# Experimental research on the mechanical characteristics of mortars containing wasted photovoltaic panels

Cercetări experimentale privind caracteristicile mecanice ale mortarelor care conțin panouri fotovoltaice uzate

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***ABSTRACT.*** *In the current context regarding energy sources' problems, it is estimated that photovoltaic panels will produce a high percentage of waste that will put pressure on the environment. Thus, the study focuses on recycling them by incorporating them into mortars by four new mortar recipes (R1, R2, R3 and R4) that integrate photovoltaic panels' dust (PVd) and pieces of photovoltaic panels (PVp), replacing the sand with PVd and PVp (1/3 to 100% of the total amount). All samples were subjected tensile bending and compression tests 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 from the point of view of the tensile strength, R2 and R4 were found similar to sample R0 in both tests. The obtained results show that used photovoltaic panels can constitute raw material for the creation of new construction materials.*

***Key words:*** wasted photovoltaic waste

## 1. INTRODUCTION

The electrical context of this situation is based on the recent problems regarding the way we collect electricity. It is believed that the photovoltaic panels, which transform sunlight into direct electricity, to become the main generator of electricity in the near future [1]. The photovoltaic industry will continue its growth and the problem lies with the waste generated after a period of 25-30 years of usage. 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 material (silver, aluminium, copper, steel, etc.), contain toxic materials such as lead [1], [2], [3], [4]. Even if you try to prolong the life of a photovoltaic panels by fixing and reusing them, in the end they will still end up as waste. The problematic thing is that the current technology for recycling photovoltaic panels is expensive and not at all efficient [1], [2]. 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 silicious 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. On the other hand, in the USA there is an exception in some state laws, the recycling of photovoltaic panels being inefficient and rarely used thus at a global level it prognosed that they will generate approximately 6 million tons of new solar electronic waste annually starting with 2030 [3], [4]. Top countries in the number of photovoltaic panels are Australia China and India, but it is also shown that third world countries such as Taiwan and Pakistan have installed over 2GW of photovoltaic panels [5]. In this paper we will discuss those aspects (the recycling and reusing of the waste) and the benefit which it brings to the environment. Give all of the above, this paper approaches new options of recycling, by integrating photovoltaic panels (the panel part) in its form, after separating the components (framework) in 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 and compressive strength.

## 2. METHODS

In the study, the lack of necessary materials such as shredded material and pieces of photovoltaic panel required obtaining them by our own means. Also, a series of tools and equipment were used: diamond disc cutting machine, handheld pneumatic compactor, manual scissors.

The usual materials used 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, monocrystalline and polycrystalline photovoltaic panels that were removed from use and stored were used. The used photovoltaic panels were cut into pieces using a diamond disc cutting machine. (Figure 1).

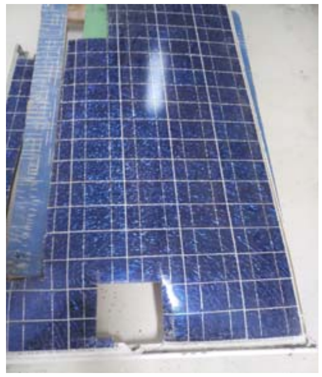
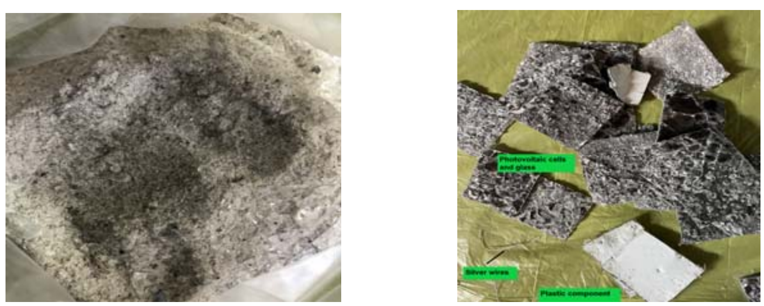


Figure 1. Slitted photovoltaic panels

The cut pieces of the panel were crushed by compaction with a compactor (handheld pneumatic compactor), 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 pieces of material resulting after the first compaction phase are shown in Figure 2.




a) b

Figura 2. The final materials obtained at the end of the compaction process, used for the study

a) PV dust, b) PV crushed

Due to the fact that it was also desired to integrate larger pieces of cut PV into the mortar, manual slitting continued, the cells were made into smaller pieces, with scissors. The result of the obtained material (used in recipe R2 and R3) is shown in Figura 3.

Figura 3. Material obtained after manual cutting of PV-pieces (glass + plastic)

At the same time, the aluminium frame was collected whose recycling process is established and was not the subject of our study.

## 3. PROCEDURE

After obtaining the materials necessary to study four recipes were made: R1, R2, R3 and R4. The mixture R0 (control sample) was realised and tested in conformity SR EN 196-1 [7]. Testing was done on all 15 samples and the results from the new recipes were compared with R0.

The steps of this project are:

❖ determining the recipes for the series of probes R1, R2, R3 and R4 (Table 2);

The number of materials used to create R0 are presented in Table 1, and for recipes R1, R2, R3 and R4, in Table 2.

Table 1 Recipe for sample (R0)

| Recipies for the mixtures | Cement CEM II A-LL 42,5R [g] | Sand 0,5/1-Sort 3 [g] | PVd [g] | PVp [g] | | Water for mixtures [g] |
|---|---|---|---|---|---|---|
| | | | | glass | plastic | |
| R0 | 450 | 1350 | - | - | - | 250 |

Table 2 Recipies for (R1-R4)

| Recipies for the mixtures | Cement CEM II A-LL 42,5R [g] | Sand 0,5/1-Sort 3 [g] | PVd [g] | PVp [g] | | Water for mixture [g] |
|---|---|---|---|---|---|---|
| | | | | glass | plastic | |
| R1 | 450 | 450 | 300 | - | - | 220 |
| R2 | 150 | 300 | - | - | 150 | 210 |
| R3 | 450 | 450 | 525 | 275 | 100 | 250 |
| R4 | 450 | - | 1350 | - | - | 280 |

- ❖ the weight of the materials used (Figure 4) which were made with the electronic scale KERN, with a precision of 0.0001 g.

a) b) c) d) e)

Figure 4. The weight of the materials used

a) cement, b) sand, c) PV crushed, d) pieces of PV, e) water

- ❖ the mixture which was initially made manually and then with the help of a mixer for mortar Auto-Mortar Mixer;
- ❖ pouring the samples (Figure 5) mould with oil previously with an agent of with a removing agent of the type MasterFinish RL 450, followed by the compaction of the mixture through the usage of mechanical socks (manual). The mould used has the standard dimensions of: b × h × L [mm].

Figure 5. Pouring and compacting the mixture

- Taking the samples out of the moulds after 2 days. No degradation of the edges of the concrete can be observed (Figure 6).

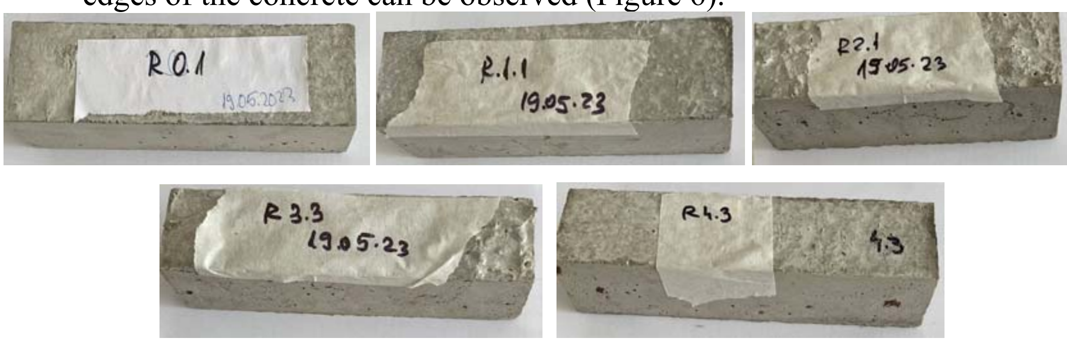



Figure 6. The appearance and the weight of the sample after taking it out of the mould

The dimension of the weight of the sample are presented in Table 3 and Figure 7.

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

| Sample | Dimensions and weight | | | |
|---|---|---|---|---|
| | m[g] | b[mm] | h[mm] | L[mm] |
| R0 | 530 | 40 | 40 | 160 |
| R1 | 553 | 40 | 40 | 160 |
| R2 | 535 | 40 | 40 | 160 |
| R3 | 506 | 40 | 40 | 160 |
| R4 | 488 | 40 | 40 | 160 |

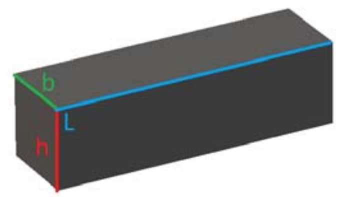
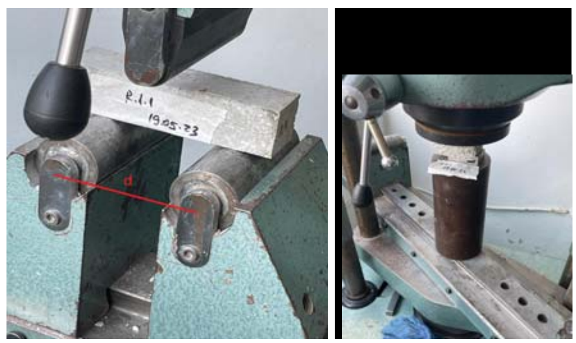



Figure 7. The dimension of the sample without the mould

- ❖ the making of the mechanical trials (Figure 8) 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)

Figure 8. Mechanical tests

a) tensile bending test, b) compression test

Table 4 The pressing forces P [daN], at which the break was initiated, are presented in

| Sample | R0 | R1 | R2 | R3 | R4 |
|---|---|---|---|---|---|
| **7 days** | | | | | |
| Pt [daN] | 160 | 145 | 165 | 115 | 170 |
| $Pc_{01}$[daN] | 3680 | 3860 | 2850 | 1650 | 2790 |
| $Pc_{02}$[daN] | 3710 | 3870 | 2610 | 2250 | 2840 |
| $Pc_{avg}$[daN] | 3695 | 3865 | 2730 | 1950 | 2815 |
| **28 days** | | | | | |
| Pt [daN] | 228 | 145 | 165 | 192 | 194 |
| $Pc_{01}$[daN] | 4125 | 4000 | 2425 | 1790 | 3080 |
| $Pc_{02}$[daN] | 3720 | 3860 | 2565 | 1500 | 3750 |
| $Pc_{avg}$[daN] | 3922 | 3930 | 2495 | 1645 | 3145 |

For analysing the results it has been used:

- The equation of the resistance at traction Ft [daN/mm$^2$]:

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

where:
P -the potential force of the machine [daN];
d- distance [mm];
b- width of the sample [mm];
H-height of the sample [mm].

- The equation of the resistance at compression Fc [daN/mm$^2$]:

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

Where:
F-the potential force of the machine [daN];
B-the width of the sample [mm];
H-height of the sample [mm];
A-the area of the section (A=b×h) [mm$^2$].].

## 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 4 new mortar recipes.

Their structure is a combination of the mortar recipe (according to SR EN 196-1) [7] and the two materials obtained from PV (dust, glass and plastic pieces). Thus, sample R1 (33.33% Sand + 66,66 % Glass), R2 (66,66% Sand, 25,92% Glass, 7,4% Plastic pieces), R3 (33,33% Sand, 20,37% Glass, 38.88% Dust, 7,4% Plastic pieces), R4 (0% Sand, 100% Dust)

The physical and mechanical characteristics of the samples that have been analysed after 7 and 28 days, under the influence of mentioned loads, is presented in Figures 9-11.

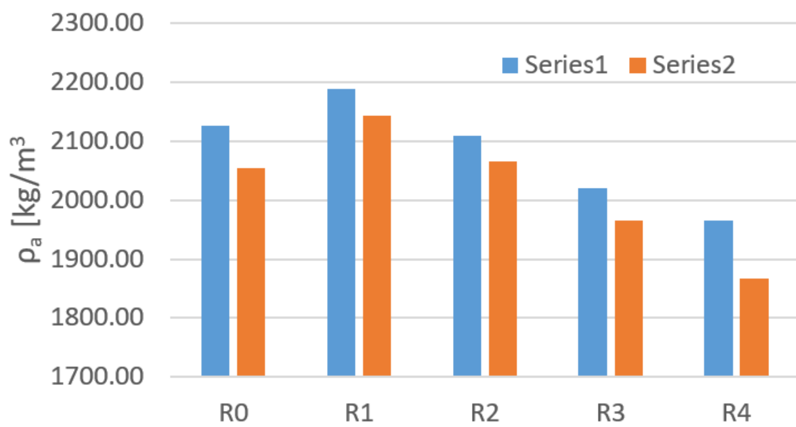



Figure 9. The apparent density

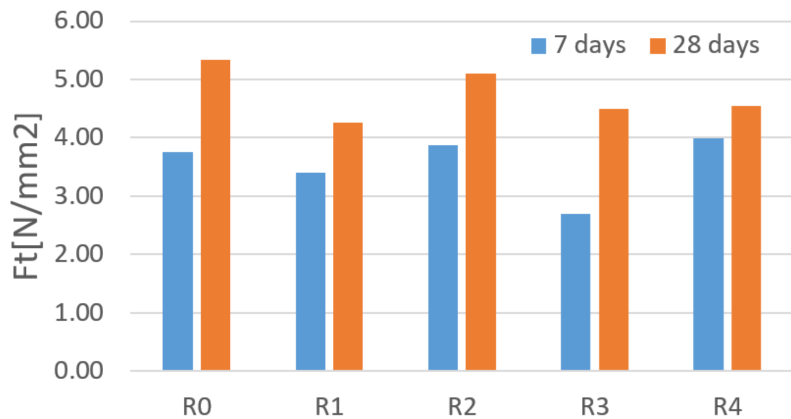



Figure 10. The resistance at traction

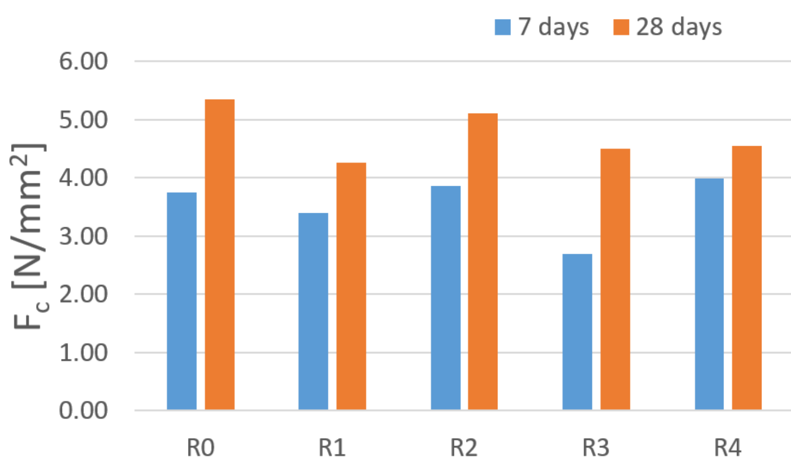



Figure 11. The resistance at compression

It can be noted that there is a growth in the density of the sample R1 with a 1,03% after 7 days and with a 1,04% after 28 days, compared to the control series

(R0), no significant change in the density of R2, and a decrease in density of samples R3 and R4 with 2,75% and 5,03%, after 28 days. From the comparative analysis of the values of the physical-mechanical characteristics determined at 7 and 28 days (Figures 10-11), and from the point of view of the tensile strength, R2 and R4 were found superior to sample R0 by 3,03% (7 days) and 5,88% (7 days) respectively and in the compressive test R1 was found superior to R0 by 2,17% (7 days) It can be seen that after 28 days the proprieties of samples R1-R4 have grown compared with the ones that were tested at 7 days.

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.

The new materials obtained, both the crushed (PVc) and the one in bigger pieces (PVp) have superior mechanical characteristics compared to the material obtained by the standardized recipe (R0). In addition, the R4 material is lighter (Figure 9).

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 construction repair mortars.

## 5. Conclusion

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 two different recipes for new materials which integrate different forms of wasted photovoltaic panels resulting in new materials with superior properties compared to the classic material made through R0. Through R4 a lighter material was obtained, with 7,57% (7 days) and 9,13% (28 days) lighter density than the classic recipe R0.

The R2 and R4 samples' traction and compression resistance are similar to the control sample R0.

With the fast evolution of photovoltaic technology, it is important that the industry of recycling plans an adaptable recycling infrastructure. However, unfortunately, there is no major action referring to prevention, reduction and recycling of PV waste. Remaking the whole chain of production could lead to the concept that the waste resulting from a process can become primary source for another one or even the same. That way, earlier presented results show the fact that wasted PVs can become a resource for the construction industry. From the point of view of the journey that wasted photovoltaic panels have in present it is stated that the introduction of them in constructions and infrastructure can have a significant impact on reducing the waste quantities which are deposited in nature, waste which puts pressure on the surroundings. That way, this study shows that something that is considered useless can be seen as waste or resource depending on the way it is used.

## 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. Physical-mechanical characteristics were determined at 7, 28 days, to be determined at 90 days, and the ongoing experimental program will continue with other new mortar/material recipes.

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