EVALUATION OF INERT GAS PROTECTION SYSTEM FOR Al-Mg ALLOY CASTING IN A ELETRIC RESISTIVE FURNACE *

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Abstract

Aluminum has its properties enhanced when combined with others metals, such as in the Al-Mg cast alloys, which have appreciable mechanical resistance and the best corrosion resistance associated to the lowest weigh of all aluminum alloys. However, magnesium has a strong negative Gibbs free energy, which means it oxidizes and picks up hydrogen easily, especially during melting, making it hard to process alloys containing it. Therefore, mechanisms to reduce or avoid atmosphere contact to the melting bath have been studied; some proposals involve the use of solid fluxes, vacuum atmospheres, laminar barriers of inert gas or the expansion of liquid gas. This study has developed a device that is capable of protecting the molten metal from atmosphere interaction through circulation of argon inside a refractory cone to form a uniform cover. The methodology used consists of projecting the apparatus and its manufacture, testing the system through experimental melts of Al-Mg alloys and, finally, analyzing the metal losses. As shown in the results, the system has proved to be functional, the argon flow was stable and there was a reduction of 0,8%wt in the content of magnesium oxidation. Thus, it is possible to conclude that the device provides an inert gas atmosphere above the liquid metal surface in order to reduce the Mg oxidation losses in production of Al-Mg cast alloys very efficiently.

Keywords: Inert gas blanketing; Oxidation losses; Aluminum alloys processing.

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1 INTRODUCTION

Nowadays, several light alloys, such as aluminum and magnesium alloys are used in low cost manufacturing products and in high technology applications (e.g., aerospace, automotive, sports). Regarding the aluminum cast industry, thousands of alloy compositions have been developed, however most of them contain a relatively limited number of alloying elements [1,2].

The alloying elements used for cast aluminum alloy design can be classified into three groups: principal alloying elements, dopants, and impurities. Depending upon the nature of an alloy, the same elements may play different roles. In most cases, silicon, magnesium, zinc and copper are recognized as principal alloys elements because they are introduced into aluminum alloys in (relatively) large amounts and define its microstructure and properties [1].

In general, Al-Mg cast alloys (5xx series) are an important group of aluminum alloys, in which magnesium is the principal alloying element. This series are non-thermally treatable alloys and they have excellent mechanical and chemical properties, including the best corrosion resistance and the lowest weight among aluminum alloys. However, the presence of high quantity of magnesium as alloy element increases the oxidation losses of liquid aluminium [1,3].

Al-Mg alloys (4-10%wt of Mg) oxidize rapidly during melting process and also pick up hydrogen immediately, for this reason is recommended to use on this alloy series a flux cover to reduce the contact with atmosphere oxygen and the molten alloy. However, use of solid flux cover can be the source of non-metallic inclusions during the tapping process, and in this approach, its necessary a degassing step in the production process [3,4].

A blanketing method and apparatus for ferrous and non-ferrous melts with gaseous argon were described by Zurecki and Best (1996). In this system, argon is injected tangentially upon the liquid metal surface, and circulates and is contained within a refractory cone (Figure 1).

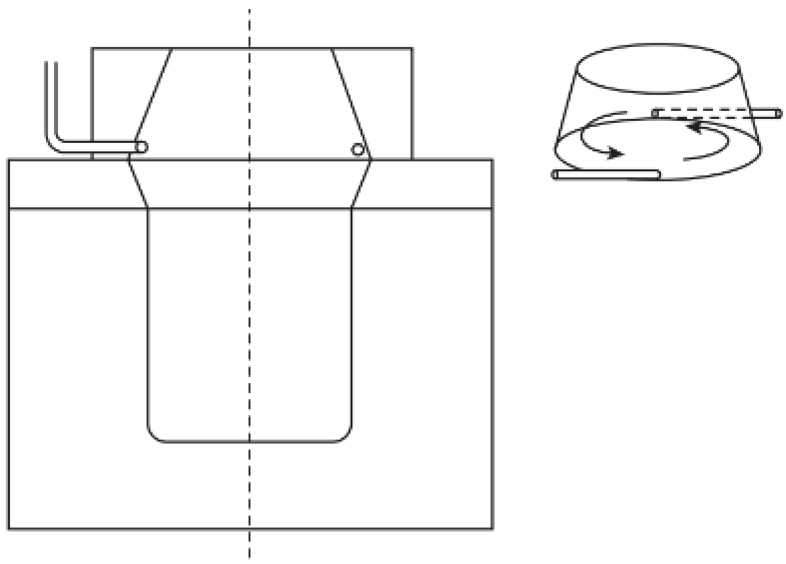

Figure 1. *Schematic representation of proposed blanketing apparatus [4].*

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The injection of the gas parallel to the inner walls of the cone avoids the entrance of atmospheric air, and the swirling technique organizes the gas so that the gas usage rate is highly efficient. Finally, the heated and expanded gas finally escapes from the top of the cone. This technique improves metal yield and the recovery of alloy elements additions. It also reduces slag build-up and crucible maintenance [4,5].
In this research a blanketing apparatus was designed in a laboratory scale, based on the Zurecki and Best model. For the manufacturing of a refractory cone, 3D-printing Acrylonitrile Butadiene Styrene (ABS) die/mold was developed and a high-alumina cone was fabricated to fit the top a crucible with 0.4 L capacity. Finally, the refractory cone was assembled in a crucible and the efficiency of the system with a Al-6Mg alloy melted at Argon inert atmosphere was evaluated and compared with the open atmosphere melting.

2 DEVELOPMENT

2.1 Argon Blanketing apparatus development

2.1.1 Summary description of inert blanketing system

According to the apparatus proposed by Zurecki and Best creating a swirling flow, in the form of a stable vortex, of inert gas adjacent to the open top of a reactor, ladle or furnace, results in blanketing of the molten metal surface and reduction of infiltration in the ambient atmosphere. A device suggested was a heat-resistant (e.g. refractory) cone which is placed over the top of the crucible. The swirl pattern is achieved by introducing the inert gas tangentially into the refractory cone wall at a point close to the top of the crucible.
Creating a stable vortex of inert gas, covering the liquid metal surface, depends on the geometry parameters of the cone, diameter of inlets and an adimensional parameter called Swirl number (S), calculated to predict the stability of the vortex inside the cone. Lower the S-number for the system, more stable is the vortex inside the refractory cone. S-number is calculated according the Equation (1).

$$S = \frac{2}{3} \times \frac{T_{inlet}}{T_{exit}} \times D_{base} \times \left[D_{base} \left(\frac{D_{exit}}{nD_{inlet}^2} \right) \right] \quad (1)$$

Where: T_{inlet} = blanketing gas inlet temperature;
T_{exit} =blanketing gas exit temperature (assumed bath temperature);
D_{base}=diameter of the base of blanketing cone;
D_{exit} = diameter of the top exit of blanketing cone;
n = number of tangencial gas inlets;
D_{inlet}= diameter of tangencial gas inlet;

According to the model description and experimental results reported from Zurecki and Best, high inert gas flow rate and inlet velocity increase air penetration in the system as shown at Figure 2.

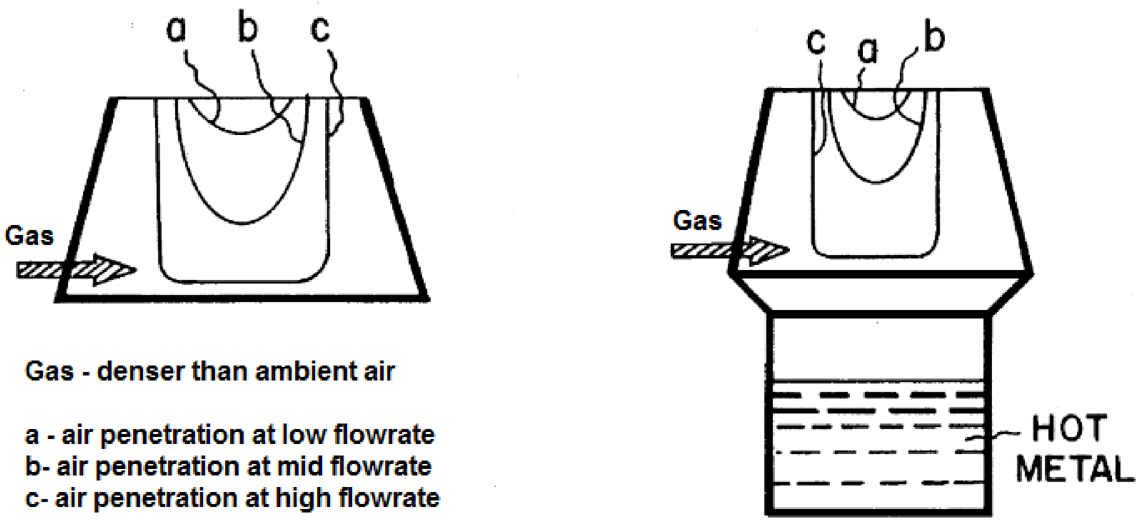

Figure 2. Air penetration profile for swirling flow at different inert gas flowrates. [5]

2.1.2 Blanketing apparatus scale reduction

According to the Zurecki and Best model proposed, the geometry parameters and S-number are variable to adaptation for different vessels (e.g. furnaces, ladle) respecting the basic parameters described in Table 1.

Table 1. Geometry and Swirl number parameters range.

Parameter	Symbol	Min	Max
Inlet Diameter	D_{inlet}	0.25 mm	D_{exit}
Exit Diameter	D_{exit}	D_{inlet}	D_{base}
Base Diameter	D_{base}	D_{exit}	3600 mm
Height of cone	H	$0.25D_{exit}$	$5D_{exit}$
Velocity	v	0.003 m/s	1.2m/s
Swirl number	S	1	1000

Observations: $D_{inlet} < D_{exit} < D_{base}$

The design for a reduced scale system of a small capacity crucible was calculated based on the limited inert gas flow rate capacity (0.08 - 0.2 L/s). The geometry parameters and S-number for this project are presented in Table 2.

Table 2. Geometry and Swirl nuber experimental parameters

Parameter	Symbol	Experimental
Inlet Diameter	D_{inlet}	10 mm
Exit Diameter	D_{exit}	55 mm
Base Diameter	D_{base}	85 mm
Height of cone	H	55 mm
Velocity	v	1 m/s
Swirl number	S	10

Observations: Considering T_{inlet}*: 300K and* $T_{exit}=T_{bath}$*:1025K*

2.1.3 Laboratorial-scale blanketing apparatus manufacturing

A 3D-printer was used to manufacture the ABS-die (Figure 3), according to the geometry parameters showed in Table 2. A slurry refractory blend was prepared using high alumina cement powder, water and sodium silicate (4% of cement powder weight), which is additioned to the mixture to improve the agglomeration of refractory slurry blend.

Figure 3. 3D-printed ABS-die.

ABS-die was filled with the high alumina mixture and compacted afterwards. Then, a resistive furnace was used to dry the refractory cone in a two-step heating process. At the first step, the ABS-die and the refractory were heated for 1 hour at 50°C. Secondly, the refractory cone was carefully removed from the ABS-die and heated for 5 hours at 180°C to complete the dry process. At end of the dry process a solid refractory cone was manufactured as shown in Figure 4 assembled in the crucible.

2.2 Argon blanketing apparatus - Experimental evaluation

A blanketing apparatus efficiency was evaluated in the production of a Al-Mg alloy. Two charges of the cast alloy, both with approximately 6.3%wt Mg and Al for balance (Table 3), were prepared and melted in a resistive furnace at 1025K.

Figure 4. Refractory cone and apparatus assembled.

Table 3. Charge composition used in experiments.

Charge	Aluminum (99.8% purity)	Mg-based alloy (Mg-6%wtAl)
Open Atmosphere	768.7 g	51.6 g
Argon Atmosphere	772.0 g	52.3 g

The first charge was melted in an open atmosphere, where the Mg-based alloy (94%wt Mg and 6%wt Al) was added in the liquid aluminum using an immersion bell process. After total dissolution of Mg-alloy (t=0 min), samples were collected at different time periods (0 min - 5 min - 10 min - 15 min). Same methodology was performed for the second charge using the blanketing apparatus. Optical Emission Spectrometry (OES) analysis was carried on the collected samples to evaluate the incorporation of magnesium in the alloy and to quantify the oxidation losses during the melting in both situations.
The comparison for the incorporation of magnesium in the different castings in function of time is shown in Figure 5. The data presented in it refer to the OES analysis results. The “estimated” curve, indicates the target value to the magnesium incorporation mentioned previously (6.3%). The open atmosphere curve indicates the melting performed without the atmosphere protection system. Finally, the inert gas atmosphere curve shows the results collected from the melting with a blanketing apparatus. 5 min indicates the Mg addition, 5 min indicates total dissolution and only after these times, the specimens were withdrawn.

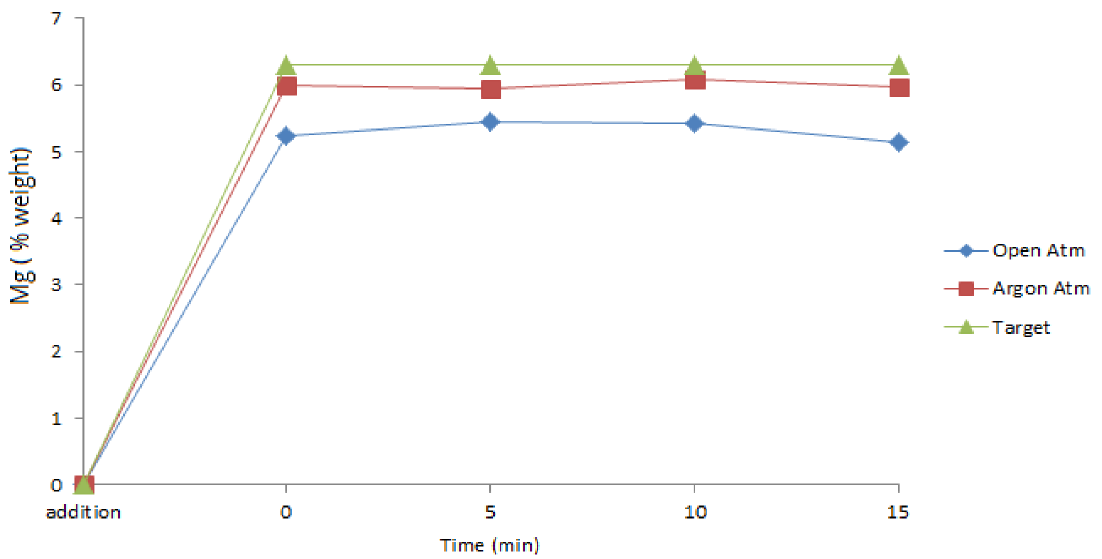

Figure 5. Magnesium content in the different castings in function of time.

After graphic analysis it is possible to conclude the melting with the inert atmosphere obtained a more satisfactory result regarding Mg content maintenance, although it is not the target value yet. This conclusion may be considered due to the distance of the experiment curve, without inert atmosphere, from the calculated curve. After 5 min of addition, it is noted that the Mg percent value strongly decreases, remaining practically invariable during the rest of the melting. This may be an indicative the higher oxidation occurs in the first minutes of the process.

The last observation about this graphic relates to the stability of the presented curves. There is a perceptible difference, however slight, on the curve variability without the inert atmosphere, which probably would continue to decrease if the melting was extended. Thereby, the argon atmosphere was also capable to control the oxidation loss during the melting, holding more uniform levels of incorporated Mg content.

3 CONCLUSION

Based on the experiments results, it is possible to conclude the blanketing apparatus proved to be an efficient device to provide an inert gas atmosphere above the liquid metal surface in order to reduce the Mg oxidation losses. The inert gas atmosphere also presents a potential to operate as a degassing reactor because it reduces the partial pressure of gases, such as oxygen, nitrogen and hydrogen in equilibrium with the metallic bath.

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