REDUCING THE LEVEL OF INCLUSIONS FROM THE METALLIC ALUMINUM MELTING, USING A DOUBLE FILTRATION SYSTEM

V. SERBAN-TANASE[1], M. CIURDAS[2*], D.A. NECSULESCU[3]

The paper presents the research carried out at an industrial aluminum foundry, with the aim of finalizing a technological solution that ensures a minimum level of inclusions in aluminum alloys. A high level of quality of aluminum products used in strategic fields can thus be ensured. The application of the research results allows increasing the market competitiveness of the aluminum products. The authors have demonstrated the possibility of increasing the quality of the products by increasing the performance of the operations of the technological flow of casting by introducing a modern system for filtering inclusions, which are the main cause of the appearance of defects during subsequent use of the products.

Keywords: aluminum alloys, inclusions, filtration, casting, ceramics.

1. Introduction

Two types of metallic and non-metallic solid inclusions are known from the literature in aluminum melts such as:

- inclusions, as dissolved elements,
- inclusions, as particles in suspension.

Inclusions, as dissolved elements are inclusions of the oxide type of the elements in the chemical composition of the melt, which are formed during the processes of melting or which come from the raw material used, such as: complex or simple oxides of Mg, Na, Fe, As, Sr [1-5].

Inclusions, as particles in suspension are: aluminum oxide Al_2O_3 and inclusions such as boron, carbides or particles, dust and refractory materials.

These inclusion particles are phases separated from the melt, both physically and mechanically (ex: MgO and Al_4C_3concentrationersed particles, with sizes from a few microns to films of inclusions or clusters that extend over

[1] Ph.D Student, Material Science and Engineering Faculty, University POLITEHNICA of Bucharest, Romania, e-mail: avst11@yahoo.com
[2] Lecturer, Faculty of Materials Science and Engineering, University POLITEHNICA of Bucharest, Romania, e-mail: ciurdasmariana@yahoo.com *corresponding author
[3] Lecturer, Faculty of Materials Science and Engineering, University POLITEHNICA of Bucharest, Romania, e-mail: alinanecsulescu@yahoo.com

several millimeters, and their concentration can be in a range from a few ppm to a few mass percentages.

The presence of solid inclusions in aluminum alloys affects the mechanical properties, processing capacity, plasticity, corrosion resistance and electrical conductivity and lead to the appearance of defects in the processes of casting, extrusion, lamination/drawing [6-8].

Typical inclusions found in aluminum melts and their sizes are shown in table 1.

Table 1

Typical inclusions in aluminum melts [24]

Type of inclusion	Shape of inclusion	Density [g/cm^3]	Size [μm]
Al_2O_3	Particles, films	3.97	0.2-30;10-5000
MgO	Particles, films	3.58	0.1-5;10-5000
$MgAl_2O_4$	Particles, films	3.6	0.1-5;10-5000
Salts, chlorides, fluorides	Particles	1.98 - 2.16	0.1 - 5
Al_4C_3	Particles	2.36	0.5 - 25
TiB_2	Particles, agglomerates	4.5	1 - 30
AlB_2	Particles, agglomerates	3.19	0.1 - 3

In the melt of aluminum alloys, Al and Mg interact with H_2 and O_2 and forms oxides - chemically stable compounds with a low thermal dissociation coefficient. These dispersed particles are not wettable by the aluminum melt; they are not part of the solidification process, being the main source in the formation and appearance of casting defects [9-12].

The type, shape, size and distribution of the inclusions in the lattice of the final product is considered a performance characteristic of the casting. Inclusions, of any type, affect all the mechanical properties of the molded product and the plasticity of the material, determining the behavior in processing and subsequent use [13-15].

The presence of inclusions in the aluminum melt, even as small particles, between 10 – 50 μm, can lead to a poor-quality surface of the product, internal porosity, discontinuities in the structural matrix, reduction of physical-mechanical properties: mechanical resistance, elongation, corrosion resistance and resistance, which ultimately lead to the rejection of the final products. The inclusions provide centers for crack propagation under fatigue, forms hard spots that lead to reduced processing capacity, or interact with H_2 dissolved in the matrix and lead to the dramatic degradation of the material.

The removal of solid inclusions can be done by melt filtration

The filtration is the most effective step in eliminating/reducing the level of inclusions, even those dissolved in the aluminum melt. The elimination/reduction of inclusions by filtration strongly improves the mechanical properties of the products [1-3, 16-20].

The filtration efficiency is defined based on particle counts (either total or grouped into suitable size ranges) [9]:

$$\eta = (C_i - C_o/C_i)*100 \tag{1}$$

Where Ci is the concentration of particles entering into th e filter per unit time, and Co is the count of particles out of the filter per unit time.

The filtration efficiency depends directly on:

- the size of the inclusion particles: more larger inclusion particles, the efficiency of filtration is better.

- the dimension of the filter pores: the smaller pore size of the filter, the smaller the size of the captured inclusions particles.

Filtration is widely used in the development and casting of light alloys (aluminum, magnesium) and aluminum bronzes.

The selection of filter is important for filtration efficiency.

The filters used to refine non-ferrous alloys can be classified according to the following criteria:

-according to the inclusion retention mechanism: active filters, and neutral filters.

-according to the manufacturing method (technology), granular bed-consisting of flux particles/balls, minerals (SiC, Al_2O_3) and/or different refractory materials, glass fiber, extruded ceramic fibers, multicellular ceramic foams, plates (tubes) porous pressed, pressed, with holes.

-according to the filtration technology, special filtration systems, filters located on the casting network.

The efficient operation of these filtration installations outside the melting furnace is based on direct contact between the liquid alloy subject to filtration and the filter material. In any modern foundry, the filtration system on the casting line is the final step of the production flow that ensures the cleaning of the cast metal, and the filtration system chosen as well as the number and type of filtration units are important for the efficiency and result of the filtration [21-23].

In the case of filters, the choice of their porosity level depends on the cast product, the required metal flow rate, the flow rate of the melt and the quality requirements of the product, the technological requirements are regarding the level of inclusions, the porosity of filter must be higher.

In the literature, recommendations are made regarding the porosity of the filter, depending on the cast product; these recommendations are presented in table 2.

It should be stated that, worldwide, depending on the destination area of the product type, the fineness of the filter for products with special destination in top areas can reach 80 ppi, including using several stages or types of filtering.

Table 2

Recommended porosity of the filter depending on the characteristics of the cast product

Casting type	**Metal speed [mm/sec]**	**Metal flow rate [kg/sec/m^2]**	**Recommended filter type**
Casting of bars	10-19	19-36	30-40
Casting of slabs	6-15	17-29	40-65
Continuous casting	3-10	6-19	20-50

In the literature, several methods of improving the filtration efficiency are presented, but in practice the following are used:

-reducing the filtration speed;

- agglomeration of small inclusion particles;

- the use of in-line filtration batteries - multistage filtration, combining several filters of different porosities or several types of filters of different porosities.

Reducing the filtration speed implies changes in the pouring line, which are not always viable:

-increasing the filtering surface - large filter placement space and additional costs;

- reduction of the metal flow, which leads to a decrease in the productivity of the casting machine.

Agglomeration of small-sized inclusion particles - "dirty" aluminum melt from a melting furnace can have a level of inclusions of 10,000 mm^2/kg, with diameters >15 µm and 100 times more inclusions with diameters of 1 – 5 µm.

The removal of small size inclusions is difficult to achieve by any of the filtration systems used. For this type of inclusions, the applicable solution is to agglomerate them in the oven (by electromagnetic mixing), resulting in large-sized inclusions that can be captured using the available filter systems.

The most frequently used methods to ensure high efficiency filtration are the use of the "ElectroMagnetic Stirrer System" for particle agglomeration complete with degassing with inert gases and max 0.5% Cl_2 and a filter battery with two or more filter stages, using different types and porosities of filters.

The in-line filtration use a filter systems in several stages ensures a high level of cleaning of the liquid metal with advantages in the homogeneity and reproducibility of the internal structure, reducing the risk of casting defects, respectively subsequent processing and non-compliant physical-mechanical properties.

The cast products from aluminum alloys have applications in top fields such as the automotive industry, the aero and military industry, the electrical industry or civil constructions, which require a guaranteed internal quality, respectively strict conditions imposed on the cast product, regarding the chemical composition, level of inclusions, of hydrogen or alkaline elements, shape and surface, etc., in order to obtain the properties and parameters of the finished product. In an aluminum foundry, according to the usual production flow, the treatment of the metal bath is carried out in the furnace, using deoxidation salts/fluxes and Na/Ca removal and in the degassing pot, using a gaseous mixture (Ar +Cl_2.)

2. Experimental research

During the experiments, on the route of the metal transfer troughs from the tallow casting plant, after the degassing pot, an additional filter box was installed which, together with the already existing one, would ensure a two-stage filtration system.

The standard chemical composition, according to SR-EN 573-3, of the three alloys is shown in table 3.

Table 3

Standard chemical composition of the experimental alloys

Alloy	Si, %	Fe, %	Cu, %	Mn, %	Mg, %	Cr, %	Zn, %	Ti, %	Other		Al
									Each	Total	
5083	0.40	0.40	0,10	0.40-1.0	4.0-4.9	0.05-0.25	0,25	0,15	0,05	0,15	bal
6061	0.40-0.8	0.70	0.15-0.40	0,15	0.8-1.2	0.04-0.35	0,25	0,15	0,05	0,15	bal
7075	0.40	0.50	1.2-2.0	0,30	2.1-2.9	0.18-0.28	5.1-6.1	0,20	0,05	0,15	bal.

The technological flow diagram of the filtration process of aluminum alloys is presented in Fig. 1.

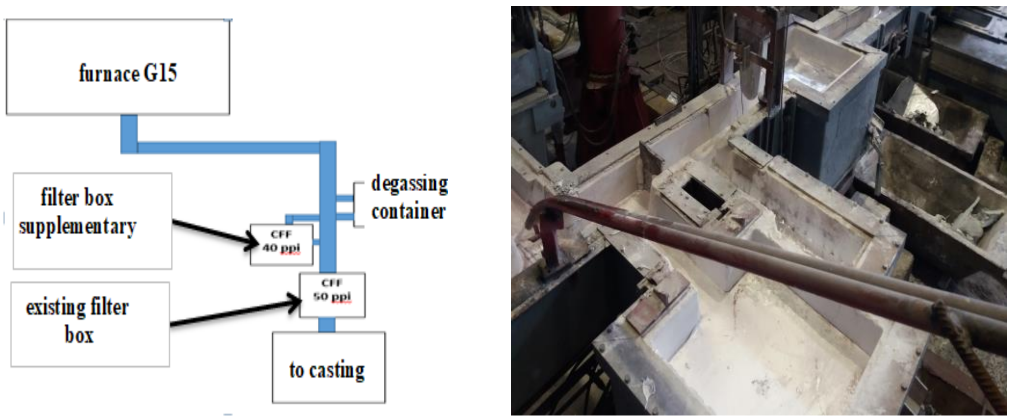
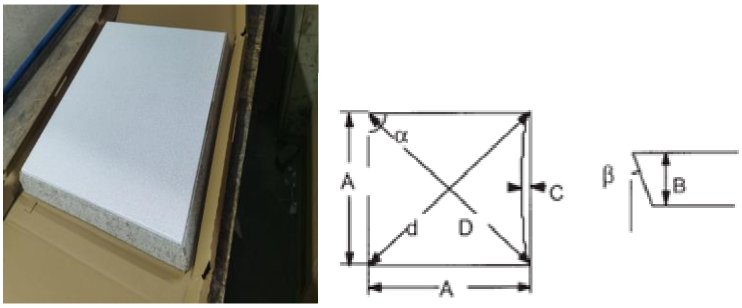


Fig. 1. Schematic of the technological flow of filtration process a) with two-stage filtration in aluminum slab casting plant, b) image of the two-stage filtration system in an slab casting plant

Filtration of the liquid metal flow is carried out in an in-line filtration system, a single filtration stage using a filter 584 x 584 mm (23 inch) and 40 ppi porosity. Ceramic foam filters are used worldwide to filter molten aluminum. It is an alumina-based, high-purity, phosphate-bound product whose characteristics can be found in Fig. 2.

Ceramic foam filters (CFF) were used for the tests as follows:

- stage 1 (newly installed filter box) – CFF 40 ppi filter, in all cases.
- stage 2 (existing filter box) - CFF filter 50/60 ppi



FILTER SIZE	DIMENSION A (MM)
7 inch	178 x 178 ± 2
9 inch	229 x 229 ± 2
12 inch	305 x 305 ± 2
15 inch	381 x 381 ± 2
17 inch	432 x 432 ± 3
20 inch	508 x 508 ± 3
23 inch	584 x 584 ± 3
26 inch	660 x 660 ± 4

PROPERTY	SPECIFICATION
angle α	90° ± ½°
angle β	17½° ± ½°
B	50 mm ± 2 mm
bend C	± 1½ mm on each edge
D-d	≤0.6% x A

Fig. 2. Shape and specificiation of CFF filter used for experiments

To determine the level of purity of the metal bath, periodically, samples are taken, which are analyzed in Metallographic Analysis Laboratory. Out of the total of 5 castings proposed to be carried out.

Since the usual recipe used in the casting of these alloys was used, without making any changes, the batches were started in "manual" mode, tilting the furnace as much as the capacity of the transfer chute allowed, ensuring the approximate 800 kg more.

The "Dual Stage" filtering system, installed at the slab casting line, was tested when casting slabs from alloys 5083, 6061, 7075, format 1650 x 500 mm, the CFF configuration used is shown in table 4.

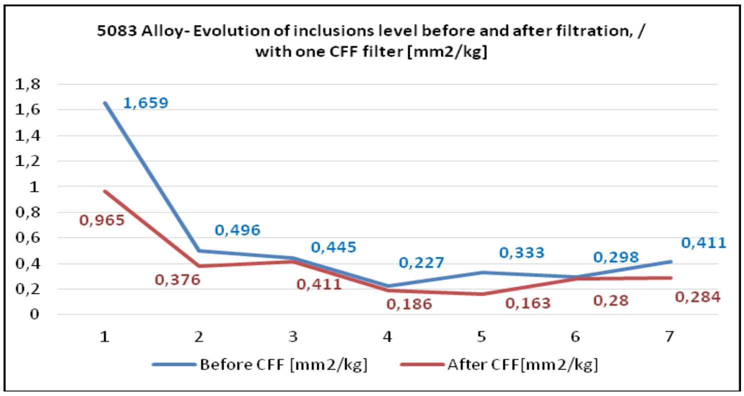
Table 4

Configuration CFF two stage filtration system and cast alloys

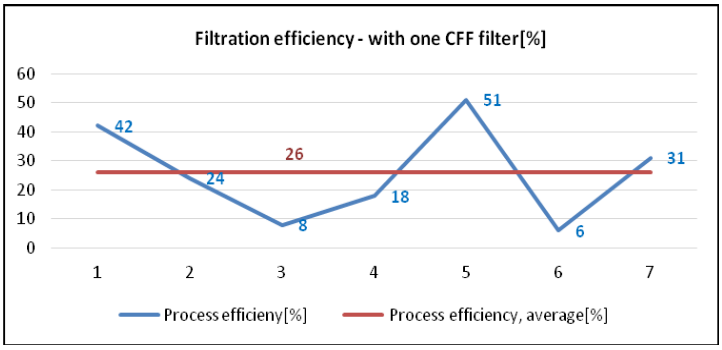
Two-stage filtration system		**Alloy type**	**No of castings**	**Observations**
Stage 1	Stage 2			
CFF 40 ppi	CFF 50/60 ppi	5083	2	At the start of casting, a larger amount of metal is required to prime the additional filter (+approx. 800 kg). The transfer chute has the capacity to take this additional quantity; the operator must start in "manual" operating mode. After starting, the level of metal on the chute balances, the casting proceeds normally, without problems (samples were taken in all cases).
		6061	2	
		7075	1	

3. Results and discussions

The evolution of the level of inclusions in the produced slugs and the efficiency of the process, in the filtration system currently used with a filtration stage using a CFF 40 ppi filter is shown in Fig. 2 (a and b), for aluminum alloy 5083 and Fig. 3 (a and b) for aluminum alloy 7075.

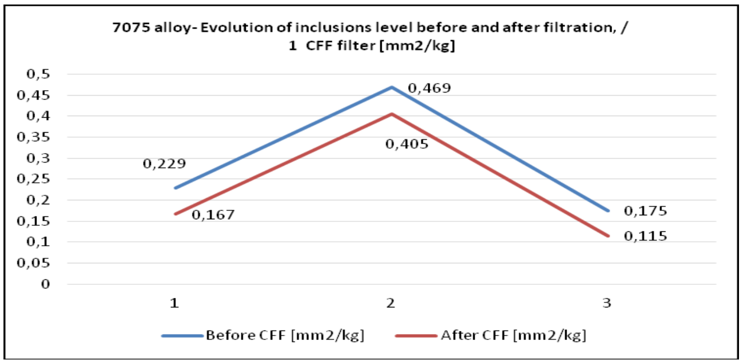


a)

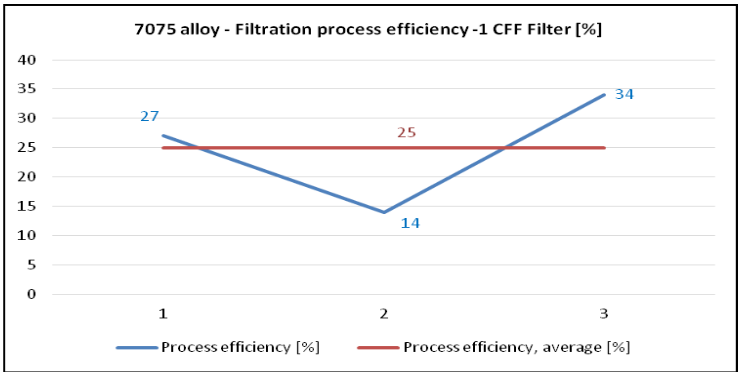


b)

Fig. 2. Alloy 5083 – a) Level of inclusions before and after filtering, CFF filter 40 ppi, b) Filtration efficiency,%



a)



b)

Fig. 3. Alloy 7075 a) Level of inclusions before and after filtering, CFF filter 40 ppi, b) Filtration efficiency, %

The level of inclusions before filtering represents the level of inclusions in the metal bath in the processing furnace, and the level of inclusions after filtering represents the level of inclusions in the cast product. It is observed that both the level of inclusions and the efficiency of the filtration process have a random behavior, and the final result depends, directly proportionally, on the level of inclusions in the metal bath in the furnace, after it has been treated with flux and the slag extracted.

Three samples were taken for each batch as follows:

- a sample when the metal is in the furnace, before the degassing pot;
- a sample after the first filtering stage (CFF 40 ppi filter)
- a sample after the second stage of filtering (CFF filter 50/60 ppi)

The results are presented in table 4.

Table 4

The results of the analyzes on the experimental samples

Alloy	Batch	Sample		Discussions
		Prelevation zone	Level of inclusions mm^2/kg	
5083	1	furnace	0.931	The evolution of the level of inclusions indicates a good filtration of the metal, the total efficiency of filtration = 88% (stage 1 = 56%, stage 2 = 73%)
		after filter 40 ppi	0.406	
		after filter 50 ppi	0.107	
	2	furnace	1.999	The evolution of the level of inclusions indicates a good filtration of the metal, the total efficiency of filtration 93% (stage 1 = 87 %, stage 2 = 49%)
		after filter 40 ppi	0.263	
		after filter 60 ppi	0.135	
6061	3	furnace	0.122	The evolution of the level of

		after filter 40 ppi	0.106	inclusions indicates a good filtration of the metal, the total efficiency of filtration = 68% (stage 1 = 13%, stage 2 = 64%)
		after filter 50 ppi	0.038	
	4	furnace	0.179	The evolution of the level of inclusions indicates a good filtration of the metal, the total efficiency of filtration = 64% (stage 1 = 42%, stage 2 = 38%)
		after 40 ppi filter	0.104	
		after 50 ppi filter	0.065	
7075	5	furnace	0.846	The evolution of the level of inclusions from one filtering stage to another indicates an error in the sampling or traceability of the samples. Efficiency of filtration = 89 % (stage 1 = 84%, stage 2 = 34%)
		after filter 40 ppi	0.135	
		after filter 60 ppi	0.089	

Thus, comparing the total result of filtering in the case of batch 5083 using a single CFF 40 ppi filtering stage (fig. 2 a, b), the maximum filtration efficiency obtained 51% is lower than the result obtained in the case of using two stages of filtering (CFF 40 ppi+ 60 ppi) where the total efficiency of the process is 88%.

Also, comparing the results obtained during the tests after each of the two casting stages, the filtration efficiency obtained after the second filtration stage is higher than the efficiency obtained after the first filtration stage.

The efficiency obtained after each filter stage and the total efficiency are presented in Fig. 4.

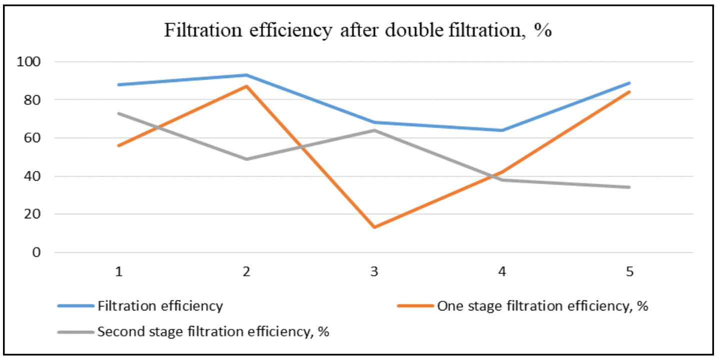


Fig. 4. Double filtration efficiency, %

According to theory, the CFF 40 ppi filter retains inclusions with size >20µm and the CFF filter (50/60 ppi) retains inclusions with size <20µm.

It is obvious that the high efficiency obtained on the second filtering stage is due to both the retention of inclusions with dimensions <20µm and the retention of inclusions with dimensions >20µm, which passed the 40 ppi filter (stage 1)

The addition of the second filtration stage to the production flow from the foundry section involves additional costs, both in relation to the second CFF filter and in relation to the purchase of a high-performance filter box for the second filtration stage, to avoid drastic temperature drops at start-up and to reduce the risk of rejecting the charge.

4. Conclusions

The liquid metal filtration system can be improved by adding an additional filter box and testing the efficiency of the filtration installation in two stages, using CFF 40 ppi filters, in stage 1 and CFF 50/60 ppi filter (or other porosity, depending of the destination of the finished product), in stage 2.

On the test samples whose results can be taken into consideration, comparing the result obtained after two filtration stages (CFF 40+50/60ppi) with the results obtained using one filtration stage (CFF 40 ppi) it can conclude:

- in the case of alloy 5083, using one filtration stage (CCF 40 ppi), the filtration efficiency is 56% is lower than the result obtained in the case of using two filtration stages (CFF 40 ppi+ 60 ppi), where the total efficiency of the process is 88 %.

- in the case of alloy 6061, using one filtration stage (CCF 40 ppi), the efficiency = 13% is lower than the total efficiency of the process = 68%, obtained in the case of using two filtration stages (CFF 40 ppi+ 50 ppi).

The efficiency values presented above show that, by using a two-stage filtration system, an increase in the efficiency of removing inclusions from the liquid metal can be obtained.

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