

Aluminum Slag Separation Process Analysis Through a Vibratory Machine in the Foundry Process

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Abstract

A The aluminum smelting industry has some challenges, due to the characteristics of the alloy that cause reactions that should be controlled. During the foundry process, the alloy is oxidized by contact of the molten aluminum with the ambient air. Oxide films forming on the surface of the molten metal must be removed during the cleaning of the furnaces in order to avoid contamination of the alloy to be used in the production of parts. Analyzing the melting process of a metallurgy at the industrial complex in Manaus,

we saw that during the cleaning of the furnaces a metal tool is used to remove the slag, which brings with it a high level of aluminum brought about by the mechanical drag of the tool. As the company in question does not have resources to recover the metal aluminum contained in the slag, it is destined for the other institution which carried out the processing through the process of refusion of the slag and extraction of aluminum. The high level of losses in the process due to the discarding of slag generates considerable financial damage to the institution, reflected directly in the cost of manufacturing the products. In this way, the aim of the present work was to develop equipment for the extraction of the metal aluminum contained in the slag and consequently to reduce the losses in the process. The design of the equipment was chosen through a product development methodology, which made it possible to define the design specification, which can count on a container for the receipt and separation of the slag by means of the vibration brought on by motorvibrators installed at its ends, followed by a slingshot drawer responsible for the storage of the metal after the solidification and support/translate cars of the containers.

Keywords: Foundry, Aluminum, Slag, Separator

1. Introduction

Foundry is a fundamental industrial process for the production of metal articles. However, in spite of technological advances, this process still presents some challenges related to the losses arising from the oxidation of the alloy, causing the formation of oxides (slag) films on the surface of the molten metal, and the cleaning of the alloy before the transport for the production of parts is necessary. The formation of slag is inherent in the aluminum smelting process, with the factors that potentiate the generation of slag related to the quality of the alloy used, the parameters of the melting process and the removal and handling of the molten metal.

In general, slag can be classified into three types: white, black and saltcake (TENORY, 2001). Table 1 shows the chemical composition of the main types of slag found in the process of obtaining aluminum:

Table 1: Chemical composition of the main types of slag found in the process of obtaining aluminum.

Rubber Type	Al %	% Oxides	% Salts
White Rubber	25 - 80	20 - 85	0 - 1
Black Rubber	7 - 50	30 - 50	30 - 50
Salt Rubber	3 - 10	20 - 60	20 - 80

Source: Guidelines and Definitions (2002).

The chemical composition of this layer depends on the supply of the material produced and manipulating the raw materials necessary for the process, but also the surplus of the slag is made up of an oxide (25 to 30%), metallic (65 to 75%), aluminum carbide (2 and 3%), aluminum nitride (3 to 5%), iron (0.5 to%) and silicon (0.5 and 1.5%) (ABAL, 2007).

It is estimated that around 500 companies operate directly in the aluminum industry (producers, recyclers and consumers). five companies of primary aluminum, the other stages in the other stages of the production-mining chain, refinery, transformation and recycling/production of alloys. In 2010 the world consumption of aluminum was 40 million tons, it is estimated that for 2020 this consumption will be 70 million tons (ABAL, 2012).

The slag removed from the fuser furnaces brings with it a high level of aluminum, brought about by the mechanical drag of the tool and by the imprisonment of particles of the metal in the inside of the spongy body formed by the segregation of the oxides and other impurities. According to the analyzes carried out in the process, on average 6% of the metal introduced into the furnaces for foundry, come out in the form of slag (OLIVEIRA, 2016). Every time the furnaces are cleaned, on average, 800 kg of aluminum slag is removed, which, considering a medium-sized industry, generates a monthly volume of approximately 35 tons which are destined for sale to another institution. The discarding of the aluminum present in slag represents a considerable financial loss to the institution as a result of the average devaluation of the material's sales value (LME, quoting the site and the date corresponding to the price at the time of the analysis) and (purchase price of COMETAIS slag, with this the monthly loss can reach R\$ 402,141.93).

Since it is an industrial waste of Class I, aluminum slag must be treated properly and destined for its own places, since it can cause the human organism from anemia due to iron deficiency to chronic intoxication (BRAZIL ENVIRONMENT, 2020). In order to receive this type of waste, industrial landfills must keep the layers impermeable in order to protect soil and water from contamination. According to Abrelpe (2013), in 2012 Brazil generated 62 million tons of solid waste, a fraction corresponding to approximately 326 kg/inhabitants, or about 0.94 kg/daytime.

Some studies were carried out with the aim of recovering the metal aluminum contained in the residual slag. Wang (2008) presents a study for the recovery of aluminum from the slag made by the refusion in electric furnaces with the addition of founding salts. For slag from reverberation furnaces and from the transfer process, the return on recovery is around 55% and 83%, respectively. The recovery data shows that there is a much higher aluminum content in the slag from the transfer of the metal than in its processing by melting in a venerable furnace.

As for Melo (2007), he is presenting a similar study for the recovery of the black sludge, merging this material into induction furnaces. The results indicated are values in the order of 40.3% of aluminum recovered from the thinnest portion of slag below 0.83 mm for the SAE alloy 329 and 42.9% for the SAE alloy 32. For the portion below 0.83mm recovery was 54% for SAE 329 slag mixed with SAE 326 slag.

1.1 Factors influencing the formation of slag

Slag is formed mainly by oxidation of the liquid metal during the foundry process, Figure 1. The thickness of the layer depends fundamentally on the temperature at which the liquid bath is located. The optimal melting temperature of the aluminum oscillates between 700°C and 750°C, higher temperatures tend to increase the thickness of the layer of aluminum oxide during the process (ABAL, 2007).



Figure 1: Aluminum bath level flame contact.

Source: Elaborated by the authors (2020).

Another preponderant factor in the generation of slag is the chemical composition of the metal. The presence of magnesium (Mg) in the aluminum alloy facilitates the generation of slag, since magnesium is an element sensitive to oxidation (ABAL, 2007). Thus, aluminum alloys containing high magnesium levels are the ones with the greatest losses in the process.

Productivity losses in the aluminum processing industry range from 0.5% to 1.5% in the primary aluminum fusion processes and from 2.0% to 7.5% in the secondary aluminum processing processes (ABAL, 2007).

A third important factor for productivity losses in this sector is the source area to be merged. Oxidation occurs to a greater degree the greater the ratio of the area/weight of the material, that is, the smaller the thickness of the material to be melted, the greater will be its oxidation in that bath and consequently the greater will be the generation of residues. (ABAL, 2007).

1.2 Processing of Aluminum Slag

Recycling activity is of paramount importance for the foundry industries, as besides establishing an alternative source of the metal, the recovery of aluminum acts under the environmental impacts caused in the production of primary aluminum, since the energy consumption corresponds to one third of the process costs (approximately 15,2 kWh/kg), while in order to carry out the recycling of aluminum, taking into account the whole process from preparation to the fusion of the scrap, they are consumed around 6 % to 8% of the total energy needed to obtain primary aluminum by the electrolyte process (ABAL, 2012).

The slag generated has economic value added by the content of metallic aluminum contained (approximately 10-70% aluminum) (ABAL, 2007). The aluminum sludge generated in the foundry process is generally sent to the other institution carrying out the processing by means of pyrochemical processes, where it is exposed to very high temperatures in rotary furnaces where the metal is concentrated and can be separated from the accompanying impurities.

The search for a reduction in the cost of production means that companies develop projects that minimize losses and consequently increase the efficiency of the process, in order to make them competitive and to guarantee survival in the market. The development of sustainable projects has provided a very

positive return to the companies that see them implementing them, both financially and in terms of increased operational efficiency, which contributes to reducing environmental impacts and positively favors the company's image in the eyes of investors and society.

In this way, the present work presents a new concept for the recovery of aluminum contained in the residual slag, by implementing equipment developed from studies carried out in the process of founding a metallurgical company from the industrial complex of Manaus. The equipment designed to work in the extraction of aluminum has a vibration mechanism generated by pneumatic motorcycles attached to the receiving compartment of slag, responsible for the classification and separation of the oxide/aluminum mixture, allowing the metal to recover and minimizing the metal aluminum content discarded from the process.

2. Methodology

With the objective of extracting the aluminum contained in the slag, we began the development of a piece of equipment (oxide/aluminum separator), starting from the mapping of the process of forming slag during the aluminum fusion, the destination of the waste and the methods of processing, in order to establish a design of the equipment that would make it possible to reduce the level of metallic aluminum contained in the residual slag discarded from the foundry process. Mantovani (2011) establishes a product development model that can be divided into three steps as Figure 2.

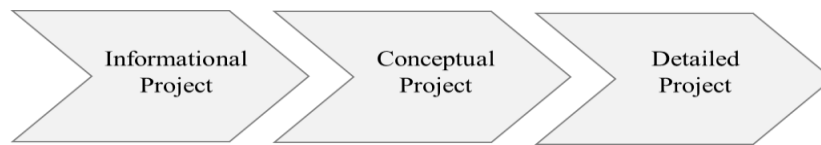


Figure 2: Project development steps.
Source: Adapted from Mantovani (2011).

With the customer/user requirements pre-defined in the information project stage, we started the conceptual project where these requirements are transformed into product designs to determine an initial prototype for making the equipment, the oxide/aluminum separator. At this stage, the overall function of the equipment is to be established, where it has been defined according to the waste processed and the energy input, taking into account the inputs and outputs as outlined in Figure 3.

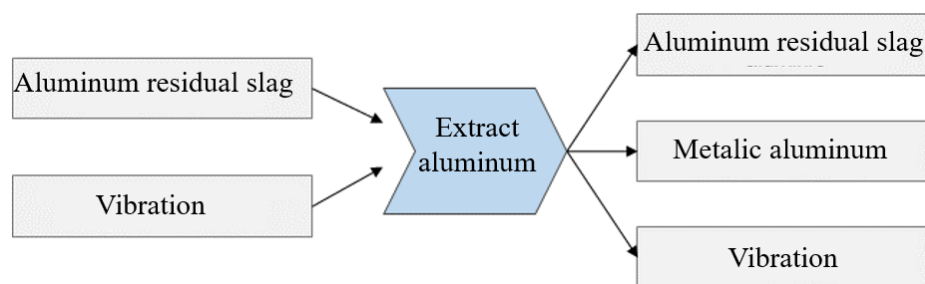


Figure 3: Global function of the aluminum oxide separator.
Source: Elaborated by the authors (2019).

Given the overall and structural function of the equipment, it is possible to work on transforming an abstract design into a concrete design by listing the possibilities for solutions from the defined requirements.

The peripherals that made up the equipment were developed based on the requirements previously raised during the information collection stage. While the project objectives and their customer/user requirements are defined, there are numerous solution principles for your service. By exploring the possibilities for alternative solutions to address the problem, we have put together strengths to select the design specification in order to select the best alternative for each product peripheral, the selection result is shown in Figure 4.








Proposed conception to meet the project requirements						
Residual slag Receiving	Transportation cart structure	Ingot tray	Ingot tray cart	Cart wheels	Springs	Motovibrators
						

Figure 4: Design selected to meet project requirements.

Source: Elaborated by the authors (2019).

After the choice of equipment design, the detailed project development phase was initiated by the technical design as shown in Figure 5.

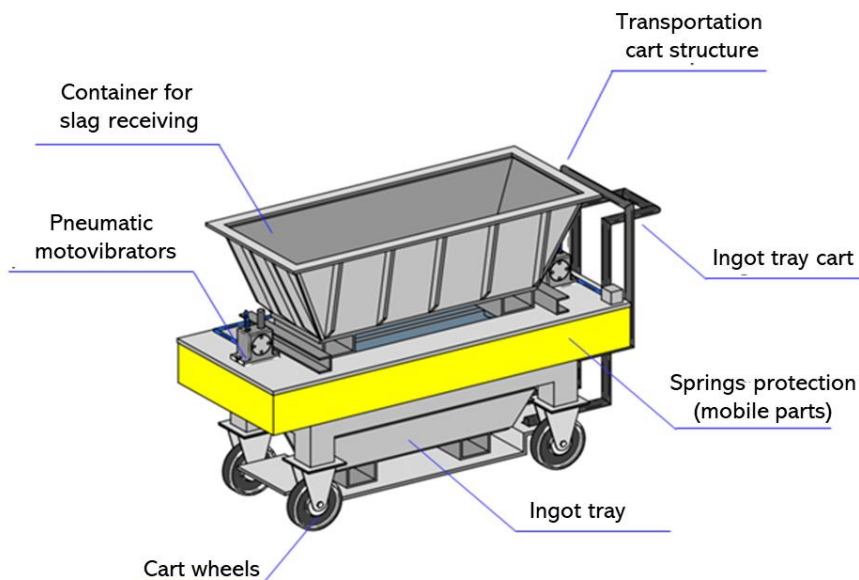


Figure 5: Prototype of the aluminum oxide separator.

Source: Elaborated by the authors (2019).

For the manufacture of the equipment, we use steel for working at high temperatures, essential for the making of the container for receiving slag in which it is responsible for conditioning the residue and for separating the metallic aluminum contained in it. This separation occurs by classifying the mixture by separating the aluminum through the specifically sized pass-through holes. The structure of the trolley is

made up of metal supports of high mechanical and thermal strength, in which it is responsible for the support and translate of the slag-receiving container, and it is also the interface between the container and the ingot tray. The ingot tray is a container constructed of steel with a high thermal resistance, the ingot tray is responsible for receiving the metallic aluminum during separation, its geometric form was developed to facilitate the extraction of the aluminum ingots formed after solidification. Helical springs have been specifically scaled for their strength to boost the vibration inserted into the system by the pneumatic motor vibrators. The equipment was moved by fixed and mobile casters with high thermal and mechanical resistance.

2.1 Operation Test

The equipment's operating test was carried out at a metallurgical company at the Industrial Complex of Manaus, which operates in transforming aluminum into the HD2G and HD4 alloys into parts for meeting the demand for the production of the two and four-wheel pole. These alloys have distinct characteristics, as a function of the concentration of magnesium, an element in which they gain a gain in mechanical resistance, besides improving their machinability and allowing for natural hardening, however, this same element provides for the oxidation of the alloy, the generation of slag and "hard points" in the piece, making the process difficult throughout the production chain. The HD4 League has 4.5 times more magnesium than the HD2 alloy, which makes it a difficult alloy to be worked on, as well as the high loss rate, it still shows low fluidity, which makes it difficult to produce parts.

3. Results

3.1 Analysis of the Alloy Fusion Process and Assessment of Oxide Formation Factors

As stated above, among the parameters analyzed in the aluminum smelting process, the one that has the greatest influence on the generation of slag is the working temperature of the oven, this being directly proportional to the thickness of the oxide films that are formed on the surface of the molten aluminum. After the analysis of the oven working temperature, it was possible to project the rate of formation of oxide films on the surface of the aluminum as a function of the melting time and the magnesium content of the alloys HD2G and HD4 as shown in Figure 6. It is observed that the layer of oxide formed is directly proportional to the melting temperature of the bath, where high temperatures result in layers of thicker oxides with a content of Mg between 4% - 5%, that is, the greater the presence of Mg, the alloy will show an oxide formation higher than the others.

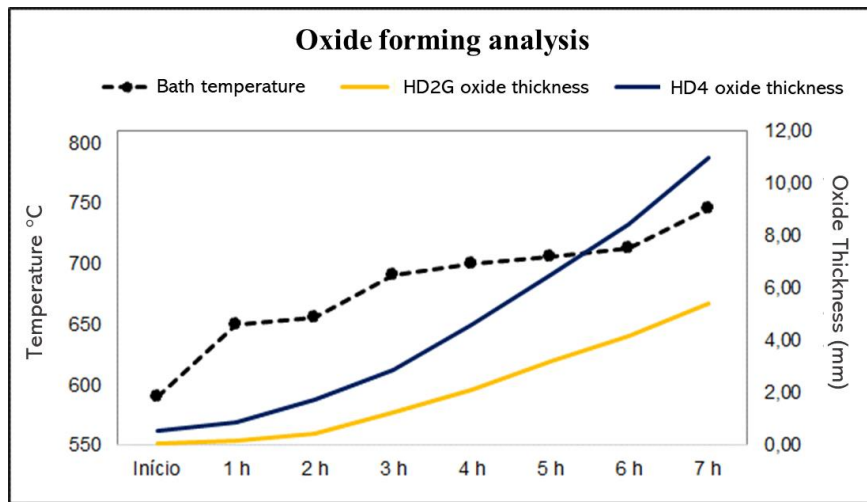


Figure 6: Aluminum oxidation.

Source: Elaborated by the authors (2019).

3.2 Equipment efficiency

In order to assess the efficiency of the equipment, the Schmitz (2006) methodology was used, in which the yield is calculated as a function of the quantity of slag processed and of the metal aluminum extracted with the use of the equipment. The data collected and processed is presented in Table 4. The slag processed in the equipment originated from the process of melting the alloy coming from the furnace composition with Scrap (aluminum that returns from the production in the form of patches) and ingots (the geometry in which the aluminum of the suppliers is purchased). In this way the equipment's work towards the process took place in the most real manner possible, with the objective of identifying negative factors and points of improvement to be implemented, in order to maximize the results with the inclusion of the equipment in the systematic process for the manufacture of the molten aluminum.

As shown in table 4, we can see the percentage of sludge generated due to the aluminum alloy used in the process. It appears that the HD4 alloy has a higher percentage of sludge generation compared to the HD2G alloy, confirming the increase in the oxidation of the alloy provided by the Mg concentration level. Such increase in the generation of sludge makes the HD4 alloy more complex to work with, since this alloy is used for the production of parts with grade A safety (parts for vital use where they will be exposed to greater demands: traction; compression; buckling, etc.), being extremely important the guarantee of the absence of oxide, since this factor negatively affects the mechanical properties of the parts.

Table 4: Analysis of the efficiency of the separating equipment.

Aluminum recovery process analysis – Equipment efficiency											
Alloy	Description	1 st day	2 nd day	3 rd day	4 th day	5 th day	6 th day	7 th day	8 th day	9 th day	10 th day
HD2G	Scrap	5.937	13.372	10.106	9.412	12.436	10.010	11.502	7.258	10.198	11.148
	Ingot	5.860	5.467	7.858	4.729	5.569	4.836	5.963	4.636	6.663	10.614
	Sludge	364	345	416	248	156	130	247	351	624	494
	% Sludge	3,1%	1,8%	2,3%	1,8%	0,9%	0,9%	1,4%	3,0%	3,7%	2,3%
	Al Recoveried	118	116	132	100	46	37	76	112	186	156
	% Al Recoveried	32,5%	33,6%	31,7%	40,3%	29,6%	28,5%	30,6%	31,9%	29,8%	31,6%
	Slag disposed from process	246	229	284	148	110	93	171	239	438	338
	% Slag disposed	67,5%	66,4%	68,3%	59,7%	70,4%	71,5%	69,4%	68,1%	70,2%	68,4%
HD4	Scrap	5.161	8.015	4.954	4.845	5.920	3.220	7.082	6.730	9.105	9.368
	Ingot	4.119	3.937	6.433	1.054	1.514	900	3.070	2.650	4.797	5.451
	Sludge	581	715	842	650	423	117	585	663	819	650
	% Sludge	6,3%	6,0%	7,4%	11,0%	5,7%	2,8%	5,8%	7,1%	5,9%	4,4%
	Al Recoveried	204	247	305	206	154	41	230	242	284	205
	% Al Recoveried	35,1%	34,6%	36,2%	31,7%	36,5%	34,8%	39,4%	36,5%	34,7%	31,6%
	Slag disposed from process	377	468	537	444	268	76	355	421	535	445
	% Slag disposed	64,9%	65,4%	63,8%	68,4%	63,5%	65,2%	60,6%	63,5%	65,3%	68,4%

Source: Elaborated by the authors (2019).

As a result, the slag-generating characteristics of the HD4 alloy, the efficiency of the equipment is directly influenced, as larger quantities of metallic aluminum are trapped next to it, which will then be submitted to the extraction process carried out by the oxide/aluminum separator. The results of the equipment were followed up for 10 consecutive days, which enabled us to analyze the efficiency in relation to the slag from the alloy used in the process, as shown in Figure 7.

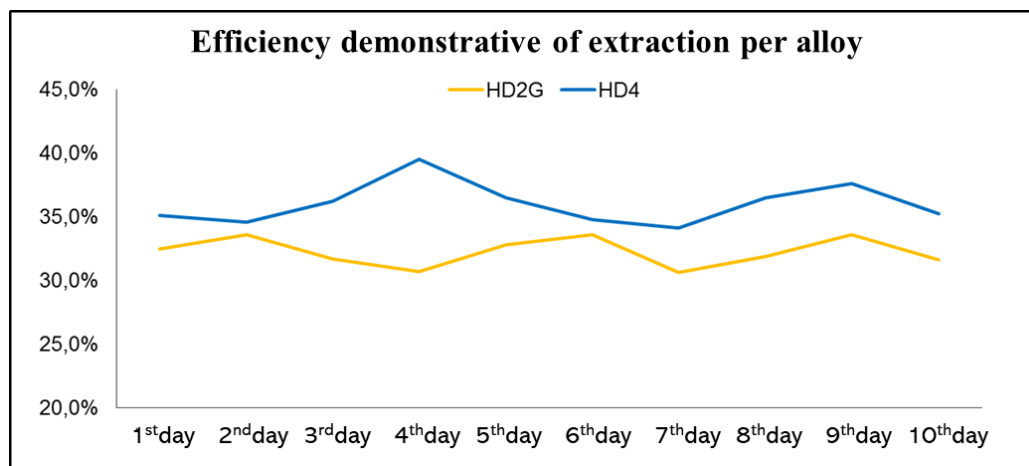


Figure 7: Equipment efficiency per alloy.

Source: Elaborated by the authors (2019).

3.3 Characteristics of Samples

3.3.1 Chemical Characteristics

Generally, the processed slag is basically made up of metallic aluminum 64.8%; Aluminum oxide 25,0 %; Mg oxide 1.5%; Al carbide 3.5%; Al 2,9% nitride; Fe 1.3% oxide and Si 1.0% oxide; as shown in

figure 8. Part of the metal aluminum contained in the slag was free between the oxides, and their removal from the furnaces was due to the mechanical drag caused by the tool used for cleaning. After the removal, the aluminum is trapped amongst the other residues during the solidification process, making it more difficult and expensive to extract when making use of more complex equipment.

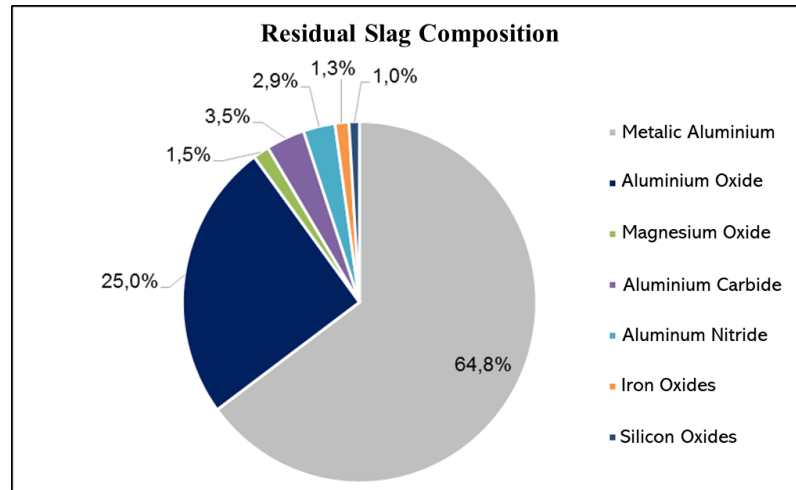


Figure 8: The composition of the residual slag.
 Source: Elaborated by the authors (2019).

Therefore, in order to guarantee the reliability of the extracted material, since it will return to production through the reuse of aluminum system, the chemical analysis of the samples collected in the sling tray was carried out. The production of parts using the alloys mentioned above is governed by the internal standard of the company, where the company sets the tolerance limits for each element of the composition of the alloys. In this way, the chemical analysis carried out had as its evaluation parameter the values indicated by the abovementioned standard. The data obtained are previously attributed to the spectrometer reading system and at the time of the analysis the equipment has the resources to identify the alloy corresponding to the analyzed material and to verify the variation in the composition elements of the aluminum extracted using the equipment. The results obtained are presented through a control worksheet, presented in Tables 5 and 6.

We can observe, in a general manner, that the aluminum extracted did not undergo any major alterations in its composition. In Table 5 (assessment of the chemical analysis of extracted aluminum — HD2G), we found that only iron and manganese had a positive variation of 5.7% and 0.4%, respectively, while the other elements remained within the tolerance established in the standard. In Table 6 (chemical analysis assessment of extracted aluminum - HD4), the element variation was even smaller, where only silicon had a different behavior from the standard (+5.5%), with the other elements of the HD4 alloy as well as those of the HD2 alloy that had not changed, remaining within the standard specification.

Table 5: Assessment of chemical analysis of extracted aluminum — HD2G.

Chemical analysis evaluation of extracted aluminum – Alloy HD2G									
	Cu	Si	Mg	Zn	Fe	Mn	Ni	Pb	Sn
Standard	1.0 ~ 2.5	8.5 ~ 11.0	0.20 max.	1.0 max.	1.0 max.	0.30 max.	0.30 max.	0.20 max.	0.10 max.
Result found	1,736	10,204	0,094	0,281	1,057	0,304	0,054	0,052	0,025
Variation	-	-	-	-	0,057	0,004	-	-	-
% Variation	-	-	-	-	5,7%	0,4%	-	-	-

Source: Elaborated by the authors (2019).

Table 6: Assessment of chemical analysis of extracted aluminum — HD4.

Chemical analysis evaluation of extracted aluminum – Alloy HD4									
	Cu	Si	Mg	Zn	Fe	Mn	Ni	Pb	Sn
Standard	0.10 max.	0.50 ~ 1.10	0.40 ~ 5.5	0.10 max.	0.50 ~ 0.8	0.50 ~ 0.8	0.10 max.	0.20 max.	0.10 max.
Result found	0,114	1,161	3,637	0,065	0,720	0,585	0,009	0,022	0,012
Variation	-	0,061	-	-	-	-	-	-	-
% Variation	-	5,5%	-	-	-	-	-	-	-

Source: Elaborated by the authors (2019).

It was previously expected that the HD4 alloy would behave differently from the HD2G alloy in terms of the generation of slag during the alloy fusion, a theory that was confirmed when we analyzed individually the percentage of generation of borer per alloy. At the end of the collection of the data done during the 10 days in which the equipment was in constant operation, we carried out the calculation of the percentage of slag daily, based on the quantity of aluminum loaded from the scrap + lingote furnace, and of the slag removed at each melting cycle. The values resulting from the calculation of the daily generated slag percentage are shown in Figure 9. The HD4 alloy showed in an absolute manner a higher percentage of slag every day analyzed, a phenomenon for which it is justified by the presence of Mg 38.6 times greater than in the HD2G alloy. Magnesium, as seen before, provides oxidation of the aluminum alloy, which brings about the formation of oxide films over the level of bath of the molten metal and consequently increases the index of generation of borer.

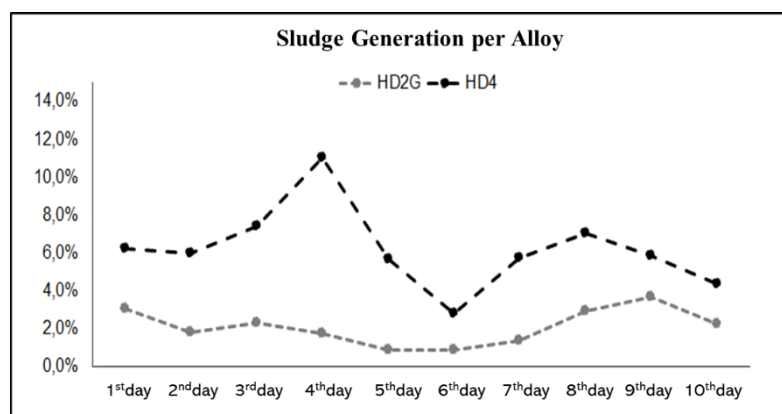


Figure 9: Chemical analysis of the extracted HD4 aluminum.

Source: Elaborated by the authors (2019).

We can observe that even when dealing with the same alloy, there is still a certain variation in the percentage of slag as the day analyzed. To explain this phenomenon, we took into consideration other factors that influence the generation of slag, such as the temperature parameters of the furnace and the degree of purity of the aluminum used, these being fundamental factors for controlling the oxidation of the alloy that results in the control of the generation of slag.

The material to be reused in the process originates from the separation of oxide and other impurities that are found in the form of solid particles mixed with the aluminum that is removed from the furnaces during the cleaning. The oxide micro-particles, when they are removed from the furnaces and deposited in the equipment's container, are added to form a porous body through which the aluminum flows, as a function of the vibration inserted into the system, which potentializes the extraction beyond the process of gravity flow. Aluminum still melted through the Ø20mm holes and is collected in the lingoteric drawer. In carrying out this process, we verified that the aluminum brings with it some microparticles of oxide that are dispersed in the alloy, as presented in the micrographic test carried out through the digital microscope carried out with the samples collected from the aluminum extracted, Figure 10.

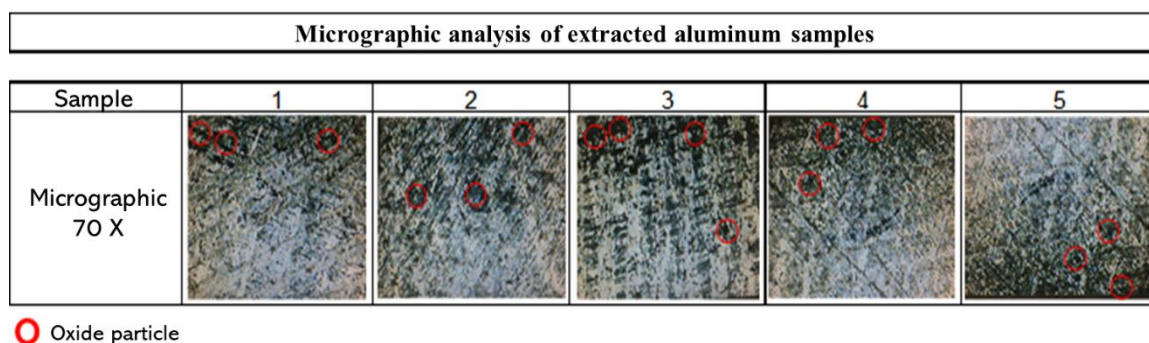


Figure 10: Micrograph of the extracted aluminum samples.

Source: Elaborated by the authors (2019).

We also carried out an analysis of the resistance of the samples of the aluminum extracted and of the ingots conventionally used in the process. Samples of aluminum extracted to the HD4 alloy were collected for resistance testing. The methodology applied to motorcycle brake levers was used to check the resistance of the samples collected. The samples were flex-inflated through the EMIC Dynamometer - DL - 100 KN to their breakpoint. To assess the variation in resistance, we carried out the test on a sample with the same dimensional characteristics taken from the ingot used and then compared to the resistance of the samples of the aluminum extracted, Figure 11.

By superimposing the data for a comparative analysis of resistances, we found that the recovered aluminum samples exhibited a behavior similar to that of the conventional ingot used, with a difference of only 6.2% as a function of the force borne up to its breaking point. Likewise, the deformation of the samples occurs in a very similar manner, except for the fact that the alloy originating from the ingots deforms a

little beyond the samples of recovered aluminum, a phenomenon justified by the presence of microparticles of oxides, which degrade the malleability of the alloy, reducing the deformation at the moment of rupture.

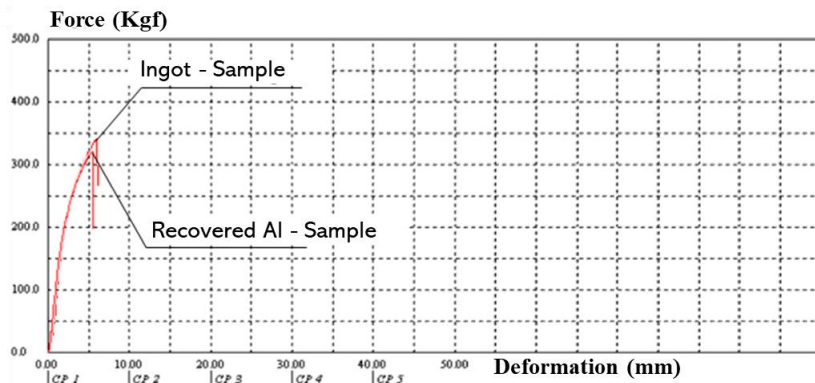


Figure 11: Comparison of resistance of the samples.

Source: Elaborated by the authors (2019).

3.3.2 Economic viability of the project

The development of the aluminum oxide separator took place as a function of the need to reduce the losses of aluminum arising from the foundry process. The main raw material of the metal foundry (in this case aluminum) is the metallurgical industry, so any change in the process is either beneficial or evil, and it has considerable impact on the company. With a view to the economic and financial analysis after the implementation of the separator, the process was monitored using the monthly cast aluminum production indicators and the corresponding borer generation index as Figure 12.

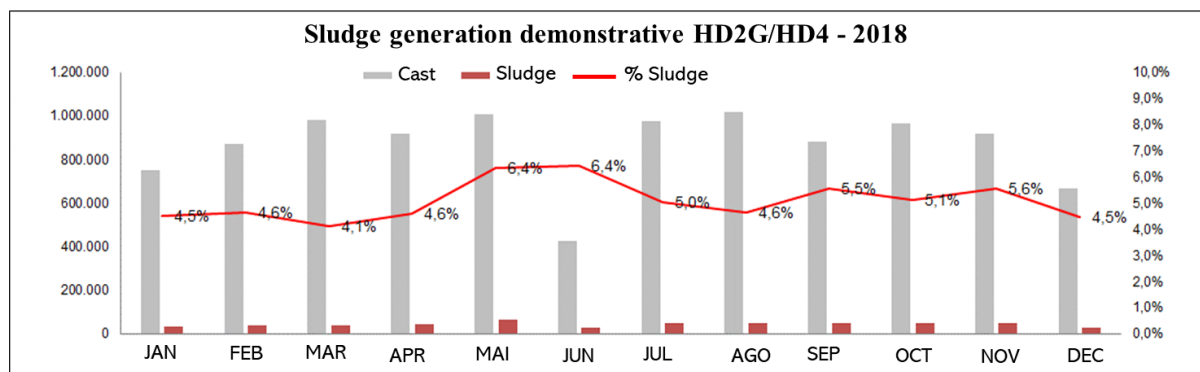


Figure 12: Showcase of sludge generation.

Source: Elaborated by the authors (2018).

Parallel to the production and waste records of the process, the corresponding data was also pointed out for the equipment's work in the aluminum recovery process, which previously had been discarded from the process along with the slag. Figure 13 shows the data on the generation of sludge and the recovery of aluminum, values in which they reveal the efficiency of the equipment, an average yield for the reuse of roughly 35.2% of all slag processed. The extracted material returns to production by means of the reuse system used in the process, in order to guarantee the quality of the parts produced. The aluminum sludge after passing through the extraction process on the separator is destined for another institution that is still working on its processing by way of the process of refusion of slag.

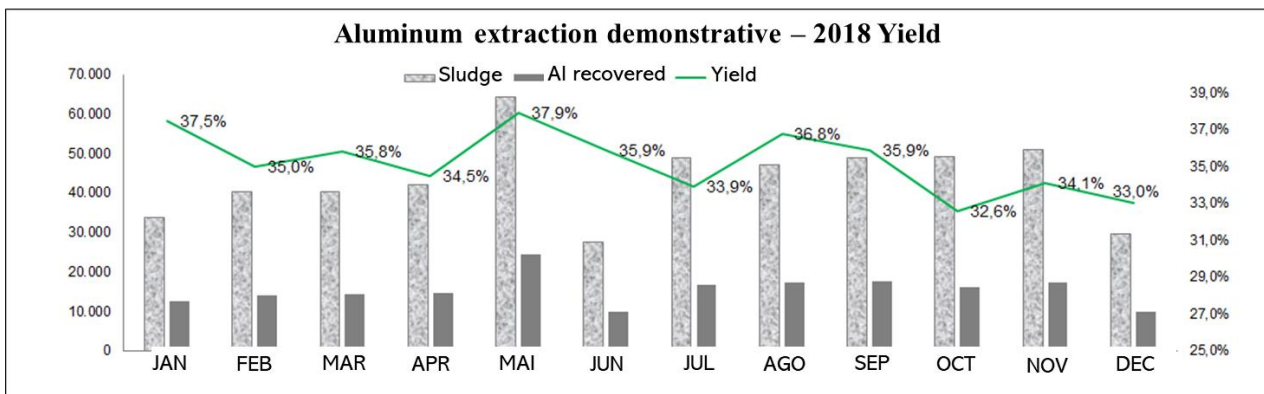


Figure 13: Showcase of blur generation.

Source: Elaborated by the authors (2018).

We have carried out an analysis of the operating cost of the equipment in relation to the energy consumption from the use of compressed air by the motor vibrators and the input used in the process. The operating costs are shown in figure 14.

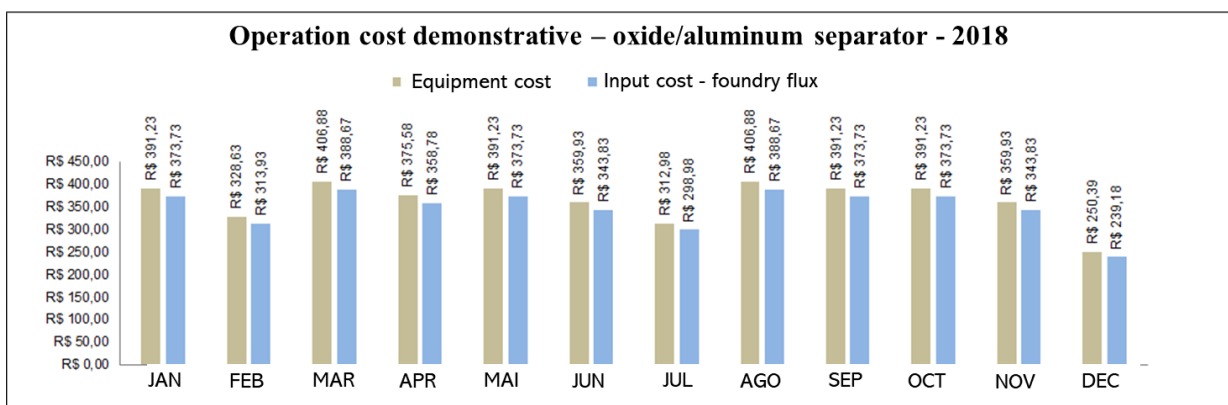


Figure 14: Operation cost - Oxide separator.

Source: Elaborated by the authors (2018).

As previously seen, the discarding of aluminum in the foundry process generated a considerable loss for the company, an average monthly cost of approximately R\$ 402,141.93, a factor that reflected directly in the cost of manufacturing the parts. The loss occurs as a result of the devaluation of the metal, a reduction of 81% in comparison with the purchase value of the alloy and the sale of the sludge. After the implantation of the aluminum oxide separator, we can verify, according to the monthly statement of savings, figure 15, an average savings of R\$ 109,821.97, as a function of the valuation of the recovered aluminum.

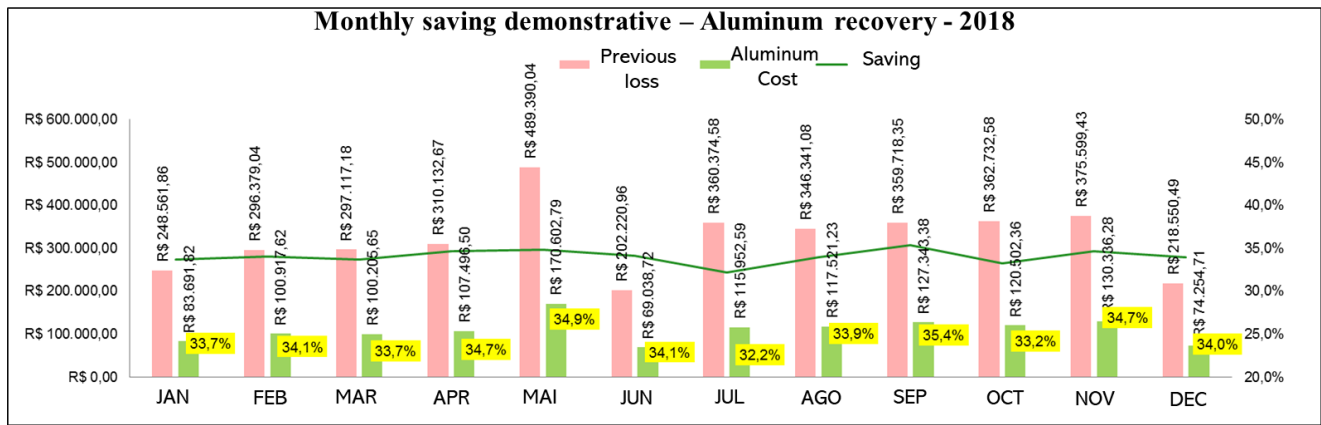


Figure 15: Statement of Work and Monthly Savings.

Source: Elaborated by the authors (2018).

During all the stages of the project development process, equipment was sought that made use of simple mechanisms that are easily accessible to the market, in order to meet the customer/user requirements and at the same time viable from the financial point of view. To construct the equipment, an investment of R\$ 13,093.95 was made for each piece of equipment. For the company studied, four pieces of equipment were needed to meet the production demand, totaling the investment of R\$ 52,375.80, a value amortized immediately in the first month of the equipment's operation, as shown in figure 16. In view of this, the equipment fulfills the function in which it was conceived, maximizing the institution's results through a high economy with raw material aligned with the low operating cost, factors that collaborate in a positive way for the company's survival in the metallurgical industry, maintaining its competitiveness in the face of market challenges.

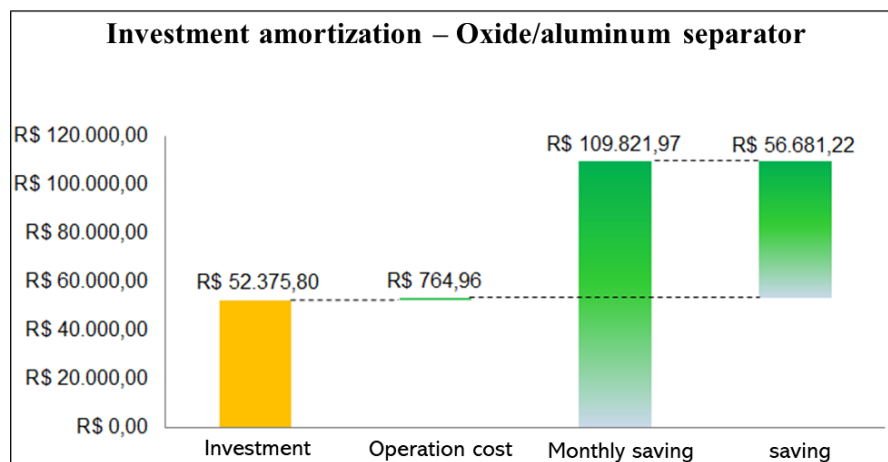


Figure 16: Amortization of investment - Oxide / aluminum separator.

Source: Elaborated by the authors (2018).

4. CONCLUSION

With the carrying out of all the stages of the development of the equipment, governed by a methodology for the research and development of the product, it was possible to select the best design of

the project, which in an efficient manner attended to the needs and requirements brought about during the development of the work, which had the objective of developing equipment to act in the reduction of the losses of aluminum by separating the metallic content contained in the slag coming from the foundry process and consequently reducing the cost of the raw material in the manufacture of the parts.

The equipment showed an average yield of 35.2%, given the content of metallic aluminum extracted from the slag. The alloy yield analysis shows that the recovery rate for the HD4 alloy is higher than that of the HD2G alloy, a phenomenon justified by the higher concentration of metallic aluminum in the slag of the corresponding alloy.

The chemical analyzes carried out on the recovered aluminum samples made it possible to verify the variation in the concentration of the composition elements of the alloys HD2G and HD4. In general, we find that there was a small variation in the chemical elements of the alloy, a factor easily corrected by the re-use system adopted in the process.

The visual characteristics of the recovered aluminum samples were maintained according to the material already used in the process. The micrographic analysis of the samples revealed the presence of aluminum oxide microparticles dispersed between the alloy that are trapped in the extracted material and remain there during the solidification.

The resistance test of the recovered aluminum samples showed a similarity of resistance compared to conventional ingot samples. There was a variation in the resistance of -6.2%, a factor justified by the reduction in the property of the alloy's elasticity as a function of the presence of microparticles of oxides.

By analyzing the cost-effectiveness of deploying the equipment, we have seen the reduction in financial losses. The company had an average monthly cost with the discarding of the slag of R\$ 402,141.93, brought about by the depreciation of the alloy as a function of the selling price of the slag. After implanting the separator in the foundry process, an average reduction in losses of 34% corresponding to the material recovered was observed, which brought the company an average monthly savings of R\$ 109,821.97, reflecting directly on the reduction in the manufacturing cost and contributing to the company's survival in a competitive market.

By analyzing the monthly economy, we check the viability of the project, taking into account the cost of operating the equipment and the monthly savings it provides. The separator showed a low operating cost, on average R\$ 764.96/month, due to the use of a simple mechanism and the low consumption of inputs. We verified the immediate depreciation of the investment, right from the first month of operation, making the equipment viable in the financial point of view.

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