Casting of recycled aluminum, Al + Cu + Mg alloy formation and lamination process of an electric current conductor

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Abstract

This research presents a methodology for the recycling process via casting, in which aluminum cans and primary (commercial) aluminum are transformed into a laminated tape, with the possibility of industrial application. This research was classified as bibliographic, exploratory, and experimental, since it used qualitative techniques to evaluate alternative materials. Its objective was to incorporate materials of different properties that could favor the making of a tape to be laminated. In the first casting, a recycled aluminum ingot was formed only with aluminum from beverage cans and had a material yield of 51%. In a second casting, commercial aluminum was added to the recycled aluminum ingot. After the casting process with the two cast materials, the ingot had a yield of 90%. A third casting was conducted together with the aluminum that was already formed by the ingot (50% recycled and 50% commercial). The purpose of this ingot was to incorporate other materials that could provide some characteristics, such as malleability and conductivity. The third casting was made from the second ingot, and incorporated copper and magnesium. For the design of the laminated tape, a cast was made to receive the molten aluminum from the third casting. The aluminum was cast into this mold and three tapes were produced, one with a thickness of 2 mm, another with a thickness of 3 mm and the last with a thickness of 4 mm. With these tapes, the objective was to laminate them in order to reduce their thickness to values close to 0.5 mm. The casting process of aluminum cans with the addition of commercial aluminum, plus the incorporation of copper and magnesium, demonstrated facilities for thickness reduction in the process of making laminated tapes.

1. Introduction

Recycling is an economically and environmentally sound process. Its objective is to make use of waste that would be disposed of in landfills or in improper places, thus contaminating the environment (ABDEL-SHAFY; MANSOUR, 2018). With recycling, the volume of these wastes is reduced, as well as the amount of raw material used in certain processes (SHAMSUDIN et al., 2016).

With each ton of recycled aluminum, the extraction of 4 tons of bauxite is avoided. This saves up to 95% in energy production, which corresponds to approximately 700 kg of crude oil (ŠKŮRKOVÁ; INGALDI, 2014). When mentioning the term recycling, aluminum is the first to come to mind because it is a material that can be recycled countless times without losing its characteristics (BDEIR; ALSAFFAR, 2008). Some of the benefits of aluminum recycling go beyond the reduction of energy and the use of raw materials. Aluminum recycling involves social issues, since recycling is a source of income for many families of waste pickers, therefore, keeping people with a low level of education in the labor market. Thus, resources are generated for application in local economies, developing the market at local and national levels (FIGUEIREDO, 2009). According to Ghisellini and Ulgiati (2020), in Italy, recycling has become the preferred practice in most organizations involved throughout the supply chain, from post-consumer waste collection to secondary raw material recovery, recycling and production.

Aluminum recycling in Brazil has been growing in recent years. In 2002, the index was 87%, reaching 96% in 2005. According to the Brazilian Aluminum Association -ABAL (2018), almost all aluminum cans from beverages sold in 2017 returned to the production cycle, reaching an index of 97.3%. Of the 303,900 tons of cans distributed in the Brazilian market in 2017; 295.8 thousand tons were recycled. What separates aluminum from other waste is that it can be recycled without loss of physical / chemical properties. This makes it an excellent choice, especially for carbonated beverage packaging (e.g. soda and beer). The recycling process has one of its biggest advantages in saving energy, since it uses only 5% of the energy needed to produce the primary metal from ore

(DING et al., 2012). There are also relevant environmental advantages for using recycled aluminum such as: reduction of air pollution by 95% and water by 97%, as well as a reduction of greenhouse gas emissions by 95% when compared to primary aluminum production (ŠKŮRKOVÁ; INGALDI, 2014).

According to Grimaud, Perry and Laratte (2018), recycled aluminum shows enormous environmental benefits when compared to primary aluminum. Recycling provides greater care for the environment, which translates into forms of environmental education, which should be encouraged starting from primary education (HUTCHESO et al., 2018). Through environmental education, the recycling of various materials is encouraged, therefore creating environmental awareness in the population to reduce the volume of solid waste destined for landfills (PHAN HOANG; KATO, 2016).

Aluminum has good corrosion resistance, good thermal and electrical conductivity, and is very ductile (HUYNH et al., 2019). All these features make it suitable for the manufacture of very thin laminates, packaging, beverage cans, chemical industry containers, cables and electrical conductors. An electric conductor wire made of aluminum, in the proper proportion of the conductor wire area, can conduct as much electrical current as a copper conductor wire, which is twice as heavy and more expensive. For this reason, aluminum is widely used by the wire and cable industry (ROSA et al., 2016). However, primary aluminum has low resistance to mechanical stress and low levels of hardness. Therefore, for parts that are subject to high stress, aluminum resistance is not adequate (GRIMAUD et al., 2018). There are several ways to improve the properties of a metal. Chemical elements can be added and an alloy can be formed. By mechanical processes, such as rolling or pressing, aluminum can be made, for example, more resistant (ASSOCIATION, 1984). Improved results can also be achieved by the application of heat treatment processes (KUCHARIKOVÁ et al., 2019).

This study conducted research on the recycling of aluminum cans that were collected from the Santa Cruz do Sul Waste Pickers Cooperative - RS – Brazil. These cans were melted and then mixed with primary aluminum as well as magnesium (99. 98%) and copper powder, which were purchased from commercial companies. The objective of this research was to perform the casting of aluminum cans, to form an alloy with the addition of commercial aluminum in the proportion of 50%, and subsequent additions of copper and magnesium, in order to develop a conductive laminated tape.

2. Recycling Aluminum Cans

The Brazilian city of Pindamonhangaba - SP stands out for its Industrial recycling of aluminum. In 2003, it was elected by the Brazilian Aluminum Association the national capital of aluminum recycling. Brazil's two largest aluminum recyclers are located in this city: Alcan (now Novelis) installed in 1970 and Latasa in 1996, which acquired the old Aleris Recycling Plant. Together, they process approximately 70% of all scrap recovered in the country (ABAL, 2017).

Compared to the primary aluminum production process, aluminum recycling has a 95% reduction in electricity consumption (ŠKŮRKOVÁ; INGALDI, 2014). Recycling activities play a role in conserving natural resources and reducing pollution. If waste is pre-treated and properly classified, recycled aluminum can be reused for almost all industrial applications (JERINA et al., 2018). Aluminum alloy recycling has grown in interest and applications in recent years and has become an economical, environmentally friendly and reliable way to produce aluminum parts (MANDATSY MOUNGOMO et al., 2016). In addition, Mansurov et al. (2018) state that the relatively low value of casting technology provides a greater share of the demand for aluminum alloys. This is besides aluminum’s corrosion resistance properties and excellent recyclability.

According to Jerina et al. (2018), the quality of recycled material depends on several factors, including material purity, coating types and size. The control of impurities has a major influence on the mechanical properties of recycled alloys. Similarly, Mansurov et al. (2018) mention that recycling causes individual and combined addition of impurity elements, such as Si, Fe, Cu, Zn, Pb, Sn, Ni and Mn, in the alloy casting properties (DAGWA; ADAMA, 2018). Another relevant factor, especially during the smelting process, is that scrap from urban recycling is generally oxidized. Jerina et al. (2018) state that the oxide content of large pieces of aluminum can reach 2% by weight. During the melting process, Al_2O_3 floats to the surface and forms a second phase known as slag. In the process of melting aluminum scrap, about 10% of the material is lost because aluminum is mixed with slag and 10% of the metal is oxidized (GRONOSTAJSKI et al., 2000).

Iron is the most commonly found impurity element in aluminum recycling because it is very difficult to remove and gradually builds up through repeated recycling (BASAK; HARI BABU, 2016). Together with aluminum and other alloying elements such as manganese, copper, magnesium and silicon, iron produces intermediate phases, which are detrimental to the mechanical properties of the final product during solidification. According to Ashtari et al. (2012), iron is one of the most problematic impurities in aluminum castings. According to Zhang et al. (2012), the addition of a suitable neutralizer such as Mn, Cr, Be, Co, Mo, Ni, V, W, Cu, Sr or other rare earth elements such as Y, Nd, La and Ce could control the deleterious effect of Fe in aluminum alloys (ZÁVODSKÁ et al., 2018).

The process of re-melting discarded cans has a prominence in the aluminum cycle production chain in Brazil (VERRAN et al., 2005). The can is composed of body, seal and lid, each of which is made up of different alloy compositions. The can body is made from ASTM 3004 aluminum alloy, the lid is made from ASTM 5182 alloy and the seal is made from ASTM 5082 aluminum (DAGWA; ADAMA, 2018).

2.1 Aluminum Alloys

The 3xxx series aluminum features corrosion resistance, good conformability and moderate mechanical strength. This alloy presents a higher manganese content, which is added to increase the corrosion resistance and ductility in aluminum (SCHLESINGER, 2013). In turn, 5xxx series alloys have a high magnesium content of up to 5.6%, which provides greater hardness, mechanical strength and corrosion resistance, as well as improved machinability and weld properties (BDEIR; ALSAFFAR, 2008). According to Davis (2001), the chemical compositions of the 3xxx and 5xxx series aluminum are described in Table 1.

The mechanical properties of the alloys used in aluminum cans are presented in Table 2.

The American Society for Testing Materials (ASTM) standard, which is used as a reference for can manufacturing, defines the aluminum can in three different parts: body (alloy 3004); lid (alloy 5182) and seal (alloy 5082) as shown in Table 3.

In studies on aluminum can casting, Verran and Kurzawa (2008) performed tests with the addition of scorifying flux in order to optimize aluminum can casting and reduce slag formation in the process. Figure 1 represents the efficiency of the casting with the addition of scorifying flux and temperature evolution. It can be seen that efficiency stabilized with the addition of 10% by weight of scorifying flux and a temperature of 750°C. The addition of percentages greater than 10% by weight did not result in representative efficiency increases. Another factor to consider was the influence of melting temperature, which resulted in a reduction in energy consumption and oxidation losses.

Additions greater than 10% by weight improved the efficiency of the melt. However, there was a need to increase the temperature to 850 ºC. In addition, Verran and Kurzawa (2008) highlight the use of an induction electric furnace for casting, which has a better yield (71.61% average) when compared to combustion (oil / air) and gas furnaces, 55% and 60% respectively. Analysis of the chemical composition of the molten material is shown in Table 4.

There was a variation of Mg of 54.5% between maximum and minimum values. According to Kumar et al. (2018) magnesium, when subjected to high temperatures, undergoes variations in casting processes when in contact with oxygen, unless care is taken to protect the surface against oxidation. This protection occurs by the use of inert gas injection such as argon on the casting surface. Similarly, iron has a 72.5% variation between highs and lows. Contaminant elements such as Ti, Pb and Cr were found in small quantities in the recycled aluminum.

2.2 Aluminum recycling processes

According to Verran et al. (2004) in the small-scale aluminum can recycling process an induction electric furnace is used to melt the material. Then, the quality of the material collected and melted in the process is analyzed. The collected material at the beginning of the process is passed onto a conveyor belt. From there, the material is taken to a knife mill where the material is fragmented. The fragments move to an electromagnetic separator that removes ferrous materials that cannot be mixed with aluminum. Afterwards, the material passes through a hammer mill, where it is chopped into chips. Then, another magnetic separation also removes the residue of impurities. Next, the chips go through a vibrating screen that removes dirt, sand and other debris, and a pneumatic separator completes the process with air jets to remove paper, plastics and other contaminants. From there, the chips move on to the removal of inks and polymers that cover the material. This is conducted inside a rotary kiln, known as the oven kiln. Then, the chips are melted at 700 ºC, where the liquid material is poured into crucibles and transformed into ingots.

2.3 Alloy Elements

The addition of alloying elements adds characteristics to aluminum to provide the melt with properties of interest. Since the objective of this research is to produce a conductive laminated tape, it is relevant to add alloying elements such as copper, as its conductive properties are superior to aluminum. In addition, copper has better tensile strength and corrosion resistance, increased hardness, higher ductility and conformability (SHACKELFORD, 2008). Magnesium is another element that has properties that may favor the alloy composition to form the conductive tape. In addition to providing mechanical gains, magnesium allows the alloy to maintain a high level of corrosion resistance and weldability. However, magnesium is highly soluble at its melting point and it must be melted in an argon controlled atmosphere (ACHYUTH et al., 2019). Al-Mg alloys with contents ranging from 3–5% form alloys such as 5042, 5352, 5082 and 5182, which are used in the manufacture of beverage can lids (DAGWA; ADAMA, 2018).

3. Materials And Methods

This research used an experimental methodology and the recycled aluminum samples (beverage cans) were obtained through the Santa Cruz do Sul Waste Pickers Cooperative - RS - Brazil. To remove the moisture, the materials were inserted into a muffle furnace, with the temperature ranging between 150 and 200 ° C. The materials were melted without separation of the can components in an industrial Grion oven with the use of a steel crucible. The aluminum melting temperature was 750 ° C, based on Verran and Kurzawa (2008). The stages of the casting process that supported the methodology of this research are described in Fig. 2.

After the acquisition of the cans and their preparation for casting, the material was compacted and pressed. This allowed for better packing in order to provide better melting, since in a more compact load there is a lower surface / volume ratio, and consequently, a lower tendency for oxidation loss (slag formation).

The first stage involved the casting of the aluminum cans and the formation of the 1st ingot. This was conducted by placing the cans in the oven manually, Fig. 3a. During the casting process, slag formed on the surface of the melt and was removed for every 5 kg of cans introduced into the oven, shown in Fig. 3b. At this stage of the research, 20 kg of recycled aluminum cans were used.

With the mixture finally homogenized, the melt was poured into the mold. For this step, the melt, while still in a liquid state, was poured in small quantities into the mold so that the mixture, when solidified, would not become too thick. Figure 4, 10.2 kg of melt was obtained from the total of 20 kg of cans, resulting in a 51% yield.

The second stage consisted of the commercial Aluminum Casting and incorporation of the 1st ingot to form the 2nd ingot. This step occurred through the casting of 10 kg of commercial aluminum classified as alloy 6063. When the material was in a liquid state, the ingots of the first casting that came from the melting of the recycled cans were added. At the end of the homogenization of the mixtures, the material was again poured into a mold and converted into an ingot called the “50% / 50% ingot” (50% recycled cans and 50% commercial aluminum alloy). In this second casting, the mass yield was 90%.

From the aluminum ingot formed (Fig. 4) the objective was to create a 0.5 mm thick laminated tape. Since the ingot formed was 16 mm thick, it was necessary to produce a mold.

The third stage consisted of the incorporation of rice husk ash into the 2nd ingot and the formation of the 3rd ingot. In order to cast the 3rd ingot and start making the laminated tapes, it was initially necessary to cast the melt into a mold, which already had adequate spaces to receive the melt. Die casting has excellent dimensional accuracy and results in excellent mechanical properties. A flat steel bar, SAE 1045, 30 cm long and 10 cm wide was used for its preparation. This bar was cut in half to use one piece as a lid and the other piece was milled with an 8 mm tool to form the channels through which molten aluminum and the rice husk ash, while still in liquid form, would be poured. This is presented in Fig. 5.

In the upper part of the two pieces of the mold, a cavity was made to prevent spillage of the aluminum from the third casting when it was poured (i.e. to direct material to the main channels). Regarding the pouring method, the gravity method was used. The three channels were made with 2 mm; 3 mm and 4 mm of depth. Thus, the specimens had their measurements described as shown in Table 5. For the outflow and exhaust of the gases, small diagonal cuts were made in the sides of the mold and interconnected the specimens. In addition, vertical outlet cuts were made at the base of the specimens for a directional exit at the bottom of the three channels.

Samples were taken for chemical analysis, micrograph, as well as density, impact and hardness testing to validate the mixture and verify properties.

The 4th Stage consisted of the incorporation of Copper and Magnesium in the 3rd ingot and thd formation of 2 mm, 3 mm and 4 mm specimens. After the formation of the 50% / 50% ingot, a third casting was necessary, since copper and magnesium were incorporated to the melt of the third ingot. This was done to discover which structure would have the best chemical composition for the tape. The third ingot was divided into 5 batches each being 800 g, as seen in Table 6 (1st sets of specimens). At the end of the 5 casting runs, 45 specimens could be selected and identified.

The furnace used for this experiment was a "well type" resistive furnace. The third ingot was introduced into the crucible and was given 20 minutes for temperature stabilization at 750 ° C. The mold was heated in a muffle resistive oven at a constant temperature of 350 ºC. The formation of the tapes occurred from the casting runs made from the 3rd ingot, which generated three specimens for each draining of the mold presented in Fig. 5. The starting point for the casting of each batch of samples of the experiment was the 800 g of aluminum that had already been incorporated into the rice husk ash in the 50% / 50% ingot.

A previous run was also carried out, which consisted of the aluminum casting of the first ingot (50% commercial and 50% recycled), in order to verify how the formed aluminum alloy would behave. Figure 6 represents the casting of the aluminum formed by the first ingot made in the mold. 800 g of aluminum was placed into the crucible inside the oven and when it reached a temperature of 750 ºC, 20 minutes were given to stabilize the melt. Then it was poured into the mold, which was previously heated to 350 ºC. This is presented in Fig. 6.

After 5 minutes, the mold could be opened and the specimens were carefully removed to avoid fractures along the specimen (Fig. 7).

After each batch of samples obtained in the experimental sequence shown in Table 6, one sample was taken to conduct chemical analysis to identify the composition resulting from the proposed mixture in the experiment. This analysis was performed using the optical emission spectroscopy technique, performed by a CCD Plus - S5 Solar Optical Spectrometer.

It was determined that the manufactured mold achieved the objective of forming specimens closer to the final thickness of the desired laminated tape (Fig. 8). In order to reduce the thickness of the specimens from 2 mm and 3 mm to 0.5 mm, it was necessary to perform the rolling process, in the order of, 4 x and 6 x respectively on the resulting thickness of the mold casting.

The 5th stage consisted of the rolling process of the specimens in the bench laminator and the formation of the laminated tapes. At this stage, after the selection of the specimens formed by those that presented a suitable structure to be laminated, lamination was carried out with the objective of reducing the thickness of the specimens formed and that were extracted from the mold.

The final composition of the specimens after the addition of copper and magnesium can be seen in Table 7. At each run of molten material, 3 specimens were separated and the process was repeated 3 times in order to obtain the same specimen in triplicate, since each mold channel had a different thickness.

The 6th step was conducted to confirm the thickness of the laminated tapes. At this time, the thickness of the laminated tapes was analyzed and only those with thicknesses less than 0.6 mm were selected. This value is very close to the thickness that was proposed at the beginning of the research, which was 0.5 mm. Some tapes, after being laminating 5 or 6 times, broke and could not be used as specimens. Only those that were unbroken, with more than 50% of their original size out of the mold, were counted as specimens.

4. Results

The initial mass of 20 kg, acquired at the Santa Cruz do Sul Recycled Materials Collectors Cooperative - RS-Brazil, after slag removal, resulted in a 10.2 kg cast aluminum ingot. In percentage values, the yield obtained in the process was 51% over the initial mass. It is noteworthy that the casting process was carried out in an industrial furnace with a combustion process that uses liquefied petroleum gas (LPG). The research by Verran et al. (2005) obtained an average yield of 71.61% through the use of an induction furnace. In addition, a scorifying flow was used in the process, which improved the yield to values above 80% when 20% by weight of scorifying flow was added.

For the chemical analysis of the composition of the cast aluminum ingot sample, which was composed of 50% recycled aluminum and 50% commercial aluminum, the optical emission spectroscopy technique was used. The results of the analysis are shown in Table 8:

Comparing the data from the chemical analysis of cast aluminum with the data in Table 3, which shows the chemical composition of the aluminum can components defined by the ASTM standards, it is clear that the silicon levels are equivalent and the other elements presented lower values in relation to the data in Table 3. A relative similarity with the data obtained by Verran et al. (2004) described in Table 9 is evident.

The results show that the aluminum contained a very close chemical composition. It should be noted that Verran et al. (2004) used only recycled aluminum cans. The percentages of manganese are below the reference table in Table 3. As for the other elements that appear in the form of impurities, it can be stated that the values found are within the limits allowed in all standards that define chemical composition specifications for workable aluminum alloys.

Molten aluminum from aluminum cans was considered as the basic research element for the manufacture of laminated tape. Alloy elements such as copper and magnesium were added to this aluminum, which resulted from the second casting. The research evaluates whether these elements add improvements in the conduction properties of electric current in laminated tape.

With the addition of alloying elements, copper and magnesium, to the 50% / 50% ingot, the casting was mixed and nine specimens were poured into the mold and a sample was taken for chemical analysis. This is presented in Table 10.

There is a proportional increase in the addition of copper to the melt (50% / 50% ingot), which was successful, representing 4.176% of the alloy. The next addition was made with the incorporation of 40 g of magnesium. There was a slight contamination of impurities from the crucible wall, which resulted in an increase in zinc, with a value of 1.569% in the alloy.

Next, a new casting was made, an additional 30 g of copper and 80 g of magnesium were added. Due to the addition of magnesium, argon gas injection was used to control oxygen contact in the bath since magnesium is highly soluble when in contact with oxygen. After stabilization of the bath and homogenization of the alloy, the argon was turned off and the melt was poured back into the mold and heated at 350 ° C. With the addition of copper and magnesium, an improvement in fluidity was noted and, as a result, the channels were completely filled. This left the specimens at the size determined by measuring of the mold channel. A new chemical analysis was performed with the samples resulting from the mixture provided in Table 1. These results are presented in Table 11:

The percentages of copper and magnesium were 7% and 6.775% respectively. Magnesium did not reach the predicted percentage of 8% from Table 1 due to the degree of solubility and an increase in slag formation on the surface of the melt caused by magnesium oxidation. Copper behavior remained stable as in previous flows. The other elements remained practically the same in relation to the previous additions made.

5. Conclusion

Aluminum cans are a good choice for the collection and sale of recyclable materials because they are easy to collect and have a relatively high value. Of course, when it comes to recycling, impurities will always exist in the casting process, which will contribute to slag formation. Thus, researching casting methods or techniques that improve process performance is the first challenge for researchers interested in the topic of metal recycling.

The process of casting recycled aluminum shows a wide possibility for reusing solid waste. In addition to providing income to support many families of waste pickers in urban centers, recycled aluminum can be used for various industrial applications.

The sustainability bias brings another important point when considering the recycling of materials, since the continued depletion of minerals from the earth's crust is a well-known fact. For this reason, this research is relevant. Recycling aluminum allows for the reuse of materials and reduces the need for underground mining.

One of the objectives of this research focused on the reuse of recycled materials. In addition, this work proposed a more appropriate destination for industrial waste, therefore offering possibilities for saving materials. However, it is important to improve the casting process of the melt flow in order to facilitate the extraction of specimens for several applications.

By conducting this research, casting recycled aluminum from beverage cans after the separation of the initial slag, proves to add great efficiency to the recycling process of this material. However, this is only possible when the aluminum is properly separated and used correctly, without difficulties in the handling process. Therefore, casting recycled aluminum offers possibilities for other applications, simply by adapting matrices or molds to the product to be produced. There is a possibility to expand the methodologies and obtain new applications of aluminum casting, so that the use of clean technologies that promote greater sustainability can be advanced.

The addition of copper and magnesium to the molten aluminum for the ingot containing 50% recycled aluminum and 50% commercial aluminum has shown a great possibility for the casting of different materials with developed methodologies. This was demonstrated in this research through the production of a new alloy where 85% aluminum, 6.38% copper and 8.51% magnesium were obtained. This is presented in table 1.

This research will continue with the process of lamination and finishing of flat tape. The next step will be to test the tape to see if it has properties for the conduction of electric current.

Declarations

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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Tables

Table 1

Chemical composition of aluminum alloy 3xxx and 5xxx.

Chemical Element	Percent (%)	
	Alloy 3xxx	Alloy 5xxx
Aluminum	95.00 – 98.90	> 86
Manganese	0.05 – 01.98	0.05 – 1.4 %
Zinc	0.30 – 02.50	< 1.8
Silicon	0.03 – 01.60	< 1.4
Magnesium	0.20 – 01.47	0.2 – 5.6
Other	< 01.80	< 2.1

Source: Adapted from Davis (2001).

Table 2

Mechanical properties of 3004 and 5182 series aluminum cans.

Properties	Alloys	
	3004	5182
Specific mass – density (1000 kg/m^3)	2.6 – 2.8	2.6 – 2.8
Modulus of elasticity (GPa)	70 – 80	70 – 80
Tensile Strength (MPa)	215	420
Flow Limit (MPa)	170	395
Stretch (%)	10	25
Shear Strength (MPa)	115	150
Fatigue Strength (MPa)	105	140
Hardness (HB 500)	52	25

Source: Adapted from Bdeir and Alsaffar, 2008.

Table 3

Chemical compositions of alloys used in the manufacture of aluminum cans.

Componentes (Alloy)	Si (%)	Fe (%)	Cu (%)	Mn (%)	Mg (%)	Zn (%)	Cr (%)	Ti (%)	Other (%)	Other Total
Body	0.30	0.70	0.25	1.0-1.5	0.8-1.3	0.25	-	-	0.05	0.15
Lid	0.20	0.35	0.15	0.2-0.5	4.0-5.0	0.25	0.10	0.10	0.05	0.15
Seal	0.2	0.35	0.15	0.25-0.4	3.3-4.0	0.25	0.15	0.10	0.05	0.15

Source: Adapted from Schlesinger, 2013.

Table 4

Analysis of the chemical composition of the aluminum can casting used by Verran and Kurzawa (2008).

	Mn (%)	Mg (%)	Cu (%)	Si (%)	Fe (%)	Zn (%)	Cr (%)	Ti (%)	Ni (%)	Pb (%)	Al (%)
Minimum *	0.73	0.48	0.10	0.09	0.29	0.02	0.01	0.01	0.01	0.01	97.65
Maximum *	0.78	0.88	0.14	0.16	0.40	0.05	0.06	0.02	0.04	0.02	98.09
Average *	0.74	0.63	0.11	0.10	0.34	0.04	0.02	0.01	0.01	0.01	97.99

Source: Verran and Kurzawa, 2008.

Table 5

Specification of specimen measurements inside the mold.

	Test Specimen 01	Test Specimen 02	Test Specimen 03
Width	08 mm	08 mm	08 mm
Length	15 mm	15 mm	15 mm
Thickness	02 mm	03 mm	1. mm

Table 6

Experimental sequence of alloy formation of the 50% / 50% ingot.

1st Batch of samples
800 g. aluminum - (ingot 50 % / 50 %) with rice husk ash
There were 3 runs*, obtaining 9 CP**
2nd Batch of samples
800 g. aluminum (ingot 50 % / 50 %) + 30 g. copper
There were 3 runs, obtaining 9 CP
3rd Batch of samples
800 g. aluminum (ingot 50 % / 50 %) + 60 g. copper
There were 3 runs, obtaining 9 CP
4th Batch of samples
800 g. aluminum (ingot 50 % / 50 %) + 60 g. copper + 40 g. of magnesium
There were 3 runs, obtaining 9 CP
5th Batch of samples
800 g. aluminum (ingot 50 % / 50 %) + 60 g. copper + 80 g. de magnesium
There were 3 runs, obtaining 9 CP

* Running means pouring the melt into the mold and
** CP stands for specimen.

Table 7

Final composition of aluminum, copper and magnesium alloy.

Composition Mixture		
Material	Massa (g)	(%)
Aluminum Cans	400	42.55 %
Commercial Aluminum	400	42.55 %
Copper powder	60	6.38 %
Magnesium (99.9% purity)	80	8.51 %
Total	940	

Table 8

Analysis of the chemical composition of the cast aluminum (50% / 50% ingot).

Sample	Al (%)	Mg (%)	Mn (%)	Fe (%)	Cu (%)	Si (%)	Zn (%)	Cr (%)	Ti (%)
Aluminum Cans + Comercial Aluminum (50%/50%)	98.2	0.787	0.305	0.283	0.101	0.242	0.028	0.020	0.000

Table 9

Chemical analysis of specimens referring to research by Verran et al. (2004)

Sample	Al (%)	Mg (%)	Mn (%)	Fe (%)	Cu (%)	Si (%)	Zn (%)	Cr (%)	Ti (%)
Aluminum Cans	97.9	0.626	0.732	0.358	0.113	0.145	0.03	0.02	0.02

Source: Adapted from Verran et al., 2004.

Table 10

Chemical analysis of aluminum alloy (50% / 50% ingot) with the addition of 60 g of copper.

Sample	Al (%)	Mg (%)	Mn (%)	Fe (%)	Cu (%)	Si (%)	Zn (%)	Cr (%)	Ti (%)
Aluminum Base Alloy	92.21	0.69	0.323	0.343	4.176	0.593	1.569	0.014	0.026

Table 11

Chemical analysis of aluminum alloy (50% / 50% ingot) with the addition of 60 g of copper and 80 g of magnesium.

Sample	Al (%)	Mg (%)	Mn (%)	Fe (%)	Cu (%)	Si (%)	Zn (%)	Cr (%)	Ti (%)
Aluminum Base Alloy	8.79	6.775	0.368	0.379	7.00	0.564	1.96	0.012	0.025

Figures

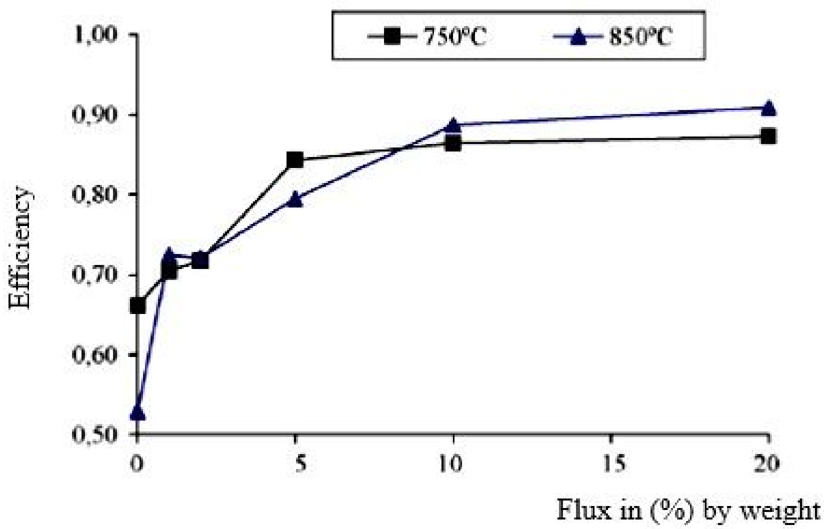

Figure 1

Casting efficiency with flux addition and temperature evolution.

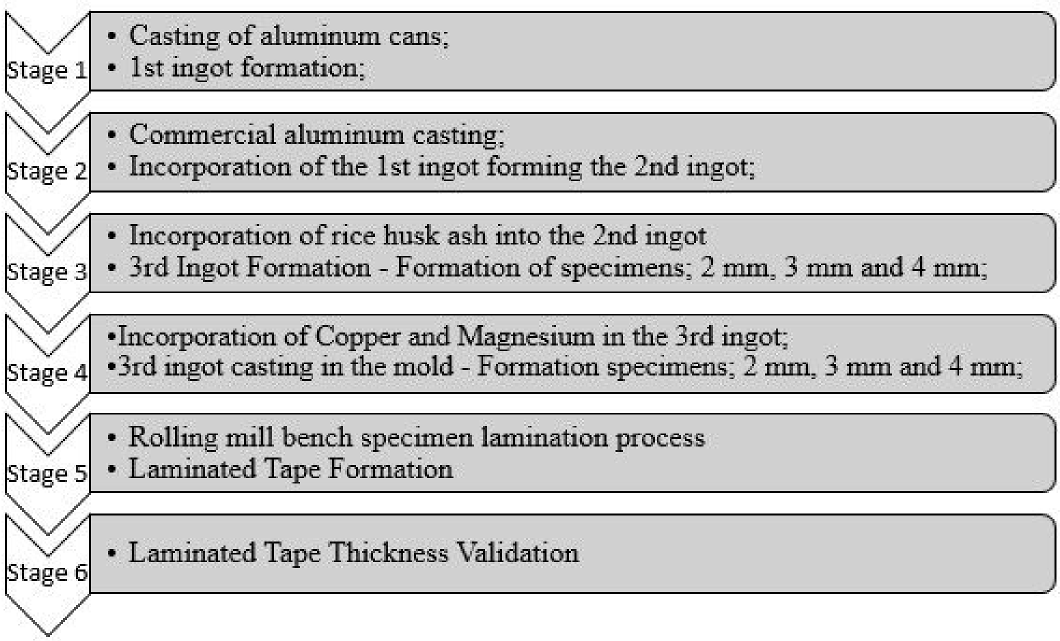

Figure 2

Methodological sequence of the research steps during the casting process.

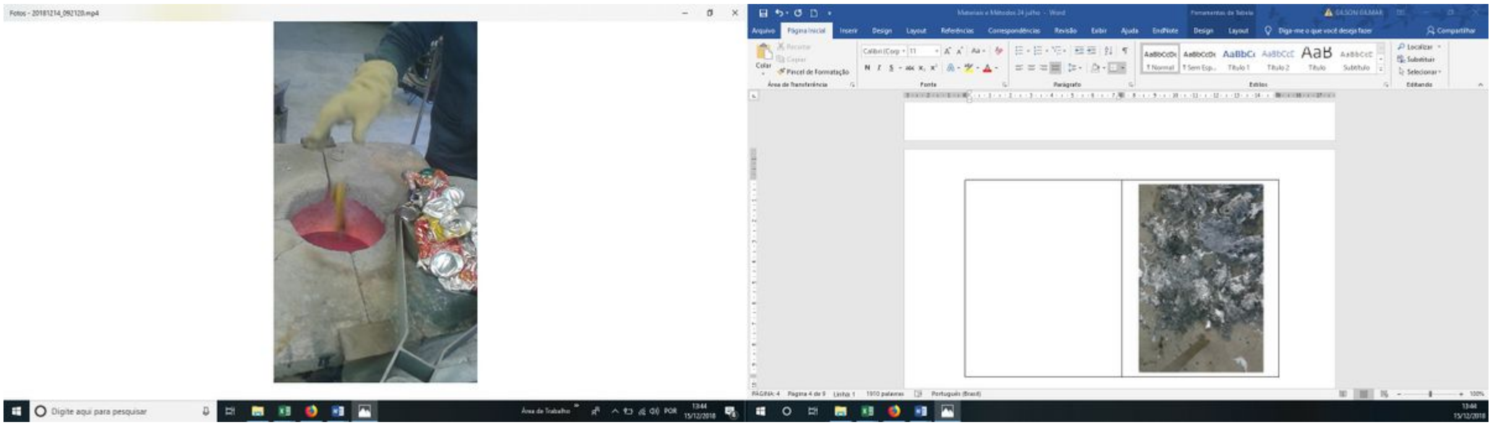

Figure 3

Manual placement of aluminum cans.

Figure 4

Slag removed from the melt.

Figure 5

Aluminum Ingots - 50% / 50% Ingot

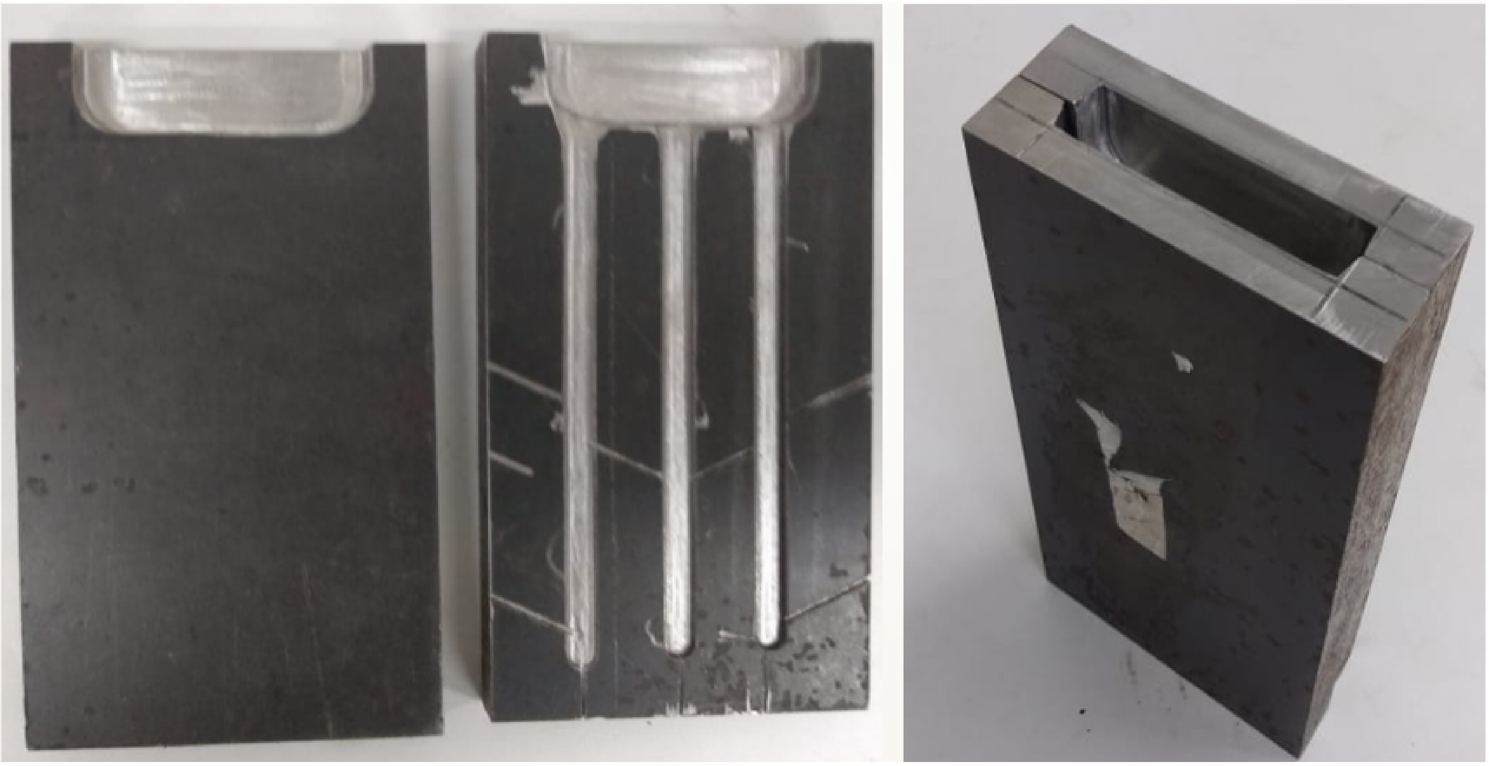

Figure 6

Mold made for pouring of the 3rd ingot

Figure 7

Pouring process of molten aluminum into the mold

Figure 8

Opening of the mold and removal of specimens from the 1st batch of samples from the 50% / 50% ingot experiment.

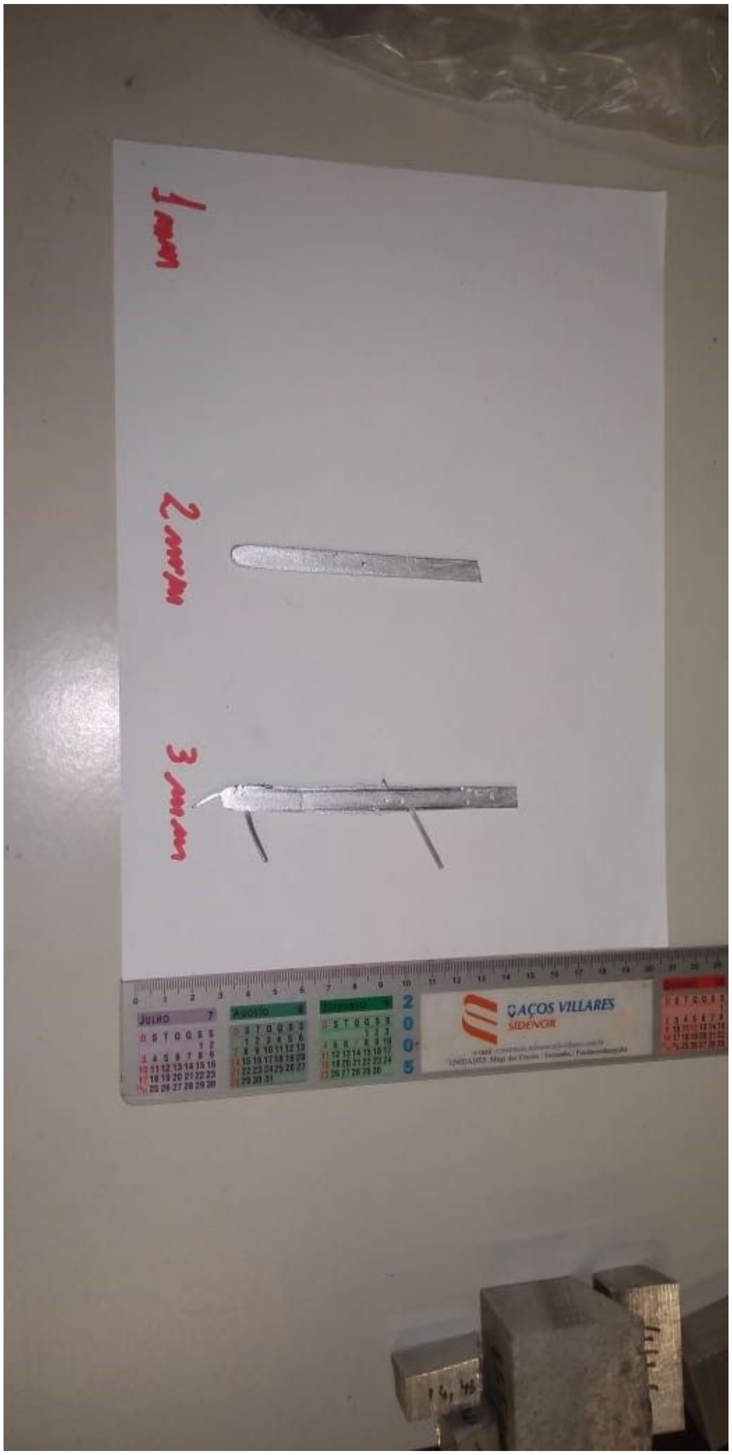

Figure 9

Identification and verification of the validity of the specimen.