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Procedure for the optimization of metallurgical treatments of EN AC 46400 alloy

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The present research focuses on the quality of the EN AC 46400 alloy in terms of inclusions content during different stages of the production process. The study evaluates the effectiveness of various fluxes to determine whether their chemical composition impacts the quantity and type of inclusions, alloy density, its fluidity and slag characteristics (drier or wetter). Inclusion analysis was initially conducted using the K-mold test, followed by the Prefil®-PoDFA test, to gain deeper insights into the inclusions development (type, size, and quantity) at different process stages. Tensile tests were performed on separately cast specimens to assess the alloy quality while excluding the influence of casting parameters (e.g., solidification time, cooling rates, and internal mold turbulence). Additionally, the amount of aluminum trapped in the slag was analyzed with the support of an external specialized company. The second part of the study focused on degassing and modification treatments, aiming to evaluate the impact of different rotor types and treatment parameters on sodium content, a highly volatile element, and rotors wear. The findings highlight optimal treatment conditions that ensure high alloy quality, reduced sodium consumption and extended equipment lifespan, contributing to economic and energy savings.

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DESCRIPTION OF THE PROCESS

The alloy is melted in a tower furnace following a ratio of 60% ingots to 40% foundry scraps, with a tolerance of ±10%. The molten alloy is poured into the ladle and transferred to the treatment station for degassing, deoxidation and modification.

The modification is done by adding sodium (Na) or strontium (Sr). If Sr is used, AlSr10 master alloy rods are added to the ladle just before tapping the alloy from the melting furnace. Conversely, when Na is used, it is introduced as salts due to its high reactivity with oxygen and low solubility in aluminum, which precludes the production of master alloys. Sodium salts are added shortly after degassing began, requiring a vortex generated by the rotor to facilitate absorption. After the salts dissolved, the rotor speed is reduced, halting the vortex, and the treatment continued to ensure complete sodium absorption and alloy degassing. The slag is then removed from the surface using a slotted spoon.

The first factor considered to improve the alloy quality was the type of slagging flux used, which can also affect the quantity of aluminum that remains trapped in the slag. Secondly, attention was focused on the shape and size of the rotors used since depending on these characteristics

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and the set treatment parameters very different results can be obtained in terms of alloy density, sodium content and rotor wear. Another parameter that can be optimized is the flow rate of the inert gas (in l/min), which however remained unchanged for this study.

After the treatments, the alloy can be poured into the holding furnace. In the gravity casting department of the company there are two types of holding furnaces: at the carousel there is a single gas furnace while in the other islands there is a dedicated electric furnace (Westomat). The different type of holding furnace was also considered in this study.

EXPERIMENTAL PROCEDURE

The initial study phase compared three different fluxes with the company's standard flux (Flux A). Table 1 summarizes their main characteristics.

Tab. 1 - Fluxes tested for the study.

Flux	Main Chemical Composition	Working Temperature (°C)
Flux A	Sodium carbonate	670–780
Flux B	Calcium fluoride + sodium carbonate	700–750
Flux C	Sodium carbonate + calcium fluoride	≥670
Flux D	Calcium fluoride + sodium carbonate	700–780

Alloy samples were collected at various process stages: from the melting furnace, after pouring into the ladle before the treatments (i.e. degassing and modification), from the ladle after the treatments, from the holding furnace after pouring and from the holding furnace after 1 hour and 30 minutes from the pouring.

The alloy density was evaluated using the Reduced Pressure Test (RPT). The alloy cleanliness was preliminarily assessed using the K-mold test and further analyzed through the Prefil®-PoDFA test (Figure 1) to measure the type, size and quantity of inclusions. The flow-rate of molten metal through a micro filter at constant temperature and pressure is monitored and used to plot a graph of weight filtered vs. time (filtration curve). Inclusions in the metal, such as oxide films and small particles, quickly build up on the filter surface during the test, reducing the flow-rate through the filter. In addition to the filtration curve, metallographic analysis of the Prefil® residue allows identification and quantification of the types of inclusions present in the metal sample. The build-up of inclusions at the filter surface during a Prefil® test creates an inclusion band, which can be quantitatively analyzed using optical microscopy. [1]

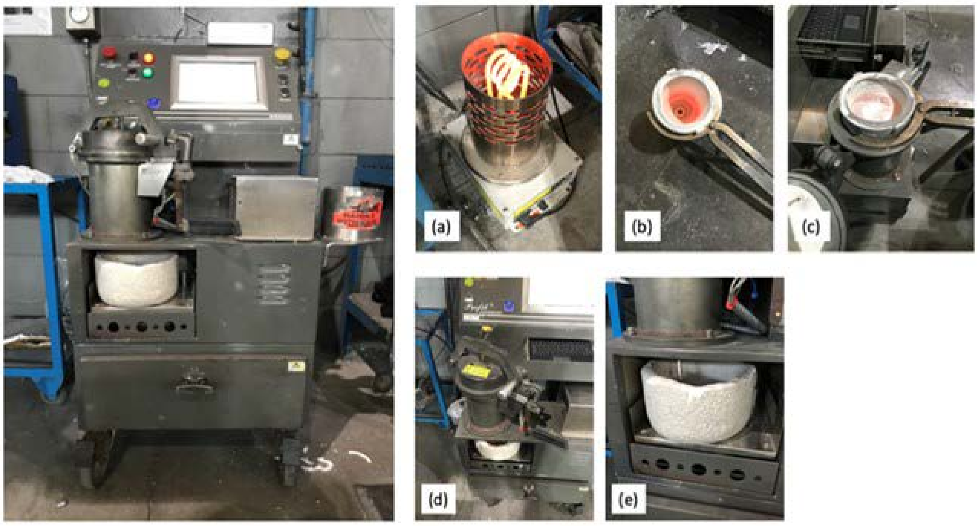

Fig.1 - On the left the pressure filtration melt cleanliness analyzer rented by Ghial for this study. On the right: (a) crucible heater, (b) preheated crucible with the ceramic filter installed on the bottom, (c) placement of the crucible filled with the alloy inside the chamber, (d) closing the chamber and starting the test, (e) alloy filtered during test. (Ferri 2023)

Following the initial filtration tests, a second series of trials was carried out, and later a third, though the latter was conducted only after the treatments. This choice was due to the lengthy nature of the tests and the observation that the results obtained from all trials performed in the ladle prior to the treatments were consistent in terms of filtered weight. This suggested that the starting conditions were essentially identical. From the samples collected at each stage of the process, 10 were selected (Table 2) for analysis in compliance with the certified PoDFA metallographic evaluation standard.

Tab. 2 - Samples analyzed according to the PoDFA standard.

Sample	Description
A	From the melting furnace
B1	Ladle after degassing (flux A) and modified with Na
J1	Ladle after degassing (flux B) and modified with Na
L2	Ladle after degassing (flux C) and modified with Na
H1	Ladle after degassing (flux D) and modified with Na
D	From the gas holding furnace (carousel) – flux A and modified with Na
F	From the gas holding furnace (carousel) after 1.5 hours – flux A and modified with Na
C	From the electric holding furnace (Westomat) – flux A and modified with Na
E	From the electric holding furnace (Westomat) after 1.5 hours – flux A and modified with Na
N	Ladle after degassing (flux A) and modified with Sr

In addition to the previously mentioned tests, tensile tests were conducted on separately cast specimens in accordance with the UNI EN ISO 6892-1 standard. These tests were performed at room temperature using a Galdabini Quasar testing machine. Elongation was measured with a knife-edge extensometer attached to the gauge length of the specimens. Three samples were tested for each condition.

As regards the quantity of aluminum trapped inside the slag, the analysis was carried out by an external company as the slag must be heated to temperatures above 800°C by making it react with a special salt.

The second study phase tested two new rotors (rotor A and rotor B) against the company's standard rotor. Rotor A featured a 25% larger size with the same shape, while Rotor B had similar dimensions but a different design. Again, the tests focused on the EN AC 46400 alloy because it has a greater impact on rotors wear due to the high temperatures, the chemical aggression of sodium and the long treatment time. Moreover, another factor that can be improved by changing the type of rotor is sodium absorption. Two series of tests were carried out for each type of rotor. For rotor A, the treatment parameters were also changed. In particular, the speed and the time of the vortex and the degassing speed were varied.

RESULTS

From the tests carried out, it was observed that the type of fluxes does not significantly influence the alloy density, which improves after degassing and it gets worse in the holding furnaces, though it remains within the limits of acceptability. Furthermore, the alloy density in the holding furnaces showed no significant changes after 1.5 hours.

Regarding the analysis of inclusion content, no macroscopic inclusions were observed in any of the k-mold samples. Before discussing the results of the filtration curves, a preliminary remark must be made: filtration curves are typically influenced by temperature, alloy type and inclusion load. It is also important to note that not only the quantity but also the size and type of inclusions affect the shape of the curve. At the plant, the curves were taken at different stages of the process, which meant that the samples could not always be filtered at the same temperature. Therefore, the interpretation of the results relies primarily on the metallographic analysis. However, some general trends can be seen from the shape of the curves. Figure 2 shows some of the filtration curves obtained:

- The alloy in the melting furnace and before treatment has a high fluidity (1,4 kg of metal is filtered before 150 seconds);
- After treatment the fluidity decreases, and this could be due to the modification;
- In the electric holding furnace the fluidity of the alloy improves 1,5 hours after pouring: this result is consistent with expectations since the impurities settle on the bottom of the furnace;
- The opposite is obtained for the gas holding furnace: this can be due to the different type of furnace but especially to the fact that sodium is topped up manually every 40 minutes. It follows that in 1,5 hours the sodium was topped up at least twice, causing a predictable worsening of the alloy fluidity.

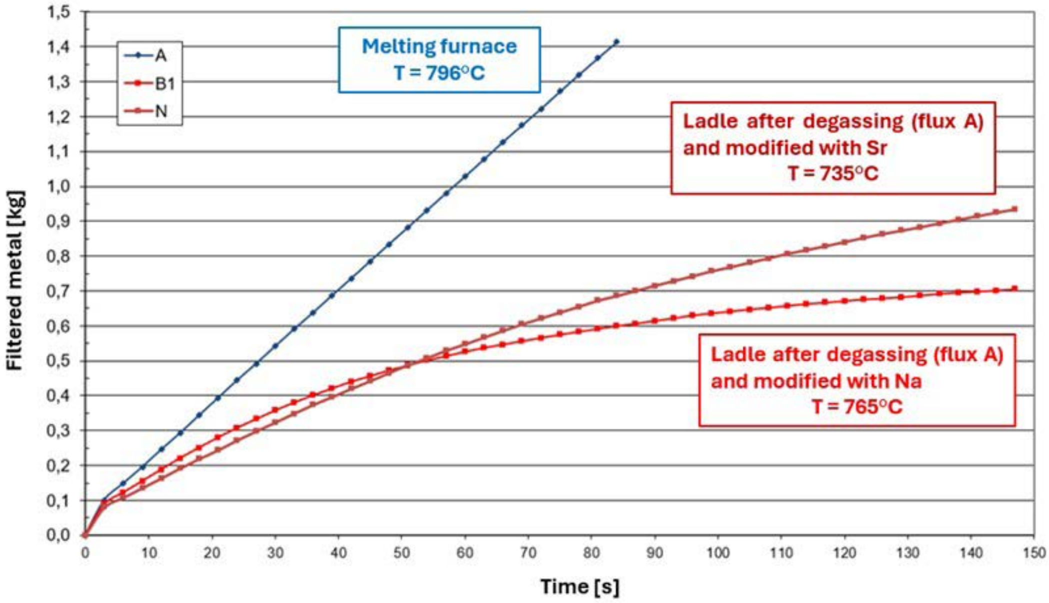

Fig.2 - Effect of the modification on the filtration curves: the alloy from the melting furnace (curve A in blue) exhibits high fluidity, in fact the final weight is reached before 150 seconds; the fluidity of the curves after modification with sodium (curve B1 in brown) and strontium (curve N in red) is significantly lower, the slope of these curves is smaller and it is not possible to reach 1,4 kg of filtered metal before 150 seconds. However, when comparing several filtration curves, the effect of the temperature (which is greater for curve A) must always be considered.

To verify the real influence of the modification on the fluidity, three test were carried out in sequence:

1. In ladle before treatment
2. In ladle after degassing and slagging
3. In ladle after modification

It has been confirmed that the modification, with both sodium and strontium, decrease the alloy fluidity and this reduction is much more marked for the sodium modification (about 40% less filtered material). In fact, an improvement in fluidity was observed immediately after degassing and a worsening after modification.

From the PoDFA metallographic analysis of the samples it was observed the presence of common inclusions, such as small (< 3 µm) and large (> 3 µm) aluminum carbides, metallurgical spinels, MgO and reacted/unreacted refractories. Less common particles were also found, such as the so called "potential chlorides" and "unwetted particles". Both have mostly its roots in flux residues that are not completely removed. As an example, two micrographs of the analyzed samples are shown in Figure 3 and Figure 4.

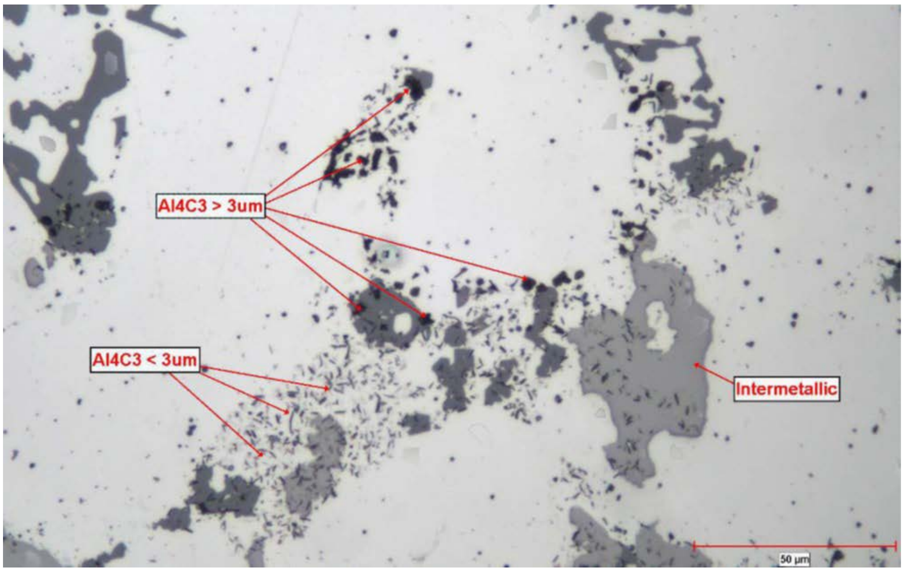

Fig.3 - Sample B1 (500x) Total Inclusion Content 0,346 mm²/kg.

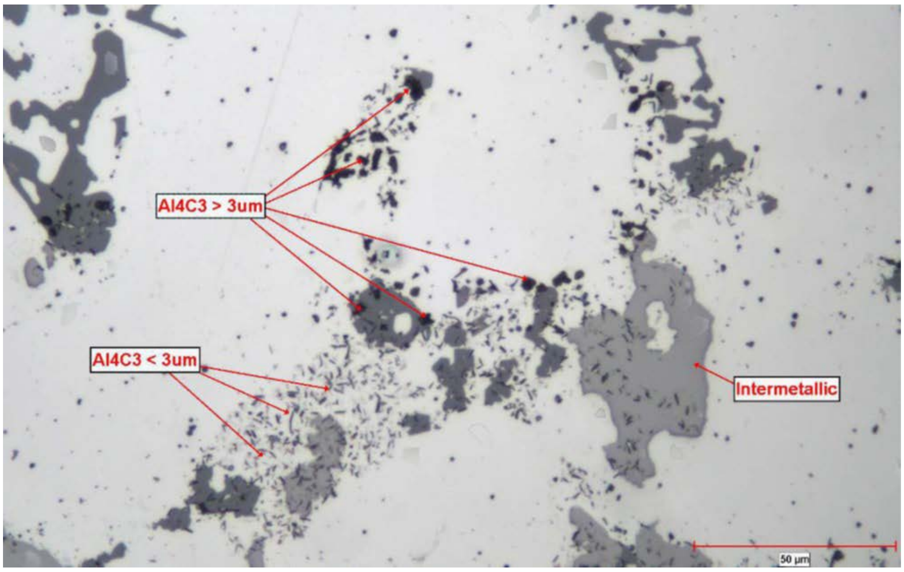

Fig.4 - Sample D (500x) Total Inclusion Content 0,676 mm²/kg.

All samples after degassing contain significant amounts of Al-carbides, which have not been seen in the furnace sample. There is no major difference in the type of flux. The small carbides are mostly derived from the primary alloy production process. The large carbides are partly derived from the remelting of scraps while another part it highly likely comes from sodium carbonate (Na_2CO_3), which is a common ingredient in fluxing salts. However, it is also well known that it can form carbides in reaction with liquid metal under certain conditions. This seems to happen here.

The growth of the metallurgical spinels ($MgAl_2O_4$) is obviously supported by the presence of Mg and oxides but also by remaining at high temperatures for relatively long times, a condition that can occur in holding furnaces. In both the holding furnaces, the presence of refractory particles was found. This is not unusual, but their formation could be boosted by flux residues since the fluorides from the salts chemically attack any furnace or ladle lining. Finally, it was observed that the TIC (Total Inclusion Content) drops after 1,5 hours, which is likely due to the setting of inclusions over time.

From the tensile tests it has been observed that Rm and Rp0.2 are quite similar for all the steps of the process and are not influenced by the type of flux. Instead, the elongation values are more variable.

From the tests carried out on the rotors it emerged that rotor A, also thanks to the new set of parameters, gave significantly better results, both in terms of sodium content and rotor life. In particular, the sodium content increased by an additional 30-40 ppm, while the life of the rotors increased by almost 50%. From these results it was decided to switch to the new type of rotor A. To confirm the results obtained, the situation has been monitored for more than a year and the data at the melting department are collected daily so as to prevent anomalous consumption and take appropriate corrective action. In conclusion, after more than a year, it is possible to confirm that the new rotors have a 30% longer life.

CONCLUSIONS

In conclusion, the tests carried out showed that the use of different fluxes does not affect the cleanliness of the alloy, which is already very good. Neither the density and the fluidity of the alloy are significantly influenced by the type of flux used. However, it was confirmed that the sodium modification significantly reduces the fluidity of the alloy, unlike the strontium modification, whose effect, although present, is milder. Finally, with regard to the content of aluminum trapped in the slag, the analyses showed good results for flux C. However, flux C should be tested for a longer period to confirm the results obtained. Of the two rotors, the one that provided the best results was rotor type A. The sodium content increased by an additional 30-40 ppm compared to the standard condition, and rotor life increased by 30%.

REFERENCES

[1] ABB Inc. "Prefil®-Footprinter Pressure filtration melt cleanliness analyzer A quick and thorough inclusion control solution." 2013.

[2] Ferri, S. «Procedura per l'ottimizzazione dei trattamenti metallurgici della lega EN AC 46400.» Fonderia Pressofusione, Giugno 2023: 54-61.

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