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EXPERIMENTAL STUDY OF A LOCAL FURNACE FOR MELTING ALUMINUM FROM USED SOLAR MODULES IN BURKINA FASO

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ABSTRACT
The manufacture of photovoltaic (PV) panels is evolving increasingly around the world. Used panels are a source of environmental pollution because recycling them is difficult. In this experimental study, we propose a solution for recycling aluminum from PV solar modules using a local furnace for melting. First, the frame is separated from the other components of the module manually. Then experimental data is obtained using a data logger by replicating an artisanal recycling route. This process of recycling the 1323g aluminum frame of the used solar module made it possible to make two plates, each weighing 392g. The impurities contained in the aluminum were of the order of 494g or 37.34% of the weight of the aluminum. We deduce that the amount of aluminum used to make the plates is 784g and the rest of the pure aluminum is 45g. The quantity of coal used is 3953g, i.e. 2630g more than the mass of aluminum to be melted. Based on the experimental results, the transfer of heat from the external environment to the internal environment generates too many losses. Indeed, the heat energy produced is not completely consumed and the temperature losses are significant. To overcome this problem we must make the different modes of heat transfer effective by playing on the thermal insulation of the oven. Also this local system requires the construction of an improved stove that will save fuel used for the operation, and channel the amount of heat lost by radiation. For the production of air it is preferable to make the operation of the solar system efficient by making a dimensioning allowing to choose in a suitable way the various components such as the solar modules, the batteries, the regulator and the protection devices. We can agree that aluminum recycling is a profitable business in Burkina Faso. Finally, this artisanal recycling channel proposed is capable of fully recycling a large quantity of aluminum from several used solar modules.

KEYWORDS: Experimental study, recycling, aluminum, solar modules, local oven.

1. INTRODUCTION
In 2011, the exceptional level among all renewable technologies reached nearly 70% [1]. In fact, although the production and installation of photovoltaic modules are increasing, the amount of end-of-life photovoltaic modules is relatively high.
In view of the reforms undertaken in the sector in Burkina Faso, the use of photovoltaic solar equipment has taken on a significant proportion. Thus, from 2010 to 2018, 83,340 tons of photovoltaic panels were imported, compared to 26,698 tons of imported batteries (according to a study carried out by ANEREE in 2019) [2]. In addition, the limited lifespan of equipment, the use of unsuitable means of transport and the flooding of the Burkinabe market with equipment of dubious quality will contribute to an increased production of waste. The challenge for reusing used modules is finding a large and sustained market for hundreds of peak gigawatts of decommissioned modules per year, and the big challenge for component mining is the sheer number of structures involved in the process of processing of materials from worn panels [3].
In order to avoid being overwhelmed by this waste and to find a solution that will be applicable in our country, it is important to anticipate the issue. During the extraction of these metals, negative environmental impacts are

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caused, including the emission of carbon dioxide and dangerous gases, the generation of considerable amounts of solid waste and the destruction of the landscape [4]. In addition, in terms of energy consumption [5], depending on the types of metals and forms of scrap, recycling can save up to a factor of 10 or 20. Therefore, great attention has been paid the reuse of scrap metal [9].

So far, two major processes have been proposed for recycling non-ferrous metal scrap, namely the conventional remelting method [6] and the new solid-state or non-melting recycling process. With regard to remelt recycling, there are several outstanding problems listed as follows namely relatively higher metal loss attributed to higher chemical reactivity and larger specific surface area of metal chips, toxic gases generated by combustion of oil emulsion adhering to scrap metal chips and relatively higher energy consumption and recycling costs. The aluminum can always be melted down again and reprocessed. Recycling aluminum does not cause any loss of quality. Profile waste is used to produce new quality profiles, but also other high-quality products. Aluminum sheets and sheets are used to manufacture new rolling products. The quantity of aluminum currently in use is constantly increasing. Once produced, aluminum remains a permanent metal forever. Secondary aluminum production has been used in a number of fields, such as transportation, construction and packaging. Its production is increasing very rapidly in recent years and it will continue to grow steadily in the future. Recycling is an essential part of the aluminum industry due to its favorable economic impact on production and its contribution to the environment. Compared to the processing of primary aluminium, recycling aluminum is very advantageous, saving around 95% of the energy consumption necessary for the production of primary aluminium. Secondary aluminum production also results in less gaseous emissions, water consumption and solid residues [7].

In a secondary aluminum processing process, the rotary kiln operates simultaneously as a smelter and a phase separator. It is capable of treating highly contaminated waste. In view of the above, it is more than necessary to have an effective recycling procedure that takes into account environmental and health impacts. The establishment of a local aluminum recycling structure will help combat unemployment and generate revenue for the state. Our work will firstly consist of describing the materials and the operating methods, secondly we will present the aluminum melting procedure and thirdly we will analyze the results obtained.

2. MATERIALS AND EXPERIMENTAL PROTOCOL

2.1. Materials

The company in which we carried out the experimentation of the project is a traditional forge for the manufacture of aluminum-based kitchen utensils. The company uses a traditional oven fueled by charcoal. The oven is equipped with a ventilation system to fan the flame and a 5 mm thick iron pot. The cooking pot comes from an empty 12 kg gas bottle cut up. Figure 1 shows the photo of the 12kg gas cylinder before cutting and Figure 2 shows the photo of the cooking pot.

Figure 1. Gas cylinder before cutting

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Figure 2. Picture of the cooking pot

The aeration system consists of a DC machine powered by a 12V battery. Air from the fan is channeled through a vent duct and directed to the combustion chamber. The figures 2 and 3 show images of the component parts of the aeration system.

Figure 3. Ventilation system

Figure 4. Engine power battery

Samples of the used solar module were taken from the COGEA INTERNATIONAL SA company store, and then sent to the technical department for analysis of the electrical characteristics.
We routed the module through the traditional landfill to extract the aluminum frame. This step involves manually removing the junction box and aluminum frame using tools such as screwdrivers and pliers. The work of disengaging the module and removing the junction box lasted 1 h and 13 min (± 12.5 min) per module [8]. The reclaimed aluminum frame has a rectangular shape with dimensions of 1.64 m in length and 0.99 m in width. It is cut into pieces and its final mass is 1313g. Figure 5 shows the photo of the aluminum frame.

Figure 5. Aluminum module frame

2.2. Experimental protocol

The initial mass of aluminum to be melted and that of coal weighing respectively 1323g and 3953g were measured by an electronic balance SF-550 compact scale. The melting process begins at 4:58 p.m. and ends at 5:18 p.m.,

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i.e. a duration of 20 minutes. The measurements of the ambient air, ember and aluminum temperatures are carried out by the temperature recorder (midi logger GL220) using type H, K and J thermocouples, and the cable which allowed the data logger power supply has a section of 2x2.5mm2. A 4G USB key was used to store the data recorded on the data logger. We used a micrometer, a meter, for the measurements of the thickness, the diameter and the length of the pot. The electrical characteristics of the current source comprising the 250 Wc solar modules, the 12V/150Ah battery and the 80W direct current motor were checked by an ammeter clamp and a multimeter. We used a sand mold and white clay for casting. This experiment was conducted at ambient air temperatures between 38 to 42.9 °C and that of the embers between 816 to 1377°C.

3. EXPERIMENTAL RESULTS

3.1. Evolution of temperatures in the device

Figure 6 shows the temperature variation inside and outside the oven over time.

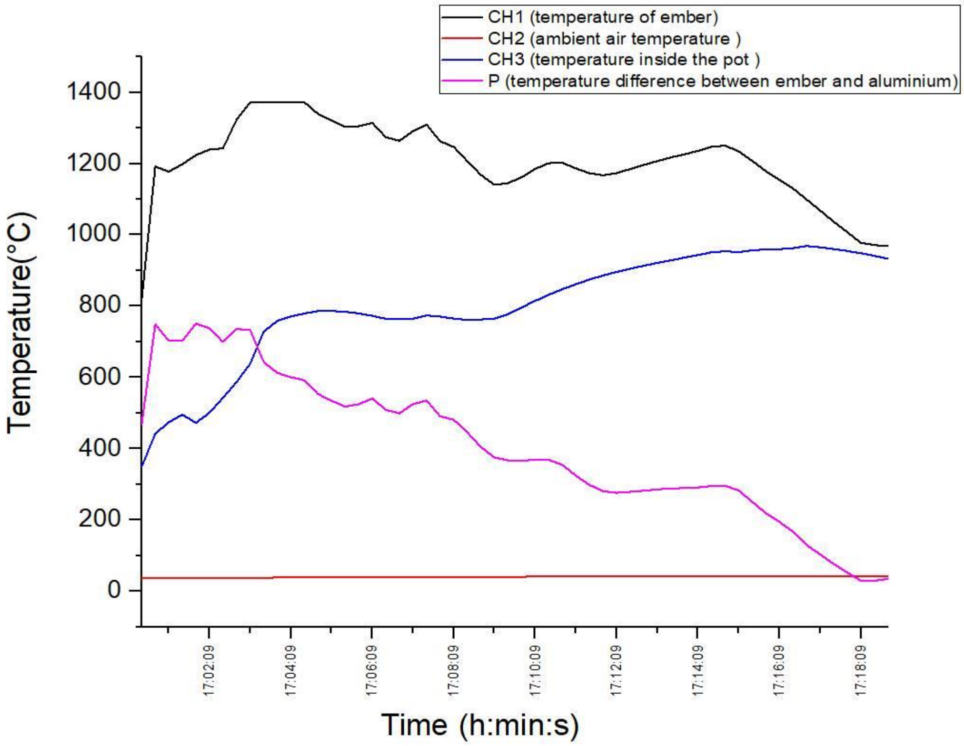

Figure 6. Variation of experimental temperatures over time

The various temperatures of the embers are higher than that of the aluminum and the ambient air. We observe that the temperatures of the embers increase as the air sent by the blower increases to reach the maximum value of 1372°C between 17h:03min:09sec and 17h:04min:29sec. We find that the temperature produced by the charcoal was not totally consumed by the aluminum over time. We record a maximum temperature loss of 749.8°C by taking the difference in temperature produced by the embers and that consumed by the aluminum at 17h: 00min: 49sec. The intersection of the temperature loss curves and that of aluminum was observed at 17h: 03min 29sec and from this point the temperature loss curve continues to decrease to 35°C at 17h: 18min: 49sec. Aluminum temperatures continue to rise to 969°C at 5:16:49.

After analyzing the experimental results, we find that the transfer of heat from the external environment to the internal environment generates too many losses. Indeed, the heat energy produced has not been completely consumed and the temperature losses are significant. To overcome this problem we must make the different modes of heat transfer effective by adjusting the thermal insulation of the oven.

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3.2. Analysis of the aluminum smelting process

This experiment involved melting aluminum from the frame of the used solar module.

- **Melting of aluminum**

The melting of the aluminum lasted 20 minutes. Five minutes after the start of the experiment we found that the aluminum had changed from a solid state to a liquid state. This explains the beginning of aluminum smelting. We also observe the temperature variation inside the pot via a temperature recorder (data logger). Figure 7 shows the change of state of aluminum.

Figure7. Melting of aluminium: transition of aluminum from solid to liquid state

- **Extraction of impurities**

The impurities contained in the aluminum were removed at the 15th minute. When the temperature of the furnace reached 1226°C, which of the aluminum was 936°C. Figure 8 shows the image of the impurities extracted from the aluminum.

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Figure 8. Removing impurities from aluminum

- **Preparing the mold**

While the aluminum was melting we made a mold out of sand. A template in the form of a plate is used to give the final structure of the sand in which the molten aluminum will be poured. Figure 9 shows the mold ready to receive the molten aluminum.

Figure 9. Mold to receive the molten aluminum

- **Casting steps**

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Once the step of extracting the impurities from the molten aluminum and that of making the mold are finished, we proceed with the casting. The molten aluminum was poured into the mold. Figure 10 depicts the casting process.

Figure 10. Aluminum casting process

3.3. Discussion

The process of recycling the 1323g aluminum frame of the used solar module made it possible to make two plates, each weighing 392g. The impurities contained in the aluminum were of the order of 494g. We deduce that the amount of aluminum used for the manufacture of the plates is 784g and the rest of the pure aluminum is 45g. The quantity of coal used is 3953g, i.e. 2630g more than the mass of aluminum to be melted. We find that the amount of coal used for the operation is very high compared to that of aluminum. In addition, the temperature produced by the charcoal has not been completely consumed over time. We record a maximum temperature loss of 749.8 degrees Celsius. This situation leads us to say that the heat transfer from the source to the aluminum is not efficient. Therefore, it is necessary to improve the heat transfer system in order to reduce the observed temperature losses. We suggest finding a suitable lid for the pot to reduce heat loss by convection with the ambient air. Also we suggest the construction of an improved stove that will save fuel used for the operation and channel the amount of heat lost by radiation. For the production of air it is preferable to make the operation of the solar system efficient by making a dimensioning which allows choosing in a suitable way the different components such as the solar modules, the batteries, the regulator and the protection devices. The implementation of an automatic system for displaying the melting temperature of aluminum as a function of time will make the system even more efficient. According to BGB-Meridian data using Burkinabe Custom's data, June 2019, the amount of solar panel waste will peak in 2042 with a value of 26,131 tons. This allowed us to estimate the quantity of aluminum waste at 1791.01874 tons in 2042. The traditional design of smelting furnaces has been based on semi-empirical methods due to the complexity of the phenomena involved, which limited the use of computational techniques based on physical principles. However, the inherent difficulty and shortcomings of experimental measurements make numerical simulations an attractive alternative for aided design, operation and scale-up. Moreover, they can help in the development of physical models or serve as a pre-evaluator of unconventional furnace technologies and multi-unit systems [9]. Other researchers have reported the efficient recovery of high purity aluminum from aluminum/plastic laminates (face masks) using thermo-delamination [10]. Both approaches could potentially be adopted to recover Al from PolyAl residues, but a systematic approach of the interactions between the components during pyrolysis would be necessary before commercialization, not only for the recovery of aluminum but also for an efficient energy production [11]. The result of the other researchers showed that energy losses through

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combustion gases are the main source of energy loss in the aluminum casting system with a value of 54.2%. In a similar work, Hasanuzzaman et al. [12] carried out an energy and economic analysis of an annealing furnace and concluded that the overall efficiency of the furnace is 16.7%. To appreciate the need for the treatment of aluminum scrap, researchers approved that recycling aluminum is a major profitable business in Nigeria and around the world. It involves melting offcuts to form billets, ingots and products of various stages. When choosing a furnace, factors such as the volume of aluminum to be produced and the type of alloy are considered [13].

Figure 11 shows aluminum trays obtained at the end of recycling.

Figure 11. Aluminum trays obtained

4. CONCLUSION

This artisanal recycling process of the 1323g aluminum frame of the used solar module made it possible to make two plates each weighing 392g. We were able to experiment with a local oven using a device comprising a data logger and an air production system. The temperature produced by the charcoal has not been completely consumed over time. We record a maximum temperature loss of 749.8°C. This fact leads us to say that the heat transfer from the source to the aluminum is not efficient. The implementation of an automatic system for displaying the melting temperature of aluminum as a function of time will make the system even more efficient. We believe that it is necessary to analyze the evolution of the temperature of aluminum as a function of time and the distribution of heat at the surface of the pot in order to understand the influential parameters during the melting process of the aluminum. Modeling and simulation of the artisanal oven is necessary if we want to optimize its performance.

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