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Research Article

Valuable Materials Recovery from End-of-Life Photovoltaic Solar Panels recycling: SIREVIVAL PROJECT

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Abstract:

The photovoltaic panels contain a variety of valuable metals and materials, which are mined and refined at increasing rates such as, silicon cells, copper metallic contact, glass, EVA (ethylene/vinyl acetate copolymer), the back sheet, the aluminum frame and the junction box. Therefore, it is imperative to create recycling methodologies, infrastructure, and policies to maintain the flow of those materials within the industry. Recycling End-of-life “eol” photovoltaic panels ensure efficient use of resources and appropriate treatment of hazardous substances and its can considerably reduce energy needs for production of materials and thus equivalently reduce emissions of greenhouse gases. In the present work, recycling methodology which includes manual pre-sorting, processing of laminates, separation and extraction of materials was applied. In brief, after manual removal of Al frames and junction boxes, typical mechanical, thermal and chemical steps was employed to delaminate the glass and then remove the metallic parts together with silicon and plastic. Leaching/etching was used to separate Si and metal. Additional treatment was used for purifying the recovered silicon. The exhaustive physico-chemical characterization using SEM, XPS, optical microscopy of the raw Silicon and other materials recovered were completed in this work before and after purification.

1. Introduction

Renewable energy sources are playing an ever-increasing role in the quest for a sustainable energy supply, and among the many environmentally-friendly renewable sources, solar energy is ecologically clean, abundant, efficient and the fastest-growing, thanks to drastically reduced investment costs and technological advances [1-4].

The dominant photovoltaic technology is based on c-Si solar cells, with a market share of over 90% [5-10].

A key technology with the rate of adoption and installation of PV modules increasing almost exponentially, from around 1.4 Gigawatts of total installed capacity worldwide in 2000 to over 500 Gigawatts in 2018 [11] with projections of a further increase to over 4,500 GW in 2050 [5].

Although PV modules do not produce greenhouse gases during use, thus resulting in minimal environmental impact, the significant increase in PV module production over the last few decades will generate a large number of end-of-life PV panels that will invade the world as waste.

The average lifespan of photovoltaic solar panels is 25 years [12-14], so the quantity of waste will increase significantly, reaching 78 million tons in 2050 [6-9].

The components that make up a photovoltaic panel are precious materials (such as silicon, silver, aluminium, copper, etc.) that must be recycled and preserved. The nature and composition of these panels will determine the type of waste treatment technology and industrial reuse once the materials have been recycled to meet the needs of manufacturing new photovoltaic modules.

By finding an appropriate way and method [15-17] to recycle photovoltaic panel materials, we can ensure production while minimizing environmental impact and increasing economic benefit.

This works presents results from experiments using, recycling methodology which includes manual pre-sorting, processing of laminates, separation and extraction of materials. According to our study, more than **99 %** of the end-of-life photovoltaic panel was recovered and can be recycle and reused on several applications.

2. Photovoltaic panel components

A Si photovoltaic panel as it's shown in figure.1 is a combination of several components [18,19], such as, silicon cells, copper metallic contact, glass, EVA (ethylene/vinyl acetate copolymer), the back sheet, the aluminum frame and the junction box as shown in Figure.1. Their specific functions and characteristics are as follows:

□ The glass component. Solar panels are made of tempered glass. The glass layer protects the main body of the panel against damaging external factors, such as water, vapor, wind and dirt.

□ The EVA component. This is a polymer encapsulating the photovoltaic cells. It protects the photovoltaic module against all environmental changes such as wind, UV radiation, temperature, and so on. It is easily degraded to air exposure, its color will change to yellow, and this degradation will affect its overall barrier properties.

□ The cell component. The cell is a component which coverts light to electricity; the most used one is silicon. The SIREVIVAL project targets to recycle only eol photovtaic panel based on Silicon .

□ The back sheet component. The back sheet acts as a moisture barrier and external protection for different weather conditions. The back sheet is made of various polymers or plastics which offer different levels of protection, thermal stability and long-term UV resistance.

□ The aluminum frame component. The aluminum frame supports the main body of the photovoltaic module.

□ The junction box component. The junction box protects the electrical connections of the photovoltaic module.

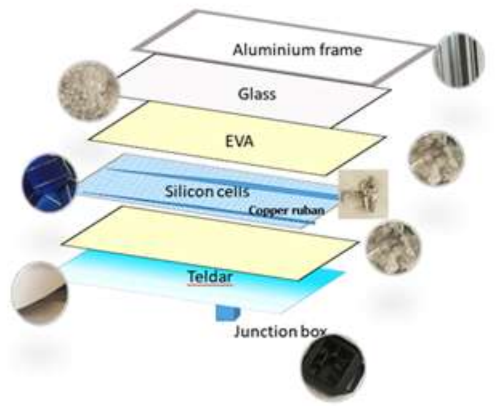


Figure 1. *The components of a PV module*

□The solar ribbon component. The so-called PV tabbing ribbon is a copper conductor installed directly onto silicon crystals to interconnect solar cells in a solar module.

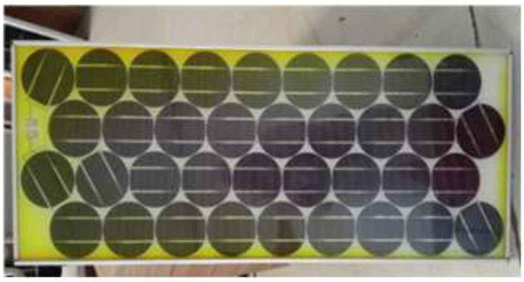


Figure.2 *the end of life panel from ARCO company*

Figure.3 *Different components of PV panels after dismantling*

Figure.4 *Back sheet removal*

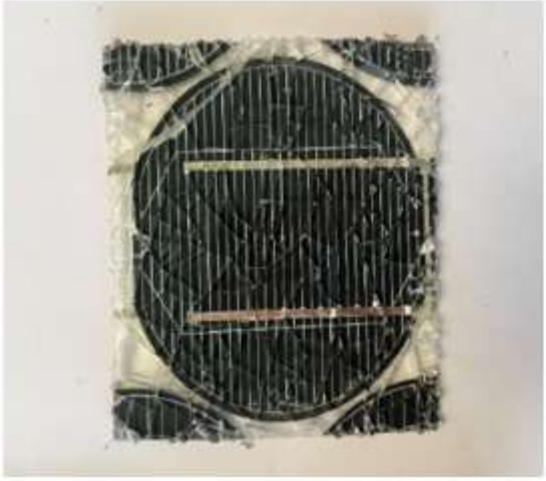


Figure.5 *A piece of eol photovoltaic panel*

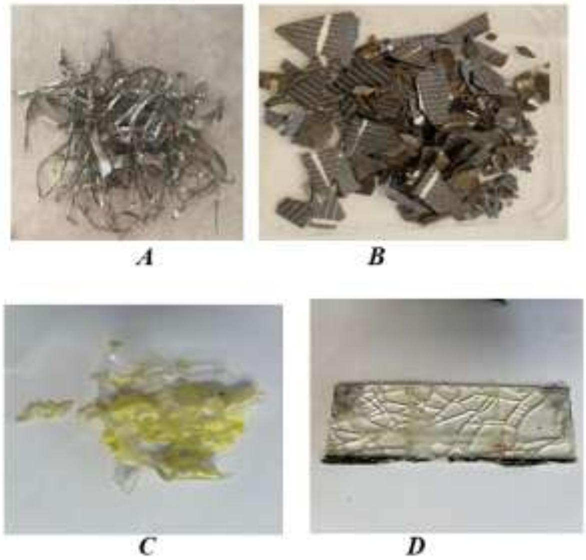


Figure.6 *Material recovery from Arco eol pv panel A-Copper tape B-Silicon C-EVA D- Glass*

3. Material and Methods

In the present work, the end of life panel studied is an ARCO (American industry) photovoltaic panel type (122×30 cm), weighing 5.512 kg with 35 round silicon cells as shown in figure.2.

During this work the removal of aluminium frame, junction box, copper cables, screws, etc. will be achieved using tools (Bosch GSR 180-LI screwdriver, various screwdrivers, cutter, multi-purpose knife).

The EoL panels were placed in the furnace for thermal treatment at 170°C. The back sheet and EVA was easily removed after 10 minutes of heat treatment at 170°C.

In order to remove the anti-reflective layer and the metallization, several experiments were realized using KOH solution.

4. Results and Discussions

4.1. Photovoltaic panel dismantling

First, the junction boxes were manually dismantled. Then, the aluminium frame was manually removed The Figure.3 highlights of different components of PV panels after dismantling.

After that, the back sheet was easily removed after 10 minutes of heat treatment at 170°C as it's shown in figure 4.

The, the panel was cut (disc chainsaw 900 W) into pieces with an approximate size of 10 x 9,5 cm^2, which underwent the separation of glass (figure.5).

To separate glass and EVA from the front; we used a hot plate at T = 250°C, 0,5 h, followed by manual extraction of the components. Finally, the tined copper tape was manually recovered then the silicon cells were recovered. The figure.6 represents the recovered material from end of life (eol) photovoltaic panel.

According to our study, more than **99 %** of the end of life photovoltaic panel was recovered and can be recycle and reused on several applications. The table.1 shows the value of the recovered materials from end of life panel.

4.2. Silicon cell characterization

4.2.1 SEM analysis

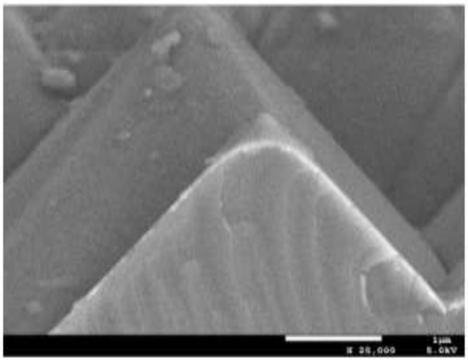
The SEM micrographs presented in the figure .7 a show the very thin layer deposited on the texturized silicon that represents the anti-reflective layer approximatively 60 nanometer width. On the figure.6 b we can observe grains with irregular morphology represents the silver metallization layer. EDS analysis presented in figure .8 show that titanium dioxide presents the anti-reflective layer and silver the metallic contact.

4.2.2. Optical micrographs

The figure.9 shows the optical micrographs of the recycled silicon from the front to the back of the cell.The blue color represents the anti-reflective layer that's covert the front of the silicon cell. The silver metallization is represented on grey.

4.2.3. XPS analysis

XPS measurements were used to describe the surface characteristics of the silicon cell. The XPS survey from the front of cell is presented in the figure .10 a, the titanium comes from the anti-reflective layer titanium dioxide TiO_2 (figure .10b) and silver Ag (figure .10c) and Lead from the silver metallization paste.Three peaks at the binding energy of 462.5 eV,458.2 eV and 454.3 eV appear in the spectrum presented on figure. 10b .The Ti 2p3/2 metal peak set at 454.3 eV, the 2p3/2 peak set at 458.6 Ev defined Ti (IV) (TiO_2) The peak at the binding energy of 462.5 eV corresponding to the characteristic peaks of Ti 2p1/2 in TiO_2 [20]**.**The XPS survey from the back of the cell is presented in figure .11 a and we can confirm from the figure 11.b that the metallic contact is silver from the front cell



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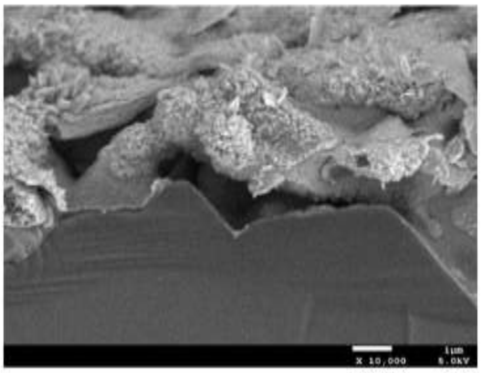


b

Figure .7 *SEM micrograph A-Silver fingers (cross section) B -The anti-reflective layer (cross section).*

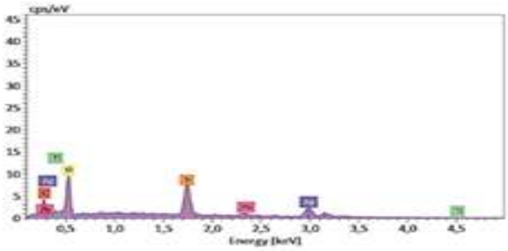


Figure.8 *EDS analysis*

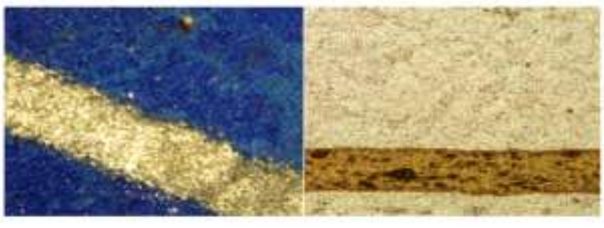


Figure.9 *Silicon micrograph before treatment (right panel/back, left panel back)*

Table 1. *Materials extraction using specific mineral processing techniques*

Parameters	Value(kg)	Value %
Initial weight	6,555	100
Weight of pv panel (withoutAl,screws,junctionbox)	5,110	77.95
Total (pv dismantled)	4,900	74,75
Weight of aluminum frame	1,263	19,26
Weight of junction box	0.164	2,50
Weight of the screws	0.018	0,274
Weight of rubber	0,210	3,20
Weight glass	4,286	65,38
Si+EVA	0,614	9,366

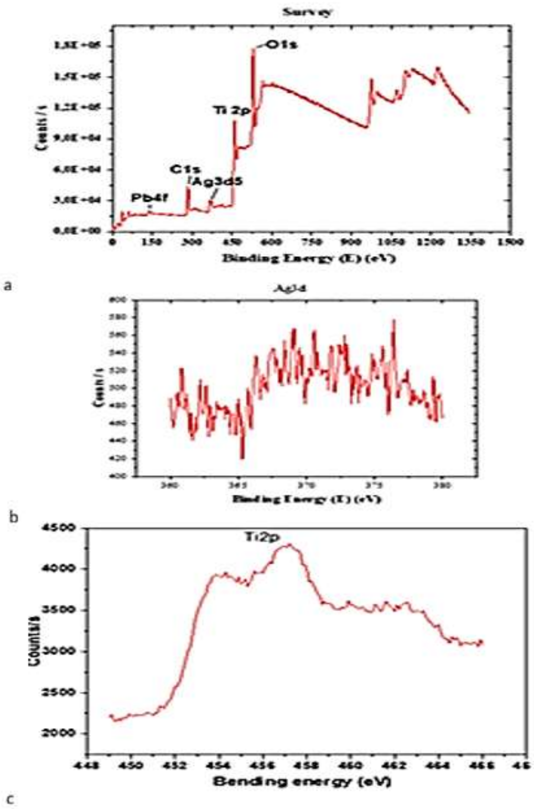
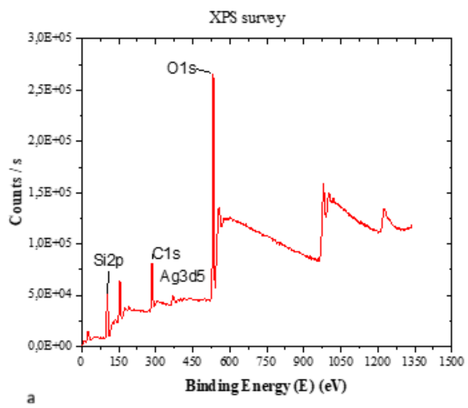


Figure.10 *a- The XPS survey from the front of the cell.b- Silver from the front of the cell c-Titanium from the front of the cell*



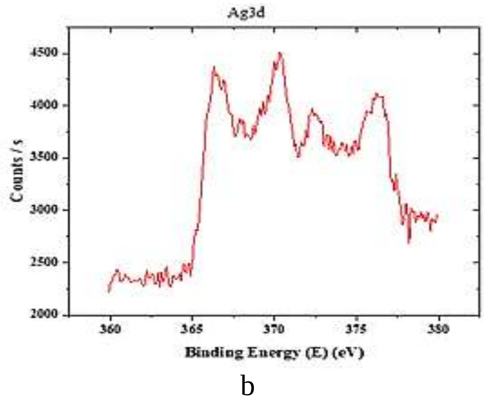


Figure.11 *a-The XPS survey from the back of the cell* b-XPS spectra of silver

Figure.12 *The anti-reflective layer removal*

Figure.13 *Silver recovery*

4.3. Experimental procedure for silicon purification

In order to remove the anti-reflective layer TiO_2 and silver, several experiments were realized using KOH 45% at 80 °C for 10 minutes.
The anti-reflective layer was successfully removal as it is shown in figure. 12.using the same solution, the silver was successfully recovered as shown in figure .13.

5. Conclusion

This study highlights the importance of recycling end of life photovoltaic panels to solve the environmental problems associated with their end-development and reducing greenhouse gas emissions. The results obtained from the recycling of an Arco photovoltaic panel show that it is possible to recover up to 99% of materials such as silicon, glass, EVA encapsulant, Tedlar, silver, copper, aluminium frame and junction box, using various mechanical, thermal and chemical treatments. The total recovery of purified silicon that we have been able to achieve is the most interesting challenge that we have been able to meet, so glass, aluminium, conductive metals and plastic are fully recyclable.

Author Statements:

- **Ethical approval:** The conducted research is not related to either human or animal use.
- **Conflict of interest:** The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper
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- **Data availability statement:** The data that support the findings of this study are available on request from the corresponding author. The data are not publicly available due to privacy or ethical restrictions.

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