ALUMINUM MELT CLEANLINESS PERFORMANCE EVALUATION USING PoDFA (POROUS DISK FILTRATION APPARATUS) TECHNOLOGY

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Prezența incluziunilor nemetalice solide în aliajele de aluminiu poate provoca scăderea valorilor proprietăților mecanice ale produselor turnate, creşterea porozității gazoase, o prelucrabilitate prin aşchiere slabă, micşorarea fluidității şi o calitate slabă a suprafeței.

Tehnicile pentru determinarea incluziunilor pot fi: metalografie cantitativă, analize chimice, teste volumetrice, tehnici nedistructive şi altele.

Scopul lucrării este studiul evaluării purității topiturilor din aliaje de aluminiu 5083 prin tehnica PoDFA.

Datele obținute prin analiză arată că probele din aliaj 5083 sunt pure. Conținutul de incluziuni este cuprins între 0,011 mm^2*/kg şi 0,025 mm*^{2}*/kg, principalele incluziuni fiind* TiB_2, Al_4C_3, Al_2O_3, *MgO, spinel şi material refractar.*

The presence of solid non-metallic inclusions in aluminum alloys can cause reduction in mechanical properties of castings, increased gas porosity, poor machinability, decrease in fluidity and poor surface quality.

Techniques for inclusions assessment can be: quantitative metallography, chemical analysis, volumetric tests, nondestructive techniques and so on.

The focus of this paper is to study the assessment of melt cleanliness in 5083 aluminum alloy using PoDFA technique.

Analysis data reflect the cleanliness of 5083 alloys actually sampled. The inclusions content was between 0.011 mm^2*/kg and 0.025 mm*^{2}*/kg, the main inclusions being* TiB_2, Al_4C_3, Al_2O_3, *MgO, spinel and refractory material.*

Keywords: aluminum, cleanliness, PoDFA, inclusions

1. Introduction

Aluminum alloys are characterized by their low specific weight, low melting point, negligible gas solubility with the exception of hydrogen, excellent castability, good machinability, and good corrosion resistance. Premium quality castings are an essential requisite for the critical structural components used in automotive and aeronautics. The production of such castings requires that inclusions and porosity be minimized (or even eliminated) to supress their

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harmful influence on the mechanical properties, so that these properties are then mainly controlled by the microstructure of the castings.

The presence of hard non-metallic inclusions in aluminum alloys can not only degrade the mechanical properties of the final product but also create a number of other processing-related problems in diecasting which include the following:

- reduction in mechanical properties of the casting

Both tensile strength and elongation are reduced drastically with the increase in inclusion content. Clean metal, in general, is characterized by high tensile properties (yield strength, ultimate tensile strength, percent elongation).

- poor machinability and high tool wear

Some of the inclusions that may often be present in the casting are brittle and extremely hard ceramic particles. The hardness of some inclusions can be measured on Mohs scale as compared to 10 for diamond. When an alloy melt is cleaned by filtration before casting, machinability improves quite significantly [1].

- loss of fluidity and feeding properties

Inclusions in molten metal produce a decrease in fluidity. Producing clean molten metal through filtration can increase the fluidity substantially, by as much as 30% at normal operating temperatures [2].

- increased gas porosity

The dissolved hydrogen level in aluminum alloy melts is the main factor responsible for gas porosity formation during solidification. The solubility limit of hydrogen in molten aluminum is significant, but reduces considerably when the metal is solidified, leading to gas porosity formation. The gas porosity after solidification depends not only on the hydrogen content in the molten metal, but also on metal cleanliness. Oxides act as pore nucleation sites and hydrides decompose upon cooling to produce dissolved hydrogen [3].

- poor surface quality and lack of pressure tightness

Defects in aluminum products such as pinholes in thin foils and razor streaks in lithographic plates are commonly caused by inclusions [4]. Inclusions, in size range of 10 – 20 μm effective diameter can, at a concentration of a few parts per million, be harmful in rolled aluminum products.

The inclusions can be classified in two categories:

- total inclusions that take into account all types of inclusions existing in the cake above the filter,
- harmful inclusions, which are the sum of Al_4C_3 > 3 μm, dispersed Al_2O_3, MgO, $MgAl_2O_4$ and potential chlorides.

The main inclusions that occur during melting of aluminum alloys or holding periods prior to casting are aluminum oxide (Al_2O_3) as dispersed particles or oxide films, aluminum carbide (Al_4C_3), magnesium oxide (MgO), spinel ($MgAl_2O_4$), titanium diboride (TiB_2), aluminum boride (AlB_2) and titanium aluminide ($TiAl_3$).

A great deal of effort has been expended over the years on the identification, quantification and removal of these inclusions [5-7] and significant progress has been made.

Liquid aluminium quality in a holistic sense entails a proper control of three interrelated parameters : chemical composition, inclusion and gas content concentration. The control of the inclusion level in the molten metal is a critical element in the melting/casting operation.

Although a substantial number of methods are used to remove the inclusions either prior to or during casting, the problem of measuring metal cleanliness through a sensitive, quantitative method is still a difficult task. The difficulty is further compounded by the fact that the inclusions to be measured are usually very small, about 10 - 20 µm.

The focus of this paper is to study the assessement of melt cleanliness in 5083 aluminum alloys using PoDFA technique.

2. Experimental materials and methods

Several qualitative and semiquantitative tests are being used by aluminum casters to estimate and thus control the inclusion concentrations in the end product.

Techniques for inclusions assessment can be classified into five categories: chemical analysis, quantitative metallography, volumetric tests, non-destructive techniques and shop floor tests.

Chemical analysis and quantitative metallography have the disadvantage that the results may depend on sampling method and sectioning technique (metallographic preparation). These vulnerabilities are circumvented by remelting a given volume of metal and forcing the inclusions to settle and concentrate. Subsequently, the inclusions, which are not “concentrated” are analyzed by conventional metallographic methods.

Filtration technique has been used for concentration of the inclusions. The sample that is to be analyzed is melted and made to pass through a filter. The residue on the filter is analyzed to obtain quantitative information on inclusion concentrations. Alcan’s PoDFA (Porous Disc Filtration Apparatus) technique, based on this principle (Fig.1), has been used for assessing metal cleanliness for many years. The PoDFA-f system includes all the equipments required for PoDFA sampling in molten aluminum: a PoDFA sampling station, crucible heater, crucible and filter.

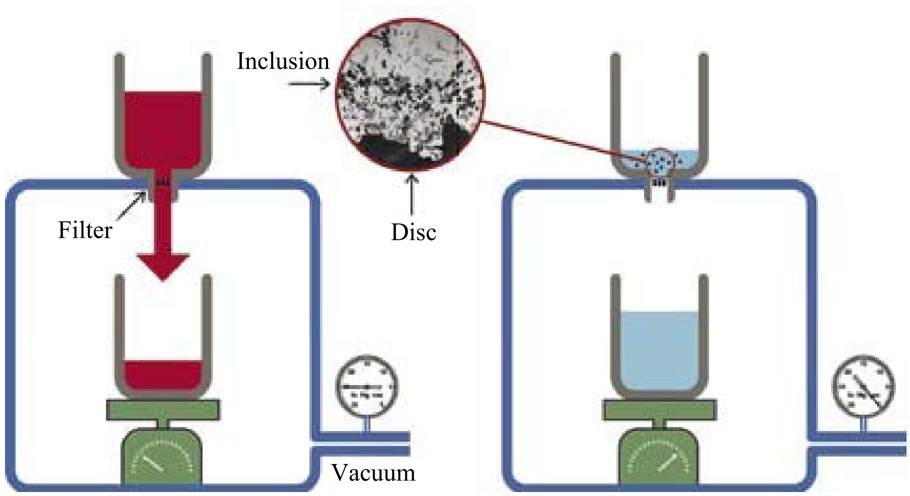

Fig.1. Principle of the PoDFA method.

It can provide both qualitative information on the nature of inclusions and quantitative information on the inclusion concentration. This technique can also distinguish inclusion types and differentiate, for instance, between the level of borides, carbides and spinels present within an individual sample. It has proved invaluable in establishing the cause of the problem in unsatisfactory metal.

Foundry and laboratory experiments carried out in this paper were performed at Aluminium Plant VIMETCO ALRO Slatina.

The chemical composition of the 5083 alloy taken for investigation is shown in table 1.

Table 1

Chemical Composition of 5083 alloy

Element	Mg	Mn	Fe	Si	Cu	Zn	Cr	Ti	Na
wt.%	4.63	0.66	0.27	0.37	0.045	0.053	0.067	0.022	0.0006

Aluminium 5083 alloy was performed in a gas furnace with a slightly oxidant flame. After melting and alloying of aluminium, the melt was in-line degassed with Ar+ Cl_2 mixture in ALPUR TS 35-24 installtion.

The samples of liquid aluminum alloys (1-2 kg) were filtered under controlled conditions using a very fine porosity filter. Inclusions in the melt are concentrated at the filter surface by a factor of about 10,000. The filter, along with the residual metal, is then cut, mounted and polished before being analyzed by means of an optical microscope by a trained PoDFA metallographer. Counting method used was GRID method and measured chord length 11.5 – 12.2 mm and magnification was 100x.

Using the grid method, the total inclusion area was obtained. This area was then divided by the weight of the metal that had passed through the filter (~1.5 kg). The method of inclusion identification is proprietary to Alcan International Limited. The total inclusion concentration area per kilogram was calculated using the formula:

Total Inclusion (mm^2/kg) = [{Mean Measured Residue Area (mm^2) x Inclusion Area Fraction}/{Filtrate Metal Weight (kg)}] x [{Nominal Chord Length (mm)}/Measured Chord Length (mm)}]

The inclusion concentration is reported in mm^2/kg indicating area of inclusions in the sectioned part. This technique is not sensitive to inclusion concentrations less than 1 mm^2/kg.

3. Results and Discussion

From the inclusion analysis of the various PoDFA samples examined in the present study, the inclusion concentrations were classified arbitrarily into five categories as listed in table 2.

Table 2

Arbitrary codes used for inclusion classification

Class	Inclusion Concentration, mm^2/kg
Very Light – (1)	0.0 – 0.05
Light – (2)	0.5 – 0.1
Moderate – (3)	0.1 – 0.4
Heavy – (4)	0.4 – 1.2
Excessive – (5)	≥ 1.2

The oxide film classification was performed following Alcan's procedure, where the films were divided into seven classes, as shown in table 3.

Table 3

Codes used for oxide film classification (Alcan's procedure)

Class	Oxide Film Type / Density
0	None
1	Thin / Slight
2	Thin / Moderate
3	Thin / Heavy
4	Thick / Slight
5	Thick / Moderate
6	Thick / Heavy

It was established that the inclusions content is between 0.011 mm^2/kg and 0.025 mm^2/kg. It should be borne in mind that the accuracy of measurements ranges from ±15% to ±25%.

There were many types of inclusions found in these PoDFA samples. The main inclusions found were grain refiner (TiB_2), and aluminum carbide (Al_4C_3) (Fig.2).

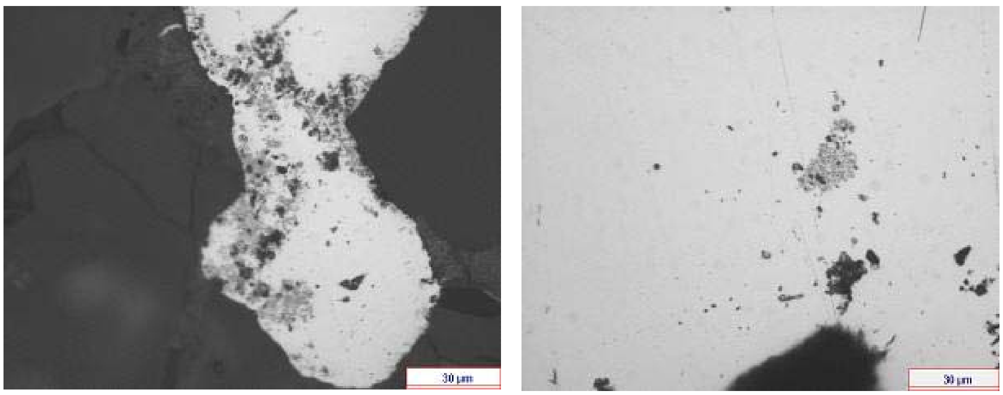

Fig.2. Micrographs of 5083 sample with TiB_2 and Al_4C_3 inclusions.

The particles are deliberately added for grain refining of aluminum alloys. The Al_4C_3 particles precipitate in the form of black needles, as shown in Fig.2. Their contrast changes with exposure to the surrounding humidity. Aluminum carbides particles that have at least one dimension greater than 3 µm usually originate from graphite deterioration or any other source of carbon contamination. It should be noted that Al_4C_3 particles that have at least one dimension smaller than 3 µm are already present in the primary liquid aluminum used to produce aluminum alloys.

We also noticed the presence of spinels ($MgAl_2O_4$), which are the most detrimental inclusions in the aluminum process because of their large size and hardness (Fig.3). The rate of formation increases as the melt temperature rises. Spinel inclusions are generally formed from the reaction between MgO and aluminum oxides. Because of their large dimensions, metallurgical spinels can easily be filtered out of the metal. $MgAl_2O_4$ particles are very dark (almost black) in color.

Another type of inclusion that was put in evidence is oxide film like γ-Al_2O_3 and magnesium oxide (MgO) (Fig.4).

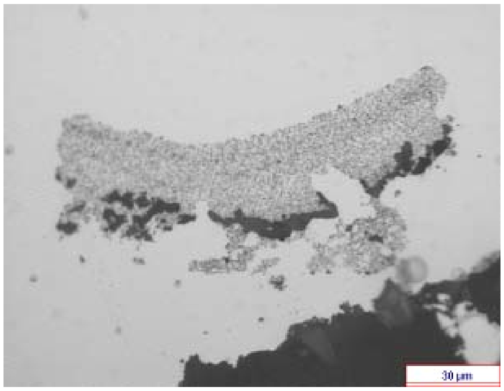

Fig.3. Microstructure of 5083 sample with spinel (dark) and refractory particles (light).

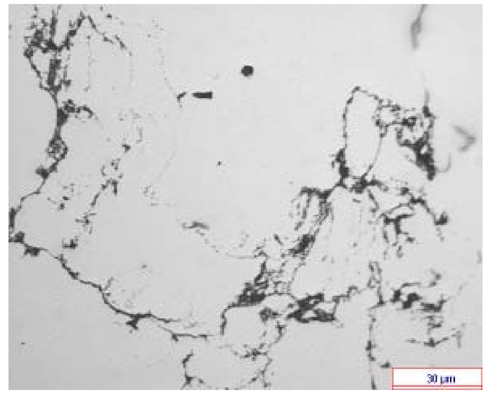

Fig.4. Microstructure of oxide films.

Fig.4 show different types of aluminum oxide (Al_2O_3), either in the form of films (thin or thick) or as dark (black) patches with irregular shapes. MgO is created by the contact of liquid aluminum alloy containing more than 2% Mg (i.e. 5083 alloy) by contact with atmosphere. In Fig.5 oxide films are associated with TiB_2 particles.

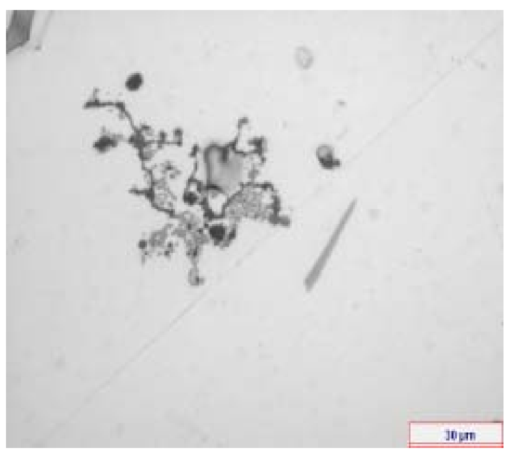

Fig.4. Micrograph of a zone containing oxide films and TiB_2.

Refractory types of inclusions (like $3Al_2O_3.2SiO_2$) are introduced into the metal when the furnace lining becomes damaged during the stirring process. After degradation in contact with magnesium containing alloys, the refractory particles become similar in texture and color as a metallurgical spinel, but due to their larger size they are easily identified. Usually, refractory inclusions are large hard particles which may be extremely detrimental to the process (see Fig.3).

3. Conclusions

1. Analysis data reflect the metallurgical cleanliness of 5083 alloys actually sampled, the inclusion content being between 0.011 mm^2/kg and 0.025 mm^2/kg. Results are reproducible but long-term metallurgical quality will depend on the standard procedures and starting stocks employed in the manufacturing process.
2. The main inclusions found were : TiB_2, Al_4C_3, Al_2O_3, MgO, spinel and refractory material.
3. PoDFA can effectively assess the effects of various operating practices and melt treatments on metal cleanliness.

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