table 2).

Table 1: Recipe for sample (R0)

Recipies for the mixtures	Cement CEM II A-LL 42,5R [kg]	Sand 0,5/1-Sort 3 [kg]	PVd [kg]	PVp [kg]		SPv	Water for mixtures [m^3]
				glass	plastic		
R0	0.45	1.35	-	-	-	-	0.25

Table 2: Recipes for (R1-R6)

Recipies for the mixtures	Cement CEM II A-LL 42,5R [kg]	Sand 0,5/1-Sort 3 [kg]	PVd [kg]	PVp [kg]		SP	Water for mixtures [m^3]
				glass	plastic		
R1	0.45	0.45	0	0.90	0	-	$22\cdot10^{-5}$
R2	0.15	0.90	0	0	0.45	-	$21\cdot10^{-5}$
R3	0.45	0.45	0.52	0.27	0.10	-	$25\cdot10^{-5}$
R4	0.45	-	1.35	0	0	-	$28\cdot10^{-5}$
R5	0.45	1.35	0	0	0	SP 331	$22\cdot10^{-5}$
R6	0.45	0.45	0.52	0.27	0.10	SP 331	$22\cdot10^{-5}$

- Weighing of the materials (Fig. 2) with the electronic scale KERN that has a precision of 0.0001 g.

Fig. 2. The weight of used materials

- The mixture which was initially made manually and then with the help of a mixer for mortar Auto-Mortar Mixer;
- Pouring the samples (Fig. 3) mold that was previously oiled with MasterFinish RL 450, followed by the compacting of the mixture through the usage of mechanical shocks (manual);

Fig. 3. Pouring and compacting the mixture

The mould used has the standard dimensions of: b × h × L [m]. The dimensions and weight of the samples are presented in Table 3 and Fig. 4.

Table 3: Dimensions and weight of the samples taken out of their mold

Sample	**Dimensions and weight**			
	m[kg]	**b[m]**	**h[m]**	**L[m]**
R0 - 4 months	0.53	0.04	0.04	0.16
R1 - 4 months	0.55	0.04	0.04	0.16
R2 - 4 months	0.54	0.04	0.04	0.16
R3 - 4 months	0.50	0.04	0.04	0.16
R4 - 4 months	0.49	0.04	0.04	0.16
R5 - 7 days	2.69	0.15	0.058	0.15
R6 - 7days	3.01-	0.15	0.068	0.15

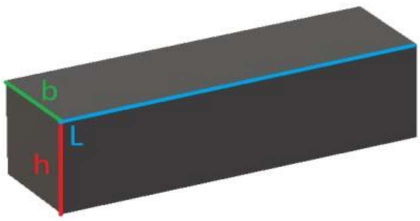


Fig. 4. The dimension of the samples without the mold

- Testing the samples (Fig. 5) with a hydraulic press, using a speed of charge of (50±10) N/sec for the bending test and (2400±200) N/sec for the compression test.

a b

Fig. 5. Mechanical tests: a) tensile bending test, b) compression test

Table 4: The pressing forces p [N], at which the break was initiated for recipes 0 through 4

Sample	R0	R1	R2	R3	R4
P_t [N]	2200	1800	1600	1480	2300
P_{c01} [N]	33800	42500	24500	22500	32700
P_{c02} [N]	31500	35500	23500	22000	35700
P_{cavg} [N]	32650	39000	24000	22250	34200

For analysing the results, it has been used:

- The equation of the resistance at traction F_t [N/m^2]:

$$F_t = \frac{3}{2} \cdot \frac{P \cdot d}{b \cdot h^2} \quad (1)$$

where:
P -the potential force of the machine [N];
d- distance [m];
b- width of the sample [m];
h-height of the sample [m].

- The equation of the resistance at compression F_c [N/m^2]:

$$F_c = \frac{F}{A} \quad (2)$$

where:
F-the potential force of the machine [N];
A-the area of the section (A=b×h) [m^2];
b- width of the sample [m];
h-height of the sample [m].

4. Data and analysis

The attempt to recycle and use photovoltaic panels and repurposing them into construction materials materialized in this research through the creation of 6 new mortar recipes.

4.1 Testing

Their structure is a combination of the mortar recipe (according to SR EN 196-1: 2016) [7] and the three materials obtained from PV (dust, glass and plastic pieces). Thus, sample R1 (25% Sand + 50 % Glass), R2 (50% Sand, 25% Plastic pieces), R3 (25% Sand, 29% Dust, 15% glass, 6%Plastic pieces), R4 (0% Sand, 100% Dust) and two recipes (R5 and R6) which are the equivalent of R0 and R3 with added additives.

The physical and mechanical characteristics of the samples R0 trough R4 that have been analyzed after 7 days under the influence of mentioned loads, are presented in Fig. 6-8.

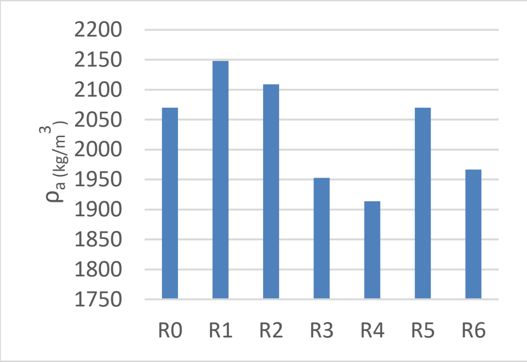


Fig. 6. Pouring and compacting the mixture

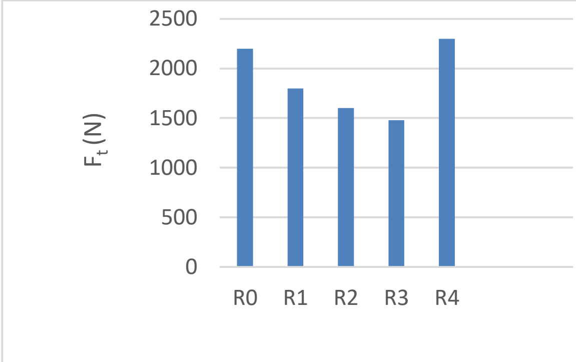


Fig. 7. The resistance at traction

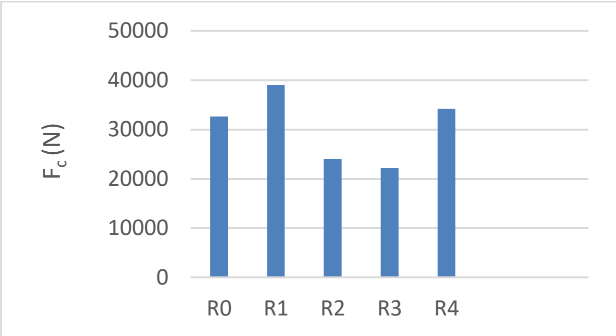


Fig. 8. The resistance at compression

It can be noted that R3, R4 and R6 have a lower density than R0 while R5 has a similar density. Sample 4 was found superior in both tensile and compression tests while R1 was found superior in the compression test.
Although in some areas the proposed recipes performed less than the control sample, they were still in parameters regarding functionality the main benefit being their small density.
Therefore, a possibility of recycling by reusing the degraded photovoltaic panels is the creation of new materials such as new mortars which could be included in the field of constructions.

4.2 Economical stand point

An economic analysis shows that all recipes but R2 help decrease the budget for mortars without compromising on quality as shown in Table 5.

Table 5: Cost savings for a sample of 1.8 kilograms

Recipes	Cement	Sand	Water	Dust	Glass	Plastic	Total RON	Savings %
ron/ton	910	40	14	22.7	19.98	18.2		
R0	0.6	0.08	0.005	0.00	0.00	0.00	0.68	0.0
R1	0.6	0.03	0.005	0.00	0.03	0.00	0.66	3.9
R2	0.6	0.05	0.004	0.00	0.00	0.01	0.67	-1.8
R3	0.6	0.03	0.005	0.02	0.00	0.01	0.66	1.5
R4	0.6	0.00	0.006	0.05	0.00	0.00	0.65	1.3
R5	Similar to R0							
R6	Similar to R3							

5. Conclusions

Nowadays, PV waste starts to become a global problem, especially in countries that invested in photovoltaic systems. However, given results presented earlier show that these can be used as a resource in the field of construction. The study has shown and proved experimentally that the six different recipes performed generally better than the standard sample R0 in a combination of all three areas of testing. R4 performed better than R0 in all three areas of testing. In addition, R3, R5, and R6 also had smaller densities than R0 while R1 performed better than the standard material in the compression test. Moreover, this new method of downcycling is beneficially from an economical point of view due to the fact that all but R2 have a lower production cost.
In light of all of the above, our study shows that the downcycling method of introducing PV waste intro construction materials can not only benefit the environment but also bring economic value.

6. Further research questions

As future research directions, we propose to create new recipes (in different mixtures) to obtain construction materials that use these wastes and the results to be a basis for research in the field. At the same time, we propose to test these materials in real operating conditions. Parallel to the mechanical tests we propose to test the current and future samples for thermal insulation.

Acknowledgement

T.A.M thanks VOLT for the materials given to conduct this study.

References

[1] Mahmoudi, Sajjad, Nazmul Huda, and Masud Behnia. "Photovoltaic waste assessment: Forecasting and screening of emerging waste in Australia." *Resources, Conservation and Recycling* 146 (July 2019): 192-205.
[2] Peplow, Mark. "Solar panels face recycling challenge." *ACS Central Science* 8*,* no.3 (March 2022): 299-302.
[3] Lewis, Michelle. "Where do solar panels go when they die?", *Electrek*, August 24, 2020. Accessed October 5, 2023. https://electrek.co/2020/08/24/where-do-solar-panels-go-when-they-die/.
[4] Heath, Garvin A., Timothy J. Silverman, Michael Kempe, Michael Deceglie, Dwarakanath Ravikumar, Timothy Remo, Hao Cui, Parikhit Sinha, Cara Libby, Stephanie Shaw, Keiichi Komoto, Karsten Wambach, Evelyn Butler, Teresa Barnes, and Andreas Wade. "Research and development priorities for silicon photovoltaic module recycling to support a circular economy." *Nature Energy* 5 (July 2020): 502-510.
[5] Masson, Gaetan. *Snapshot of Global PV Markets 2022-Task 1 Strategic PV Analysis and Outreach PVPS*, Publisher IEA PVPSV, 2023.
[6] Tokar, Miruna, and Andrea Altomonte. "Study on recycling photovoltaic panels: Their integration into construction materials." Paper presented at the 32nd Conference with International Participation on Building Facilities and Environmental Comfort ICCA 2023, Timisoara, Romania, May 4-5, 2023.
[7] ***. "SR EN 196-1: 2016 - Methods of testing cement. Part 1: Determination of strength." Romanian Standards Association, 2016.