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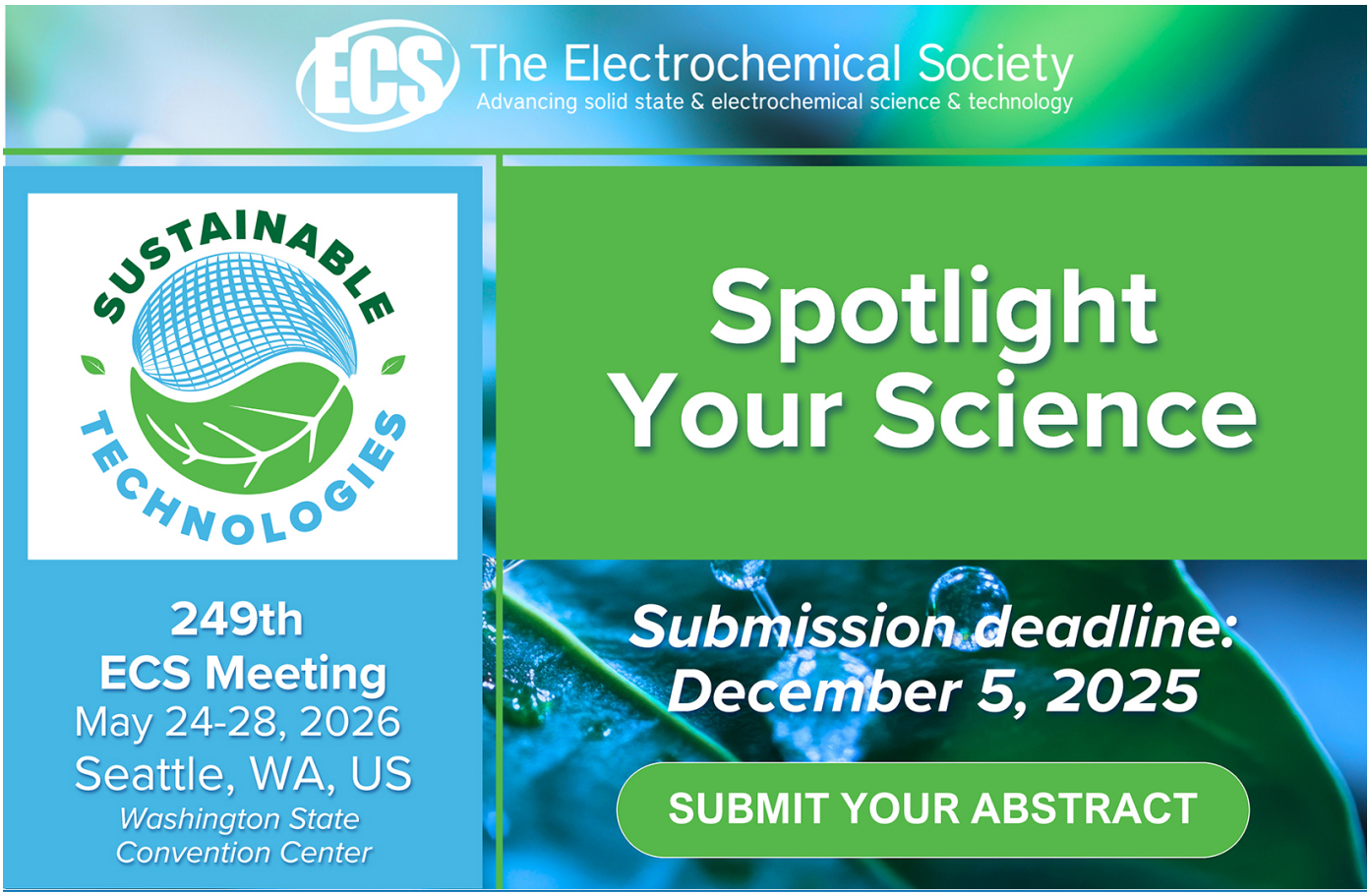
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To cite this article: N Y Perez-Rangel *et al* 2020 *J. Phys.: Conf. Ser.* **1587** 012027

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Exploitation of chips and scrap aluminum through physical processes for the development of aluminum sheets and bars

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Abstract. Colombia manufactures metals such as iron and aluminum, which consume a lot of energy to carry out these processes. There are many techniques to recycle metals and other elements to reduce the amount of energy in manufacturing processes, since smelting is generated with already manufactured materials, as in the case of aluminum, which uses recycled products such as soft drinks and beer cans. In addition, there is another type of scrap metal, such as aluminum shavings generated by machining processes, with an amount that varies from a small percentage to 70-90% of the original part. This project seeks to transform the aluminum shavings through physical processes with the application of temperature in aluminum material to be used again. The process begins with the collection of chips from mechanical workshops, in this case, from the machine tool laboratories of the "Universidad Francisco de Paula Santander, Ocaña, Colombia". Standard procedures will be carried out before the casting process by developing firing curves and phase diagrams of aluminum, where the research focuses on generating aluminum metal to be used again in the laboratories of the same university.

1. Introduction

When manufacturing mechanical parts, it is necessary to use a manufacturing method, including machining operations. These are traditional machining processes that involve the use of a cutting tool. As a result, there will be a detachment of material that is lost as chips or production scrap [1]. Recovering these wastes today is an issue that is gaining importance, mainly when it comes to aluminum, which is a material widely used in the construction and transportation sectors due to its good strength-to-weight ratio and its excellent mechanical properties [2,3]. Unfortunately, waste produced from machining parts, including large and small chips, is difficult to reuse. For the processing of these chips, it is necessary to take into account some critical characteristics such as: irregular geometry, presence of pollutants, environmental exposure, high surface/volume ratio and, above all, the formation of an alumina layer on the surface of each particle resulting from the oxidation of the material at the moment of being removed as chips. These scrap metals are sold to scrap buyers and recycling companies at a relatively low price, which is 30% of the commercial aluminum price [4].

Aluminum processing can be done by conventional or unconventional methods. The most used method is the conventional one since it is the simplest method, but it has its limitations, such as the presence of oxygen due to the casting is carried out in the presence of air. This causes the oxygen to

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react with the material to be melted, producing in the aluminum a layer of aluminum oxide or alumina, which mixes with the initial layer that covers the chip particles producing a "cream" on the aluminum casting, hindering the casting process. This layer contains approximately 90% metallic material that could be recovered in a later process to make the most of the amount of reusable aluminum. To improve aluminum casting conditions there should on average be a chip density of approximately 1 Kg/dm3. The ease of the conventional aluminum method is also restricted by high energy consumption and high operating costs, which makes the implementation of new techniques a conditioner to achieve the same results by recycling aluminum at low production and operating costs [5,6]. There is an estimated 20% loss of material during the casting process, without taking into account the losses that occur in processes such as cutting, extrusion or machining of subsequent parts [7].

In recent years, the recycling of aluminum and its transformation for subsequent uses has been widely studied by different authors, showing that, in many of the recorded cases, the total recovery rate of aluminum is only 60% [8,9]. Recent literature reports have revealed some possible variants of the aluminum recycling process compared to the conventional method, without going through the recast phase, where aluminum alloys are subjected to significant plastic deformations at temperatures below solid. In 1945, Stern [10] proposed and patented hot extrusion as a way to recycle scrap without melting the material.

In 1993, The Welding Institute (TWI) patented a new recycling process to apply to metal chips, called friction stir extrusion (FSE). This technique belongs to the same family as the stir welding friction technique (FSW) and follows the same principles. It uses the heat generated by friction, between a rotating head and the chips to be recycled, contained within a cylindrical container where the head is inserted. The plastic deformation generated by heat in relation to the friction of the rotation and progress of the head involves mixing, compacting, and extruding the chips. In this way, the FSE process makes possible to transform aluminum chips into an extruded product, with great savings in terms of energy, work, and economy compared to the conventional method of recycling by direct extrusion [11].

At the national level, in Bogotá, the capital of Colombia, different studies were carried out in conjunction with "Universidad de Los Andes, Bogotá" District Mayor's Office (2005), "Unidad Administrativa Especial de Servicios Públicos (UAESP)", and "Compromiso Empresarial para el Reciclaje (CEMPRE)", finding that 6500 tons of waste are generated daily in the domestic and industrial sectors.

According to the UAESP, in 2011, of the 2350 tons/day of residential waste generated, 0.85% was scrap metal and 0.14% aluminum. In the case of commercial establishments, waste production was 77 tons/day, of which 1.57% was metals and 0.27% aluminum. This figure is lower than that of households but higher than that reported by small producers, who generated 560 kg/day of waste, of which 0.87% were metals and 0.18% aluminum. This means that of the 2.350 tons, approximately 3.29 tons of aluminum were buried underground [12].

A similar case has happened in the machine tool laboratories of higher education institutions. The collection of scrap metal is generally done indiscriminately since the different metals used in the learning process are not properly separated. Therefore, this scrap simply becomes ordinary waste, and finally becomes part of a sanitary landfill, without taking advantage of all the benefits it can provide. These benefits include the reuse of such scrap for casting and manufacturing the original material without depleting natural resources. By reusing the scrap in casting and manufacturing, the metal is obtained with the same properties since the process that is performed only changes the shape [13].

According to information found in literature reviews on the different techniques for melting aluminum chips, an exact procedure for melting aluminum chips is not shown. Various techniques such as powder metallurgy, hot extrusion, casting and agglomeration by electromagnetic induction furnace are analyzed in a general way. For this reason, the decision to develop techniques in an experimental way to guide us towards the development of the same is made. Resorting to the study of physical processes that allow the development of techniques to carry out a good recycling process and use of metal materials that have not been reused so far. With the proposal of improving an appropriate technique for the melting of aluminum chips, different experiments were carried out, changing and

controlling parameters that would show the way to the appropriate technique. Among the parameters we have the temperature, chip type, chip compression before and/or after melting, type of furnace, decontamination of the raw material, and the type of mold to use.

2. Materials and methods

The material to be used will be aluminum chips and scrap to be transformed into sheets and bars, recycling, reusing, and contributing to the environmental conservation. According to various tests, it was determined that in order to melt the aluminum chips in a muffle furnace, the aluminum must first be cleaned before it is melted. For this cleaning, a solution of caustic soda in water was used and it was carried out in 2 phases.

In the first phase, the container containing the aluminum chips is washed and electromagnetically stirred. Afterwards, the caustic soda solution that contains dissolved alumina is removed. In the second phase, the container is gauged and stirred, after which the soda solution is removed and washed with water. The pre-treated chips are then compressed in a hydraulic press. From there, it is introduced into a muffle furnace which is programmed with a temperature curve, which rises 10 °C per minute until it reaches 750 °C. This temperature is maintained for a period of at least 3 hours and then the sample is removed from the furnace, which will be compressed again to achieve a compaction of the particles.

Finally, the sample is allowed to cool at ambient temperature and the cast aluminum part is removed. The entire process complies with the sequence described in Figure 1. The process is then completed by analyzing its mechanical and microstructural properties using optical metallography, and hardness and compression tests.

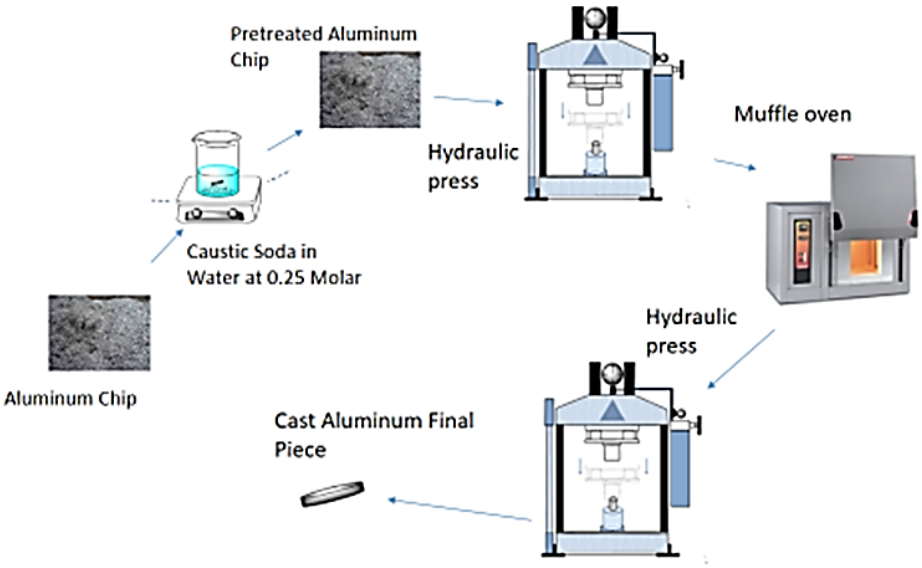


Figure 1. Flowchart of the aluminum chip casting process.

The casting process is performed taking into account the phase diagram of the aluminum as seen in Figure 2, which shows the physical state changes that occur in the aluminum as a heat source is applied and rises the temperature in the material, this physical process is important when it is going to melt aluminum shavings, since it is the one that allows the union between all the aluminum particles when it is in its liquid state, which is then poured into a mold and later it will be pressed using hydraulic pressure that generates forces on the material that will already be in its change from liquid to solid state due to thermal equilibrium due to sudden cooling to the environment, which makes the metal structure organize and obtain physical properties and mechanical characteristics of the material.

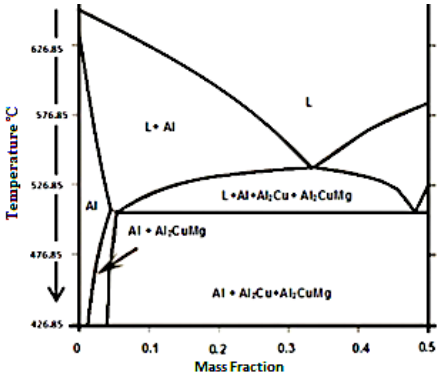


Figure 2. Phase diagram of aluminum alloy. Adapted from [14].

3. Results

Figure 3 shows the product obtained by melting aluminum chips in the laboratory, following the scheme of Figure 1 and taking into account the diagram of Figure 2 mentioned above. After the process of changes in the physical state of the aluminum is carried out, which consists of bringing its liquid state to around 700 °C for the bonding of the chip, and cooling to room temperature causes the material to solidify and generate a compact piece, it is here where hydraulic force is applied which is governed by means of Equation (1), allowing the generation of a piece with favorable physical and mechanical properties for reuse in the commercial market.

$$P = \frac{F}{A}. \quad (1)$$

Where P is the pressure, F is the applied force, and A is the area.



Figure 3. Recycled aluminum chip casting.

3.1. Hardness testing

Mitutoyo HR-300 hardness analysis under ASTM E10-18 [14] evaluates the final conditions of the material. The result makes the material suitable or unsuitable for a particular task. Aluminum is ductile and resistant to corrosion and is highly used in the industry. As a result, its hardness has to meet the standardized parameters required to be used for commercial purposes. The hardness of the molten aluminum chips sample was evaluated (see Figure 4) and the results are shown in Table 1 as follows.

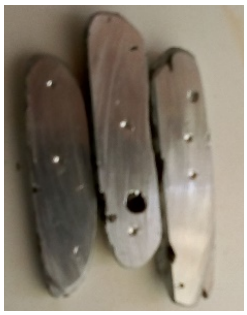


Figure 4. Hardness test specimen.

Table 1. Hardness test results.

	Brinell Hardness (HB)						
	Value 1	Value 2	Value 3	Value 4	Value 5	Value 6	Average
Sample 1	16.20	32.90	41.60	25.10	9.80	28.10	25.62
Sample 2	35.30	36.20	32.20	36.40	35.40	36.80	35.38
Sample 3	49.70	60.90	67.90	55.10	43.70	66.40	57.28
Sample 4	21.50	37.30	29.70	27.20	27.20	26.90	28.30
Sample 5	38.50	47.10	55.50	55.30	45.40	58.60	50.07

In Table 1, comparing the results with the standard values of aluminum hardness commercially found in the market, ranging from 23.27 Brinell hardness (HB) to 65 HB [15,16], it can be said that the sample obtained through the process of melting chips in a muffle furnace approximates to the standard values ranging from 25.62 HB to 57.28 HB, resulting in a solid aluminum bar with a standard hardness, suitable for any use in the market.

3.2. Metallographic analysis

Metallographic analysis with Optika B-157ALC microscope under ASTM E112-13 [17] reveals the microstructure of the material, which makes possible to microscopically detail how it was organized. This test shows whether or not there was cohesion between the particles within the sample and thus be able to determine whether the fusion between the aluminum chips was achieved. For this purpose, the results are compared with a metallographic image of pure commercial aluminum.

Figure 5 shows the metallographic images obtained. Figure 5(a) show the commercial aluminum, Figure 5(b) show the recycled aluminum chips from top of sample, Figure 5(c) show the recycled aluminum chips from the center of the sample and Figure 5(d) show the recycled aluminum chips bottom of sample. After observing and comparing the metallographic images, it can be said that the fusion between the particles of aluminum chips was achieved by more than 90%, which makes evident that the fusion of aluminum chips can be accomplished through the application of this process.

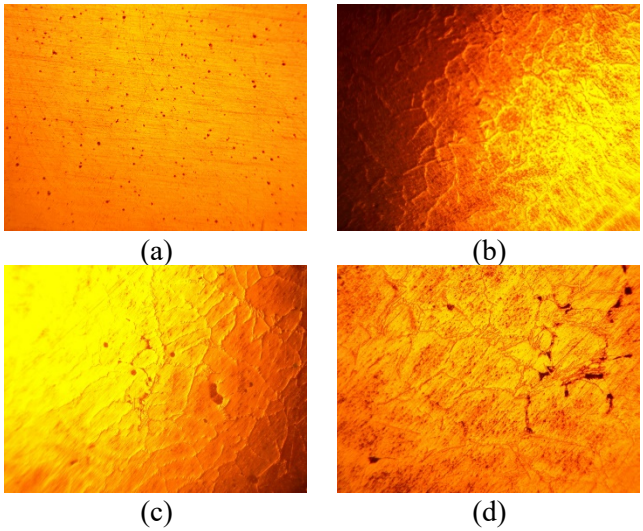
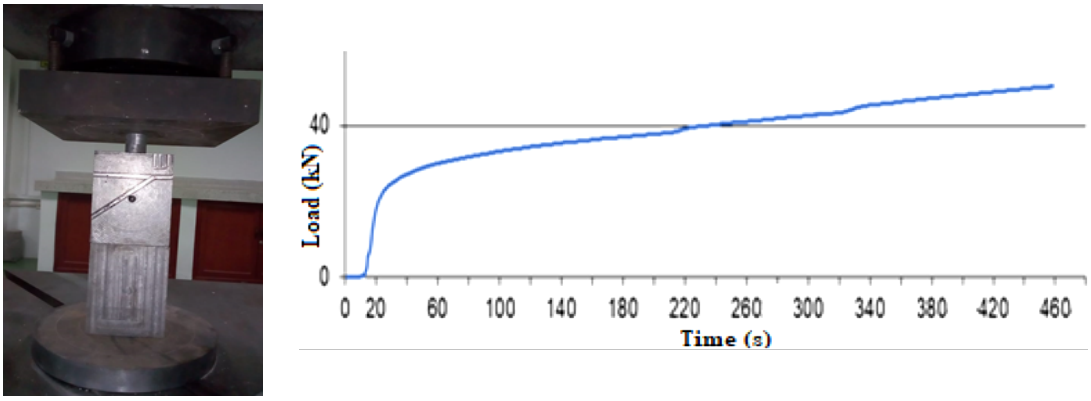


Figure 5. Aluminum metallographic images. (a) Commercial aluminum, (b) recycled aluminum chips from top of sample, (c) recycled aluminum chips from the center of the sample, (d) recycled aluminum chips bottom of sample.

3.3. Compression test analysis

The compression test was carried out on a universal machine “Pinzuar Ltda”. model PU-300M Series 109 under the ASTM E9-09 standard [18], as shown in Figure 6. Figure 6(a) show the aluminum chip specimen in compression test on a universal machine and Figure 6(b) show the compression test results of aluminum chip specimen. The aluminum material withstands a load of 50.4 kN with a strength of

117.78 MPa, showing the ability to withstand high loads and be used in different tasks as a substitute for commercial aluminum.



(a) (b)

Figure 6. (a) Aluminum chip specimen in compression test on a universal machine. (b) Compression test results of aluminum chip specimen.

4. Conclusions

The material was made from recycled chips using scrap produced by the machine tool laboratories, supporting the requirements of environmental conservation. The manufactured material was made through the interaction of physical properties such as the change of state by application of heat that produced an increase and decrease in temperature, to which the stages before and after casting were applied, using recycled chips as raw material, gave as a result hardness values ranging from 25.62 HB to 57.28 HB, which make it competent with commercial aluminum where its hardness is between 23.27 HB to 65 HB, which shows that according to its mechanical and physical conditions it can be given the same commercial use as the primary aluminum distributed in the current market.

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