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THE INFLUENCE OF THE FLUX TREATMENT ON METALLIC BATH CONCERNING THE LEVEL OF INCLUSIONS IN ALUMINUM ALLOYS

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The present research aimed to establish the influence of the methods used in an aluminium foundry for the treatment of the metallic melts, the type and amount of flux on the level of inclusions in the metallic melts. A series of tests were carried out on 5754 and 5083 alloys, varying the fluxing methods, the type and the quantities of flux used in the treatment of the metallic bath. Following the metallographic analysis, the existence of inclusions, especially oxides, films of oxides, spinel, MgO, carbides and borides, but also flux particles in the case of a batch, were highlighted.

Keywords: Aluminum alloys, flux, inclusions

1. Introduction

Most metals in liquid state contain different types of inclusions (oxides, carbides, borides, chlorides, etc.), and the formation of casting defects is an inevitable consequence of their presence. Inclusions are separate phases or agglomerations/clusters of particles, metallic or non-metallic, which are not compactly connected to the rest of the melt and which are transferred into the structure of the solidified metals, negatively influencing their quality. The cast product that develops in its structure such areas with separate phases or agglomerations/clusters of particles of considerable size is impossible to use.

In the case of aluminum smelting, the development process of inclusions is strongly influenced by the high reactivity of aluminum, especially liquid aluminum, with oxygen. The concentration of inclusions in an unprocessed aluminum melt varies between 0.005% and 0.02%, and the sizes vary from $d < 1$ μm to several millimeters and have different shapes and morphologies. The largest part of these inclusions is represented by non-metallic inclusions, with $d \leq 50$ μm such as:

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particles of oxides (Al_2O_3), spinel ($MgAl_2O_4$) and carbides (SiC, Al_4C_3), all having a melting temperature higher than that of aluminum.

The reduction of the content of inclusions in the metallic bath is achieved by using fluxes - solid salts or mixtures of solid salts. With the help of these salts or mixtures of salts, agglomeration, separation and transport of the inclusions to the surface of the metal bath are generated, to be extracted by rinsing. In recent years, the most frequently used salt is $MgCl_2$, which forms eutectics at low temperature and reacts with the alkaline chemical elements in the metallic bath forming compounds that rise, through flotation, in the slag.

Treating the metallic bath with solid salts is a temperature-dependent process that must be sufficiently high, above the melting temperature of the salt used, so that both the metal melt and the salt have high fluidity, ensure good contact between them and maximum reactivity.

The salt flux can be added to the metal melt as follows:

- manually and mixed with a squeegee
- by injection with a lance or with specialized rotors, using an inert gas as a transport agent

2. Theoretical considerations

Inclusions, in aluminum melts, appear from the process of obtaining electrolytic aluminum and from the elaboration of the metallic melt, as follows:

- the formation of non-metallic inclusions depends only on the presence of oxygen or an oxygen-carrying agent (eg: ambient humidity);
- the formation of metallic/intermetallic inclusions is strongly dependent on the chemical composition of the melt and the process temperature.

According to the theory [1], there are several classifications of inclusions depending on the form of aggregation, the chemical composition, the way of formation, their behavior, etc.

Depending on the form of aggregation, the inclusions in the metallic bath can be of three types:

a) solid, metallic or non-metallic inclusions – rigid, isolated particles of different phases, textures and morphologies that are introduced into the system through external sources (refractory lining, refining agents) or are formed by chemical reactions between the chemical elements in the process ;

b) liquid inclusions – deformable particles, generally spherical, fluorides and chlorides, which appear as a result of the reactions between the metal bath and chlorine gas or chlorine-based fluxes that are used for degassing or cleaning the metallic bath. These chlorides or fluorides are, in particular, $MgCl_2$, cryolite Na_3AlF_6 (source = electrolysis) or NaF - which, if present, forms large agglomerated inclusions;

c) salts and flux particles - which remain in suspension in the melt and are found in the cast product. This phenomenon occurs if the fluxing of the metallic bath and the extraction of the slag is not carried out at the correct temperature/quantity, in which case the flux remains in the metal bath in the form of moist salt particles surrounded by a film of oxides.

Depending on the chemical composition, in the aluminum melt there are three general types of inclusions, which influence the behavior of aluminum in processing and use:

a) gaseous inclusions (H_2), which are reduced by injecting inert gases into the metallic melt;

b) inclusions of alkaline and alkaline earth metals that are reduced by their reaction with chlorine or chloride-based salt fluxes;

c) metallic and non-metallic inclusions, which can be solids, immiscible liquids or combinations between the two types and which are reduced on several stages of the process, both in the furnace, by fluxing, and on the casting line, by filtration.

From metallurgical practice, it has been observed that any inclusion with size d > 10 µm is harmful to the cast product, and inclusions with size d < 10 µm, if present in large quantities, can cause major defects in cast aluminum products, especially in the case in which it shows the ability to agglomerate (eg: oxides, borons).The electrolytic aluminum obtained by the Héroult-Hall process has a large number of non-metallic inclusions, with dimensions ≤ 50 µm and approximate 0.5 ppm H_2. The inclusions are in the form of particles of oxides (Al_2O_3), spinel ($MgAl_2O_4$) and carbides (SiC, Al_4C_3), with a higher melting point than aluminum. [2]

3. Experiments regarding the treatment of the metal bath with flux

A series of tests were carried out on 5754 and 5083 alloys (the chemical composition is shown in table 1), with different fluxing methods, type and quantities of flux used in the treatment of the metallic bath.

Table 1

Chemical composition of 5754 and 5083 alloys

Alloy	**Si %**	**Fe %**	**Cu %**	**Mn %**	**Mg %**	**Cr %**	**Zn %**	**Ti %**	**Other**		**Obs.**	**Al %**
									Each	**Total**		
5083	0.4	0.4	0.10	0.4-1.0	4.0-4.9	0.05-0.25	0.25	0.15	0.05	0.15	-	Bal.
5754	0.4	0.4	0.10	0.50	2.6-3.6	0.30	0.20	0.15	0.05	0.15	Mn+Cr = 0.10-0.6	Bal.

The tests were carried out in the Foundry Department of ALRO S.A., the alloys were produced in gas furnaces with a capacity of 60 tone, and the casting was carried out on an installation using Wagstaff technology.

Depending on the type of alloy and the application of the cast product, on the production flux of the slabs from the Alro Foundry, the removal of inclusions from the metallic melt is carried out by dragging with salts, in one or two stages of treatment, as follows:

- one stage: manual, treatment with drossing flux;
- two stages: manual, with drossing flux + manual, with Na/Ca reduction flux;
- two stages: manual, with drossing flux + lance injection (inert gas = Ar), with Na/Ca reduction flux.

For the tests, it was used:

- the Na/ Ca reduction flux supplier A
- drossing flux, supplier B,
- Na/ Ca reduction flux, supplier C.

According to the technical sheets sent by the suppliers, the technical data of the fluxes used are presented in Table 2:

Table 2

Characteristics of the fluxes used for experiments

Flux	**Amount** [Kg/ t]	**Temperatures** [ºC]
Flux A	1 – 1.5	min. 700
Flux B	1 – 1.5	min. 700
Flux C	min. 0,5 kg/t	min. 480

After the treatment with salts, the slag resulting from the flotation process is extracted from the surface of the metallic bath. If the metallic bath has the chemical composition according to the customer's specification, for the decantation of large and heavy inclusions and for the flotation of inclusions with a specific weight lower than the melt, it is left for at least 30 minutes without interfering with it.

It should be concluded that:

- the PoDFA (Porous Disc Filtration Apparatus) samples for measuring the level of inclusions were taken at a length of the batch between 2000 – 2500 mm. Since the PoDFA analysis method is a pointed method and the movement of the inclusions during the rocking of the furnace, depending on their density and size, is random, the level of inclusions is variable depending on the casting length (degree of inclination of the furnace).

According to the literature, in the case of large-sized inclusions (≥20 μm) that settle on the bottom of the furnace, during the rocking of the furnace, they migrate

to the evacuation zone, which leads to a significant increase in their level towards the end of casting;
- in all cases the sedimentation time was 30 minute, to ensure the sedimentation of large inclusions (d≥20µm);
- in all cases the temperature was 718ºC ≤ T≥ 735 ºC, above the temperature recommended by flux suppliers (Table 2), thus fulfilling the recommendation from the literature regarding ensuring the reactivity of the metal bath - flux [3].

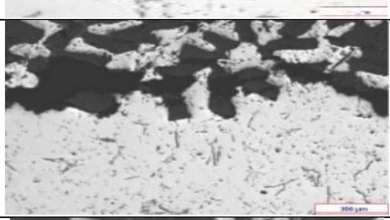
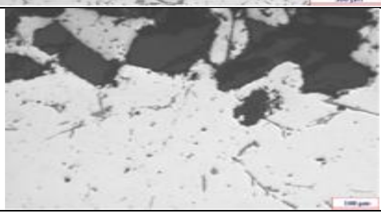
4. Experimental results and their interpretation

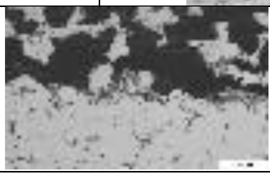
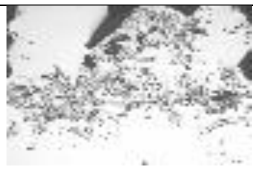
Following the metallographic analysis on the collected PoDFA samples, the existence of inclusions, especially oxides - film of oxides, spinel, MgO, carbides and boron’s, but also flux particles - in the case of some brazes (alloy 5083) was highlighted.

The results obtained from the metallographic analysis of the PoDFA samples are presented in Table 3.

Table 3

The results of the metallographic analysis of the Podfa sample, taken from the furnace after the flux treatment

Alloy	Batch	Metallographic analysis PoDFA
5754	1.1	
	1.2	
	1.3	
	The main inclusions identified are: oxides (film), spinel, MgO, carbides, borons	

Alloy	Batch	Metallographic analysis PoDFA	
5083	2.1		The identified inclusions are: oxides (film), spinel, MgO, carbides, boride
	2.2		
	2.3		
			
	For batch 2.2, in addition, agglomerated flux particles were identified, also highlighted by the high value of the level of inclusions = 1.792 [mm^2/kg]		

A. 5754 Alloy

PoDFA samples from three cast batches from 5754 alloy were taken and analysed, according to Table 4. Regarding alloy 5754, the following can be observed in Fig. 1:

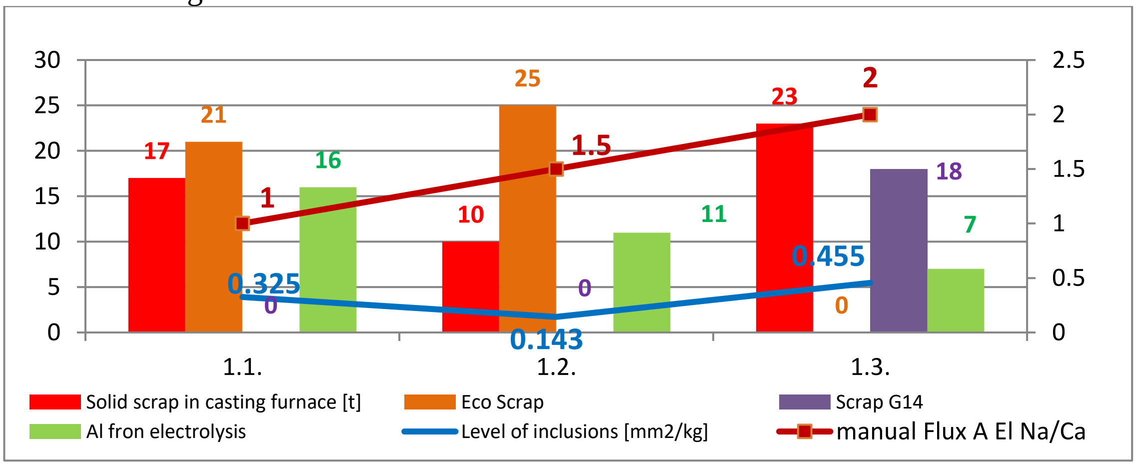


Fig. 1. The level of inclusions depending on the amount of flux used in 5754 alloy

- for all the three batches, was used waste (scraps), both melted directly in the processing furnace and previously melted in a separate furnace;
- the same drossing flux type A Na/Ca was used, the same method of fluxing the metal bath - manual fluxing - and the amount of treatment flux was varied;
- increasing the quantity of drossing flux above 1.5 kg/t metallic bath does not seem to help to reduce the level of inclusions. It can be observed that by increasing the amount of flux to q=2 kg/t liquid, the largest amount of inclusions was measured (batch 1.3, level of inclusions =0.455 [mm^2/kg]);
- the amount of electrolytic metal seems to have a random influence on the level of inclusions, batches in which the amount of electrolytic metal was higher have a high level of inclusions, compared to batches in which the amount of electrolytic metal was lower;
- the level of inclusions seems to be significantly influenced by the amount of solid waste fed directly into the processing furnace. It can be assumed that treating with flux and extracting the slag from the liquid metal coming from the melting of the waste beforehand in another furnace before being charged in the elaboration furnace reduces the influence of this type of metal on the final level of inclusions;

In the case of alloy 5754, the flux treatment of the metal bath, quantity q=1.5 kg/t using the manual method (Flux A +drossing flux Na/Ca) gave the best results, in the conditions where solid waste was loaded including in the casting furnace.

Table 4

Level of inclusions in the furnace after treating the melt, varying the quantities, methods and types of flux

Alloy	Batch	Flux				Q scarp [t]				Al liq [t]	Q total [t]	Inclusions level [mm^2/kg]
		Method	Q [kg/t]	Total flux [kg]	Flux type	Solid	Eco	G 14	Total			
5754	1.1	manual	1	1	Flux A +drossing flux Na/Ca	17	21	0	38	16	54	**0.325**
	1.2	manual	1.5	1.5	Flux A +drossing flux Na/Ca	10	25	0	35	11	46	**0.143**
	1.3	manual	2	2	Flux A +drossing flux Na/Ca	23	0	18	41	7	48	**0.455**

B. Alloy 5083

PoDFA samples from 3 cast batches from 5083 alloy were taken and analyzed, according to Table 5.

Table 5

Level of inclusions in the furnace after treating the melt, varying the quantities and methods and types of flow

Alloy	Batch	Flux						Q scrap [t]				Al liq [t]	Q total [t]	Inclusion level [mm²/kg]
		Method 1	Q [kg/t]	Method 2	Q [kg/t]	Total flux [kg]	Type of flux	Solid	Eco	G14	total			
5083	2.1	manual	1	manual	0.5	1.5	Flux B + Flux C	15	0	25	40	7.4	47.4	**0.372**
	2.2	manual	1	lance	0.5	1.5	Flux B + Flux C	13	14.1	0	27.1	21	48.1	**0.300**
	2.3	manual	1	manual	1	2	Flux C	10	14	8	32	14.5	46.5	**1,792**

Regarding alloy 5083, the following can be observed (Fig. 2):

- for the batches analysed, liquefied metal from the Eco Smelter, waste melting furnace and Electrolliza was used;
- for all the batches studied, waste melted directly in the casting furnace was used - for processing;
- as in the other cases studied, the most significant influence on the level of inclusions seems to be the solid waste fed directly into the processing furnace. It can be assumed that, because the liquid metal from the waste melting in the G14 furnace is treated with flux and the slag is extracted before being fed into the processing furnace, its influence on the final level of inclusions is reduced;
- for the studied batches, two types of fluxes were used (Vedani drossing flux and Promag SI – Na/Ca reduction flux), both fluxing methods (manual and lance) and the amount of flux used, both total and on the fluxing stage;

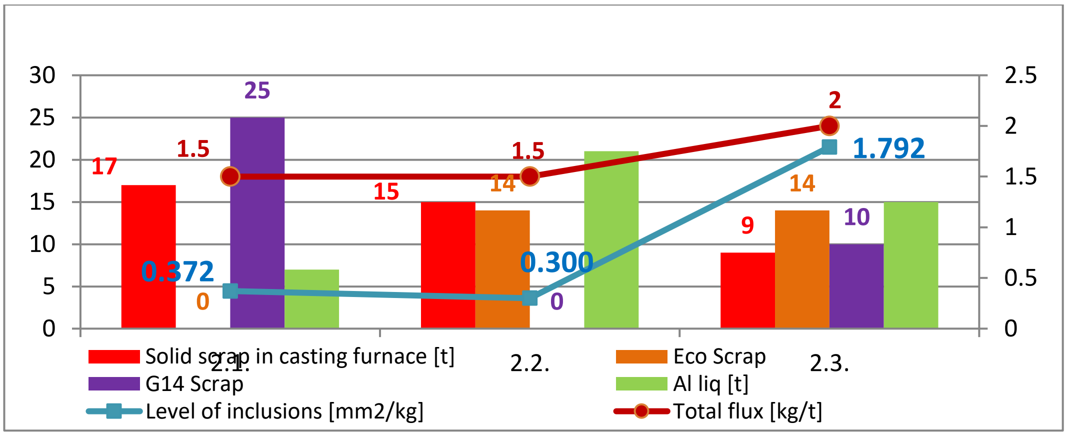


Fig. 2. The level of inclusions depending on the amount of flux used in 5083 alloy

Regarding the type of flow, the quantity and the method used, in Fig. 3 the following aspects can be observed:

- for the cases studied, the increase in the total amount of flow has a random influence. It can be observed that:

• at the same amount of flow q=1.5 kg/t, using two types of flow, the results are similar, inconclusive;

• using the same amount of flow and two different methods, the results are similar, inconclusive;

- if the amount of flux increased and the total level of inclusions increased, flux particles remaining in suspension in the metal bath were identified. However, it is not possible to correlate the increase in the level of inclusions with the amount of flow used, so it cannot be established that by reducing/increasing the amount of flow, a reduction/increase in the level of inclusions will be obtained.

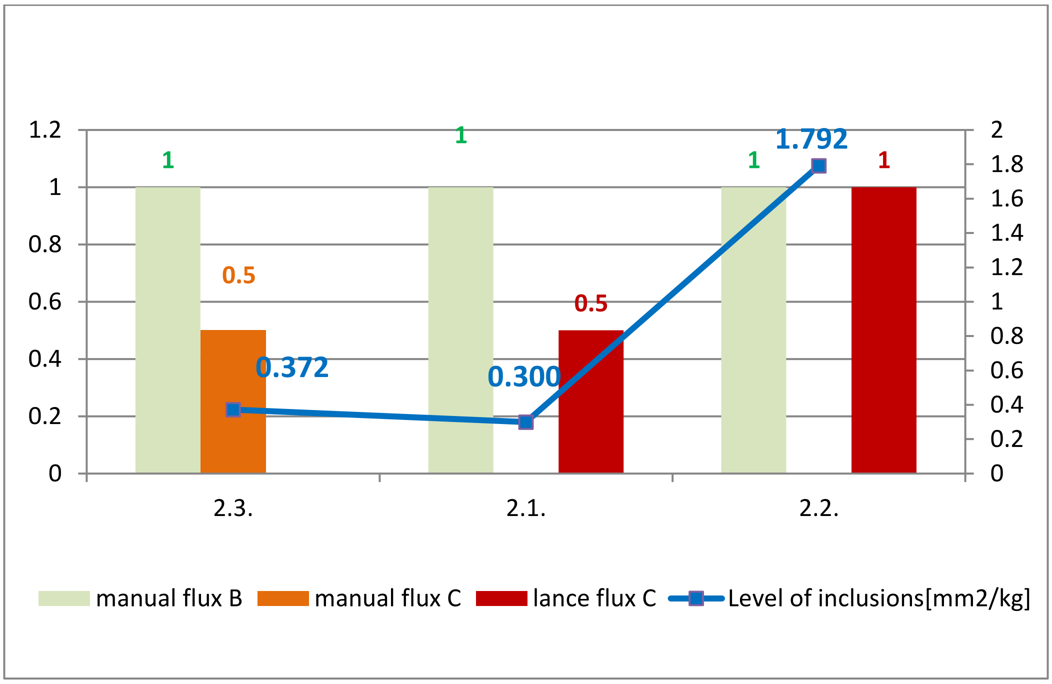


Fig. 3 The level of inclusions depending on the amount of flux and the fluxing method in 5083 alloy

Once again, it is worth mentioning the attention that must be given to the complete elimination of flux salts from the metallic bath - the influence of the human factor. Therefore, the effect of reducing or increasing the amount of flow, considering the test results, was inconclusive.

5. Conclusions

A. The level of inclusions in the metallic aluminum bath is substantial, their size and type is varied. Reducing the level of inclusions represents a challenge for aluminum foundries, the result being directly dependent on several factors and parameters that intervene in the process, the most important being:

- quality of raw materials and auxiliary materials;
- process parameters, especially temperature;
-working method;
- the human factor.

B. According to literature [4], for moulded deformable products intended for lamination for general use, the recommended level of inclusions = 0.01 mm2/kg, under the conditions that the level of H_2 < 0.1 ml/100 g liquid. In the case of cast products with special destinations, both the level of inclusions and hydrogen are recommended to be even lower.

C. Fluxing the metal bath, sedimentation and extraction of slag is a critical operation, the results obtained depend on many variables. The tests showed that if a similar amount of flux and a similar method of fluxing are maintained, the results obtained evolve randomly, in a large range of values.

D. The tests carried out in the ALRO Foundry regarding the influence of the quantity and type (commercial brand) of salt flux used on the reduction of the level of inclusions in the metal bath did not give conclusive results. Furthermore, the laboratory analyses showed that slags with a low level of inclusions developed, in the cast product, oxide in the network of considerable sizes and porosity of dimensions comparable to slags with a much higher level of inclusions.

E. It could not be established with certainty that the type of flow used influenced the increase/decrease of the level of inclusions, the results being random.

F. For the cases studied, the increase/decrease of the total amount of flux shows a random influence on the level of inclusions. Analysing the results of the PoDFA analysis shows that the level of inclusions after flux treatment is not directly dependent on the amount and type of flux used, but, according to the literature [5-8], on the level of reactivity and the dimensions of the components/inclusions in the metallic bath at the temperature the process, in particular, the density/type of particles that form the inclusions and the way of working. If the density of the particles is close to the density of the metal bath or if the working parameters for fluxing and slag extraction (temperature) are not respected, the flow has a reduced capacity to transport them so that most of them remain in suspension in the metal bath, more, remain in suspension and moistened flow particles.

G. The tests seem to demonstrate that the treatment of the metal bath with the help of the lance is not the most appropriate choice, a situation also presented in other specialized studies [5-8]. The flow blowing treatment with the lance causes strong turbulence, which can lead to the formation of bifilms of oxides that are much more difficult to remove from the melt, and which will be found as inclusions in the solidified product.

H. The high level of inclusions measured for certain tested batches probably has a consistent connection with the flux particles remaining in suspension in the metal bath and highlighted by the metallographic analysis. In the case of these bales, the treatment was the usual one (1.5 kg/t flow, method: manual + lance). Because during the treatment with the lance the temperature of the bath decreases and considering that the low temperature of the process is the factor with the greatest influence in the case of keeping these particles in suspension in the metallic bath (+ the human factor), it can be stated that the treatment with the lance adds a additional problem in the process. [5-8]

I. Reducing or increasing the amount of flux compared to the amount recommended by the manufacturer or the type of the flux does not guarantee a reduction in the level of inclusions. For this reason there is no international standard to regulate this operation, the Aluminum Association's recommendation is testing, on the production flow, both the type and the required amount of fluxes, starting from the supplier's recommendations and adapting them to the production needs.

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