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Introduction of Powder Fluxes in Rotary Degassing System Towards Intensifying Refining Process of Aluminium Alloys

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Abstract

This paper presents and describes the research capabilities of a prototype experimental bench for realising the composite processing of liquid aluminium alloys by involving gas refining by rotary degassing technology and refining with salts (fluxes) in powder form.
The constructed unit was installed in the Experimental Foundry of the Faculty of Foundry Engineering at AGH in the Department of Moulding Processes, Mould Technology, and Non-Ferrous Metals Foundry; it is an integral part of a thyristor-based medium-frequency induction furnace with a melting capacity of up to 60 kg for aluminium alloys. The new experimental bench performs barbotage refining using a rotating head with the possibility of alternating the introduction of refiners/modifiers in powder form. This method can be used in casting lines: continuous in reactors, or batch in ladles.
The innovation of the design of the stand and the treatment of the liquid metal with powdered additives consists of dosing the refiner fluid deep into the metal bath through a channel that was made in the rotor axis and the head; this differs from conventional methods in the small amounts of introduced salts and, at the same time, in the very good metal-inert gas-salt homogeneity of the treated metal bath.
This method of dosing the refining salts increases the efficiency of their use, reduces any losses, and limits the formation of post-refining slag (thus, minimising the negative environmental effect). The feedstock that was used for the test smelts consisted of recycled materials: aluminium 99.7 (in the form of wires of various cross-sections that were used in electrical engineering – so-called 'SECTOR'), and the sub-eutectic AlSi7Mg0.3 alloy (in ingot form). The scope of the tests included verifying the technical solutions that were adopted for the dosing of the bulk materials in the form of a fluid, selecting the melting temperature, and dispersing (distributing) the materials in the bath via the rotor head. The results of the trials were reviewed in terms of the changes in the hydrogen content of the performed process and information on such powder-flux-introduction parameters as the type of the rotor head and the melting temperature of the powder flux. Preliminary trials showed that the performed complex refining (rotary degassing + refining with salts being blown as a fluid into the lower parts of the liquid metal) allowed us to reduce the hydrogen content to a level that could not be achieved by gas refining alone.

Keywords: Casting, Aluminium alloys, Degassing process, Rotary degassing, Introduction of powder fluxes into metal

1. Introduction

Aluminium and aluminium alloys are among the most widely used metals and alloys due to their unique properties. They are the main materials that significantly satisfy the electrical engineering, food, automotive, aerospace, rocket, and transport industries (among others). Depending on the proportions of the alloying additives (which may be silicon, copper, manganese, magnesium, etc.), these alloys are divided into two main groups: wrought alloys, and casting alloys [1]. Regardless of the classification, the common characteristics of aluminium and aluminium alloys are their relatively low specific weights (density of aluminium 2.7 g/cm^3) and relatively low melting points. In addition to this feature, they have good thermal and electrical conductivity and a low coefficient of thermal expansion; in addition, the relative ease with which parts can be manufactured by using a variety of production methods have determined the popularity of this material [2–5]. Cast aluminium alloys are most commonly used in practice that, thanks to their alloying elements, achieve very good mechanical properties, good flowability, low casting shrinkage, good machinability, and significant corrosion resistance [6–9]. It is also worth mentioning the very popular aluminium alloys that are dedicated to plastic transformation. Depending on the additives that are used and, above all, the extent of their solubility in aluminium, the processes of strengthening and cold-work hardening or through the heat treatment and the processes of precipitation that occur depend on the additives that are used. Shaping the properties by introducing alloying additives is not the only way to achieve the maximum levels of the alloy's properties. To a large extent, the quality of the metal plays a decisive role in determining the material properties [10,11]. A very important role that favours the use of these alloys is the possibility of recycling previously used castings. Recycling aluminium scrap saves more than 90 per cent of the energy that is required to produce a comparable amount of metal from raw materials. Aluminium alloys are materials that can be recycled many times without losing their properties [12,13]. A properly conducted recycling process that consists of a number of steps (such as the segregation of metal scraps as well as the melting, refining, and casting processes) makes it possible to obtain high-grade alloys and castings [14-17].

For a long time, the refining process has been associated with modifications to the liquid aluminium alloy that are aimed at inducing changes in the morphology of the eutectic silicon precipitates or the grinding of the α-phase (so-called grain fragmentation), for example [18]. In the refining process, the main objective is to get rid of all kinds of metallic and non-metallic impurities from the liquid metal as well as the hydrogen that is present in its dissolved form [19]. Both the refining and modification processes are extremely important; if the desired quality of the liquid metal is not obtained by refining, however, the modification process may not be as effective. Therefore, the refining process should be associated with those processes that are aimed at obtaining a high-grade alloy quality in terms of low amounts of any impurities and porosity and a favourable microstructure for high properties [20].

The process of rotary degassing is undergoing continuous development, with increasing attention being paid to environmental aspects. This has led to the need to replace the highly efficient active gas chlorine with environmentally safe inert gases such as argon or nitrogen in the refining processes.

Various modern solutions have been known to implement rotary degassing; this is mainly due to design improvements of the refining heads for the purpose of improving the efficiency of the process (e.g. by increasing the bubble dispersion of the inert refining gas). The large number of highly dispersed refining gas bubbles allows for increased contact surfaces with the impurities in the liquid metal. Aluminium alloys (especially pure aluminium in its liquid state) have a high propensity to dissolve hydrogen with increasing temperatures [21–23]. Refining the time and the amount of refining gas that is used are also important factors that influence the degassing effects [24,25].

The introduction of salt mixtures in the forms of powder fluxes is intended to compensate for the losses that result from the inert gases not actively affecting the liquid metal. When introduced into a metal bath, chlorine gas has an intensive refining effect; however, it also reduces the contents of elements such as sodium and magnesium [26,27].

Methods have been developed that use systems that dispense salts onto liquid metal mirrors in order to increase the efficiency of the refining processes [28,29]. There are also specially developed refining head designs that allow for the more efficient use of refining the gases by preheating them or dosing the salt through the head [30–32].

The introduction of salt mixtures in the forms of powdered fluxes can produce varied effects; two of these can be intensifying the purification of the metal from gaseous and non-metallic impurities and obtaining refining dross with low metal contents. Another example is introducing powder mortars with the appropriate chemical compositions into the liquid metal in order to reduce unfavourable elements such as sodium (in aluminium for plastic-processing) or calcium (in aluminium-silicon alloys).

When considering the possibilities of improving the refining efficiency and the possibility of removing metallic impurities, the method of introducing this type of material in the form of powder fluxes through the gas channel of the rotor appears to be the most effective. Any method of improving the quality of the liquid metal that is carried out is reflected in its environmental aspects.

2. Materials and Methods

The equipment on which the tests were carried out was installed in the Experimental Foundry of the Faculty of Foundry Engineering at AGH University of Science and Technology; this equipment is an integral part of a medium-frequency thyristor induction furnace with a melting capacity of up to 60 kg for aluminium alloys. A view of the station is shown in Figure 1.

Fig. 1. Experimental stand for implementing powder fluxes in rotary degassing system

The new experimental bench performs classical rotary degassing by using a rotating head and introducing powdered refiners/modifiers in powder form. The innovation of the bench design and the treatment of the liquid metal with powdered additives lies in the possibility of the continuous or pulsed dosing of a refiner into the metal bath via a channel that was made in the rotor axis and head. This way of dosing the refining salts improves the efficiency of their use, reduces losses, and limits the formation of post-refining dross.

The dosing system is fully automatic, and the dosing parameters are declared from the control panel. The dosing of the refining gas and the purging of the head can be done at any precision level via the appropriate valves, and the powdered flux is fed via a screw feeder into the refining gas stream to be further ejected via a rotor from the head (which is immersed in the liquid metal) (Fig. 2).

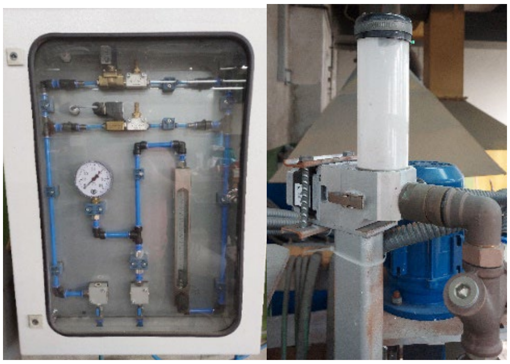

Fig. 2. Refining gas-dispensing system and powder flux dispenser in rotary degassing system

The scope of the research included verifying the technical solutions that were adopted for dosing the bulk materials in the form of a fluid, selecting the melting temperature, and dispersing (distributing) them in the bath by the rotor head. The feedstock that was used for the test melts consisted of recycled materials: aluminium 99.7 (in the form of wires of various cross-sections that were used in electrical engineering – so-called 'SECTOR'), and the sub-eutectic AlSi7Mg0.3 alloy (in ingot form). Chemical composition studies were performed with a SPECTROMAXx emission spectrometer; the results of this analysis are shown in Table 1.

The refining was carried out with argon gas (99.9999%) in a pulsed manner with a gas filling of 30% per cycle. The flux-powder was prepared on the basis of powdered NaCl, KCl, and $KAlF_4$ salts. The compositions of the slag mixtures were chosen so that the melting temperatures that were determined by the thermal-derivative method of the resulting mixtures were approximately 530°C for Powder Mortar 1 (5% $KAlF_4$, 47.5% NaCl, 47% KCl) and 650°C for Powder Mortar 2 (47.5% NaCl, 47% KCl). The outgassing was measured using an ALU COMPACT II – FMA by using the first bubble method that was established by Dardel, and the result of the amount of hydrogen that was dissolved in the metal was expressed in cm^3/100 g of metal.

The tests were carried out with two types of heads that differed in their designs and the diameters of the channel that simultaneously dispensed gas and powder mortar. Pictures of the heads that were used are shown in Figure 3.

Head 1 Head 2

Fig. 3. Views of heads that were used to introduce powder fluxes

A number of melts were carried out with varying process parameters, such as the following:

– type of head;
– amount and type of powder flux;
– speed of powder flux feeding.

These are summarised in Table 2.

Table 1.
Chemical compositions of materials that were used in study of effect of introducing powder fluxes into liquid metal (wt.%)

Al-SECTOR	Si	Fe	Cu	Mn	Mg	Cr	Ni	Zn	Ti	Ag	B	Be	Bi
	0.07	0.093	0.0013	0	0.0007	0.0009	0.0032	0	0	0	0.014	0.0003	0.0019
	Ca	Cd	Co	Li	Na	P	Pb	Sn	Sr	V	Zr	Al	
	0.0005	0.0002	0.0017	0	0	0	0	0	0	0.0014	0.0005	remaining	
AlSi7Mg0.3	Si	Fe	Cu	Mn	Mg	Cr	Ni	Zn	Ti	Ag	B	Be	Bi
	6.99	0.094	0	0	0.272	0	0	0.011	0.123	0	0.0006	0	0
	Ca	Cd	Co	Li	Na	P	Pb	Sn	Sr	V	Zr	Al	
	0.0025	0.0006	0	0	0.0005	0	0.0014	0	0.022	0.0084	0	remaining	

Table 2.
Summary of melts and processes that were carried out in powder flux application bench

Type of metal charge	Process No.	Process parameters
Al-SECTOR Mass: 55.00 kg	1A	• Melting time: 3h • Metal temperature: 730°–750°C
	1B	• Refining argon, time: 10 minutes • Rotor speed: 400 rpm
	1C	• Powder flux 1/50 g • Dosing of powdered flux at 40–30 rpm
	1D	• Powder flux 1/50 g • Dosing of powdered flux at 40–30 rpm
	1E	• Powder flux 1/50 g • Dosing of powdered flux at 40–30 rpm
Al-SECTOR Mass: 57.00 kg	2A	• Melting time: 3h • Metal temperature: 730°–750°C
	2BC	• Refining argon, time: 5 minutes • Rotor speed: 400 rpm • Powder flux 2/75 g • Dosing of powdered flux at 15–30 rpm
Metal alloy **AlSi7Mg0.3** Mass: 54.05 kg	3A	• Melting time: 3h • Metal temperature: 730°–750°C
	3BC	• Refining argon, time: 5 minutes • Rotor speed: 400 rpm • Powder flux 1/50 g • Dosing of powdered flux at 40–30 rpm
Metal alloy **AlSi7Mg0.3** Mass: 56.65 kg	4A	• Melting time: 3h • Metal temperature: 730°–750°C
	4BC	• Refining argon, time: 5 minutes • Rotor speed: 400 rpm • Powder flux 1/50 g • Dosing of powdered flux at 10–15 rpm
Metal alloy **AlSi7Mg0.3** Mass: 57.00 kg	5A	• Melting time: 3h • Metal temperature: 730°–750°C
	5BC	• Refining argon, time: 5 minutes • Rotor speed: 400 rpm • Powder flux 1/45 g • Dosing of powdered flux at 10–15 rpm

3. Results and Discussion

As a result of the trials, a range of information was obtained regarding the implementation process of the powder fluxes being introduced by means of a refining gas. Data was collected on the outgassing of the melted feedstock by determining the hydrogen content of the liquid metal as well as information on such flux-introduction parameters as the rotor head type and melting temperatures (which are summarised in Table 3).

Introducing powder fluxes through a refining head is a process that requires the adjustments of key elements for each process. Two parameters in particular deserve attention: the head design, and the melting temperature of the powder fluxes. In the first attempts at a powder mortar application, there was a problem with the flow of the powder mortar through the head's gas channel. There was a noticeable increase in the resistance to the gas flow, which eventually resulted in a complete blockage and the need to decongest the dispensing channel. The use of Head 2, with a more open discharge area and an increased diameter of the metering channel (from 8 mm [1C-D process] to 10 mm), allowed for the desired amount of powder fluxes to be introduced (although, there was a slight increase in the gas flow resistance). Important elements of the processes that were carried out were the melting points of the introduced powder fluxes. The use of Flux 2 (with a melting point of 650°C) enabled the application process to be carried out fully. Extending the refining process along with reducing the rate of the introduced powdered flux produced the best degassing effect (Process 5). The changes in the hydrogen contents for the individual processes are shown in Figure 4.

Table 3.
Hydrogen H_2 content [cm^3/100 g] and comments depending on process that was carried out

Process no.	Average hydrogen content H_2 [cm^3/100 g]	Type of head	Comments on process
1A	0.72	1	-
1B	0.25	1	-
1C	0.25	2	there was problem with flow of powder mortar through gas channel of head, increase in resistance to flow of gas, and necessity to clean dosing channel
1D	0.16	2	
1E	0.18	2	
2A	0.30	2	-
2BC	0.19	2	-
3A	0.29	2	-
3BC	0.14	2	-
4A	0.24	2	-
4BC	0.14	2	there was problem with flow of powder flux through gas channel of head and increase in resistance to gas flow
5A	0.24	2	-
5BC	0.11	2	there was problem with flow of powder flux through gas channel of head and increase in resistance to gas flow

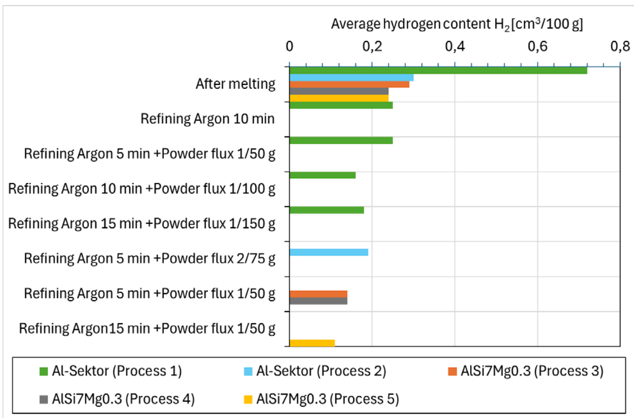

Fig. 4. Changes in hydrogen contents of processes

A characteristic effect of the properly conducted powder-flux-insertion process was the occurrence of flares, which could be observed on the surface of the liquid metal – Figure 5.

Fig. 5. Effect of introducing powder flux into metal bath – characteristic flare visible on surface of liquid metal

A measurable result of the complex process was the improvement in the quality of the liquid metal, which was directly related to the reduced hydrogen content.

4. Conclusions

As part of the implementation of the research, an experimental test rig for implementing (introducing) fluxes and refiners in granular (powdered) form into liquid alloys was constructed and tested.

The powdered mortar material and the refining gas formed a fluidal mixture. Fluidised bed batching is a well-known and frequently used method in many industries because of its advantages:

- reduced bridging and blockages in materials that tend to clump;
- improved control of material flow – enables more uniform and stable flow, which is critical in processes that require tight dosing control;
- increased dosing accuracy – improves dosing precision through uniform material distribution and stable flow.

In addition to the technological effect, the environmental aspect was very important in terms of consuming the optimum amounts of the chemical compounds in the casting processes.

The first tests indicated the need to change the design of the refining head and correct the dimensions of the head channel in order to achieve the more efficient transport of the refining powder grains. It was also necessary to develop salt-powder mixtures with the “right” melting points so that the meltings and reactions could take place in the metal bath. It was unacceptable for the material that was introduced to the melt in the head channel at the height of the liquid metal mirror to block the process.

The transport of the materials in fluidised form into the liquid aluminium encountered difficulties; these depended on the technical levels of the solutions that were used and were due to the following:

- resistance of transport channels and metallostatic pressure of metal;
- melting temperature of material being transported.

Finally, promising trial results were obtained, which showed that combined rotary degassing (barbotage refining) + refining with salts blown into the lower parts of the liquid metal allowed for reducing the hydrogen content of the alloy to a level that could not be achieved by gas refining alone.

The innovation of the design of the station and the treatment of the liquid metal with powdered additives was based on dosing the refiner fluid deep into the metal bath through a channel that was made in the axis of the rotor and in the head; this differed from conventional methods in the small amounts of salts that were introduced at the same time as well as the very good homogeneity of the metal-inert gas-salt-treated metal bath.

This way of dosing the refining salts increased the efficiency of their use, reduced any losses, and limited the formation of post-refining slag (thus, minimising the negative environmental effect).

Tests of the new bench for applying mortars and refining fluxes to liquid light metal alloys confirmed the correct operation of all of its components. In parallel with the refining effects, the possibility of introducing powder fluxes deep into the metal bath was confirmed; among other things, the purpose of this could be to additionally introduce other particles that might alter the structures of aluminium and its alloys.

The preliminary tests indicated that the work on the compositions and salt granulation of the powder fluxes should be continued. After analysing the problems that occurred during the application processes, it is our opinion that some modifications should be made to the powder mortars, the head design, and the dosing system in order to ensure that the process runs smoothly and the application effect is controlled. Modifications to the dosing system are currently being carried out in order to address the current design flaws.

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