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Recycling of photovoltaic panels by physical operations

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ABSTRACT

Recycling of polycrystalline silicon, amorphous silicon and CdTe photovoltaic panels was investigated by studying two alternative routes made up of physical operations: two blade rotors crushing followed by thermal treatment and two blade rotors crushing followed by hammer crushing. Size distribution, X-ray diffraction and X-ray fluorescence analysis of obtained products were carried out in order to evaluate their properties as valuable products. Results showed that for all kinds of investigated photovoltaic modules the two blade rotors crushing followed by hammer crushing and eventually by a thermal treatment of $d > 1$ mm fractions, was the best option aiming to a direct recovery of glass.

1. Introduction

Photovoltaic power generation system is a promising and well-established solution for renewable energy utilization. Nevertheless, as for all human activities, in few years a waste problem related to the large use of solar cell modules is expected [1]. In fact the average lifetime of crystalline silicon photovoltaic module is estimated in 25–30 years because of the deterioration of encapsulant materials and wires.

Currently the dominant photovoltaic (PV) technology uses crystalline silicon (monocrystalline and polycrystalline) as semiconductor, but the thin film photovoltaic modules using cadmium telluride (CdTe), amorphous silicon, Copper–Indium–Gallium–Selenide (CIGS) and Copper–Indium–Selenide (CIS) are recently getting much more importance because of their lower production costs and higher efficiency [2,3].

The necessity of mass recovery from these devices has been shown by different researchers [4–6] and recently even the European Union issued the Guideline 2012/19/EU (replacing the previous 2002/96/EC) in order to fix rules about end of life photovoltaic panels [7]. According to this guideline end of life photovoltaic panels must be considered as electric and electronic equipment waste (WEEE) and specific goals of collecting, recovering and recycling must be achieved within the next years. In particular:

- Minimum collecting rate as average weight of photovoltaic panels is 45% of total devices by 2016 and 65% later.
- Minimum targets as recovery and recycling are respectively 75% of and 65% as average weight by 2015.

Up to now several authors carried out research related to PV panels recycling. Fernandez et al. [8] examined the possibility of silicon solar cells recycling by insulating them into cement-based systems. Chemical studies about silicon recovery from PV panels were also carried out by using acid/alkaline agents as well as organic solvents for EVA degradation and/or dissolution [1,9,10]. Some authors focused on thin film PV panels. In particular Sasala and co-authors [11] studied the recycling of CdTe modules by both physical and chemical operations. They proposed a pretreatment by water blasting and chemical operations such as leaching, precipitation and electroplating of semiconductors materials.

Berger et al. [12] also studied the recycling of thin film PV panels (CdTe and CIS) by using wet mechanical processes like attrition and flotation as well as dry mechanical methods like vacuum blasting.

In spite of the recent efforts only two full scale processes were developed. In particular the company Deutsche Solar (Solar World) carried out the treatment of crystalline silicon modules [13], whilst First Solar have been recycling CdTe thin film panels by mechanical and chemical operations [14]. However, nowadays, neither technologies were designed for treating together more kinds of photovoltaic panels nor completely automated processes have been developed yet.

This work aimed to provide a further contribution about recycling of PV modules. In particular, in order to achieve the minimum targets of recovery and recycling fixed by the latest European Guideline 2012/19/EU, a recycling process was developed and tested to treat silicon-based (crystalline and amorphous

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Si panels) and CdTe panels, both separately and together. Moreover this goal was accomplished by developing a process easily performable by using simple and conventional technology like those used for the recycling of other electronic wastes such as batteries [15]. This feature would give high flexibility to the recycling plant and then the capability of treating different kinds of electronic wastes.

In the present work two options of recycling processes by physical operations were examined and quantitative/qualitative results in terms of mass recovery and quality of products have been provided.

Novelty aspects are the development of a process of physical pretreatment for the simultaneous recycling of different kinds of PV panels, and its assessment in pilot scale tests.

2. Materials and methods

The input material used in this work was taken from three different kinds of PV devices: a polycrystalline silicon PV module (BYD—230P6-30), an amorphous silicon PV module (Sharp NA-901 WQ) and a CdTe PV module (First Solar FS2). The silicon devices were previously manually disassembled in order to separate the modules from external frames and then, in each test, around 2 kg of photovoltaic modules were used as input materials.

Crushing operations were carried out in a two blade rotors crusher (DR120/360, Slovakia) without any controlling sieve and in a hammer crusher (SK 600, Slovakia) using a 5 mm sieve. Thermal treatment was performed at 650 °C for 1 h in a silite resistance furnace aiming to a complete degradation of cross-linked EVA.

After each operation of size reduction and thermal treatment, a sieving analysis was carried out to evaluate size and products distribution as well as mass fluxes in the process. For this purpose all samples were sieved by using 5 different sieves (8 mm, 5 mm, 1 mm, 0.4 mm, 0.08 mm) and an automatic shaker, then they were weighed. After hammer crushing, sieving was also used as process operation since only fractions $d > 1$ mm were put together and used as feeding for the following thermal treatment.

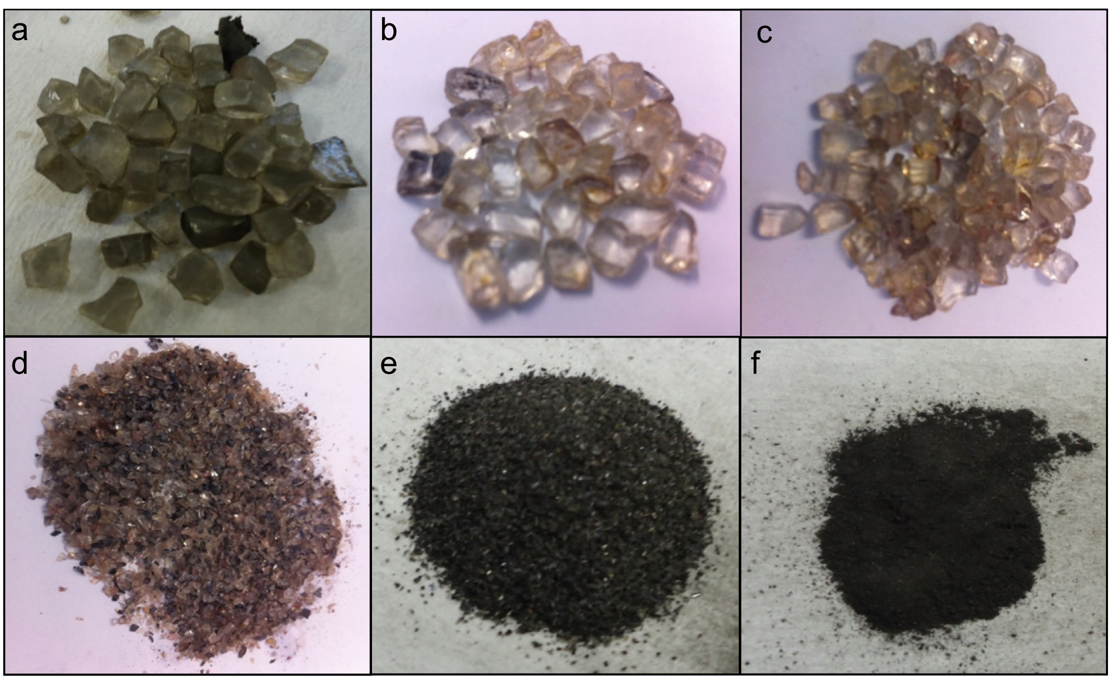

Fig. 1. Fractions obtained after crushing and thermal treatment of a polycrystalline silicon module (a) $d > 8$ mm; (b) $5 < d < 8$ mm; (c) $1 < d < 5$ mm; (d) $0.4 < d < 1$ mm; (e) $0.08 < d < 0.4$ mm; $d < 0.08$ mm).

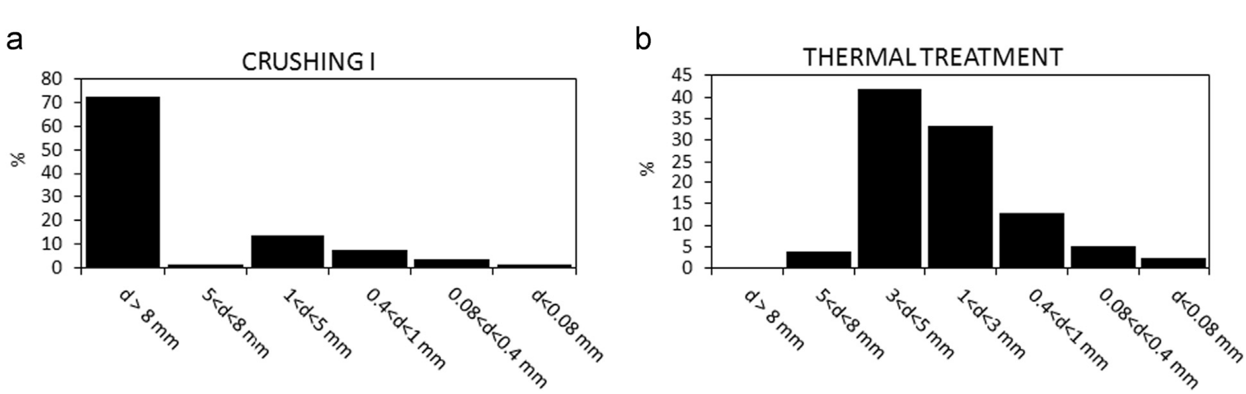

Fig. 2. Total size distribution after treatment of polycrystalline silicon module by crushing (a) and thermal treatment (b).