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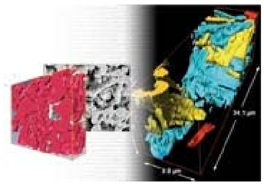

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New Trends in Aluminium Degassing –A Comparative Study

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Abstract

This work aims to evaluate the efficiency of ultrasonic degassing when applied to the AlSi9Cu3 alloy when compared with other degassing techniques. The mechanism of aluminium degassing is discussed. A suitable ultrasonic degassing apparatus including a novel MMM (Multi-frequency Multimode Modulated) technology, able to supply up to 1.2 kW power under a frequency up to 25 kHz, was developed specially for this purpose. Ultrasonic degassing is compared with rotary impeller degassing using argon and nitrogen as purging gases. Results characterization focuses the assessment of alloy density and final hydrogen content of the samples, using the Straube-Pffeifer method. Experimental results reveal that a constant value of density and hydrogen content can be reached after less than 2 minutes processing time, using ultrasonic energy, which is 3 times faster than rotary impeller degassing. Regardless of the processing time, final results (density and hydrogen concentration) achieved with ultrasonic degassing are much better than those reached using the gas purging technique.

Keywords

Aluminium, Melting, Degassing, Ultrasonic, MMM technique.

1 Introduction

1.1 Porosity in Castings

Porosity is a well known and common defect in castings and its presence impairs both their mechanical properties and corrosion resistance, thus being one of the main causes of castings rejection in foundries. Foundrymen usually tend to classify porosity as gas holes or shrinkage defects, but in fact, porosities are usually a combination of both [1]. Nevertheless, the two phenomena can occur isolated, and when this happens, its control and correction become much easier and simple for the foundry engineer.

The main source of gas porosities in aluminium castings is hydrogen, which is the only gas with significant solubility in molten aluminium. Aluminium castings usually contain 0,15–0,30 ml H_2/100 mg Al, and only in high-strength casting alloys hydrogen concentration needs to be kept below 0,1ml H_2/100 mg Al. Although, those castings with very low hydrogen content usually show more shrinkage porosities than those with higher concentration levels, and require much more accurate gating and feeding systems calculation [2]. The amount of porosity that can be tolerated in a casting is determined by the method of casting and the component specification. In high strength castings, like aerospace or automobile parts, very rigid specifications on soundness and mechanical properties are always established, thus demanding very accurate and efficient degassing methods in order to keep hydrogen concentration as low as possible. Current commercial castings are not so demanding and geometrical/dimensional conformity together with highly competitive costs usually are those requirements that prevail. In this case, higher hydrogen contents are accepted, in order to promote some controlled porosity, thus allowing higher casting yields [3].

1.2 Traditional Degassing Methods

In liquid aluminium, hydrogen is present in atomic form, not as molecular hydrogen (H_2). In order to be removed, hydrogen atoms must combine to form hydrogen gas molecules, although this is a very difficult mechanism [1]. To solve the problem of gas bubbles formation inside the liquid, hydrogen-free bubbles of inert gases (usually argon or nitrogen) are introduced under pressure in the melt, using a diffuser head coupled to a rotary shaft, or by inserting hexachloroethane (C_2Cl_6) tablets in the melt. Hydrogen atoms can then diffuse into such bubbles, where the reaction (1) can easily proceed to form hydrogen gas that is expelled into the atmosphere when the bubbles rise to the melt surface.

$$H + H \longrightarrow H_2 \qquad (1)$$

A different approach for hydrogen removal from aluminium melts is by reducing the pressure inside the melting chamber, creating a small vacuum effect that increases the hydrogen removal rate, technique known as *vacuum degassing*. Although some references to final H concentrations close to 0.08 ml H_2/100g Al have been referred [1], this technique is quite difficult and expensive to implement in foundries, due to the requests of the vacuum equipment, both in what concerns to the power of the vacuum system itself, and the equipment dimension for industrial scale application.

Whatever the technique used to remove hydrogen from aluminium melts, a significant amount of dross always results, with high environmental impact, which post treatment/inertization represent an important expense on the production cost.

1.3 Ultrasonic degassing

Recent experiments reveal that it is possible to remove the hydrogen dissolved in aluminium melts by applying acoustic energy to the melt, in order to induce cavitation [4,5]. In practice, any metal or alloy, usually contains a significant quantity of submicroscopic particles in suspension that are non-wettable by the melt, containing a gaseous phase in surface defects, where the proportion of free hydrogen is less than 0,1at% [6]. Nevertheless, this small amount of hydrogen is enough to initiate cavitation. When cavitation starts, a great number of small cavities develops inside the liquid. Due to the alternate pressures that are generated and the diffusion of hydrogen to those cavities, large bubbles start to develop and float to the liquid surface, where hydrogen is expelled to the atmosphere [6].

However, the development of cavitation in liquid metals is not an easy task, and it depends on many different variables – acoustic parameters, surface tension, melt temperature and viscosity, and volume fraction of inclusions in the melt, for example.

The main advantages of ultrasonic degassing are the high degassing rate and the reduced environmental impact of the process. The dross generated is minimum so environmental costs are negligible. On the other hand, this technique doesn't induce metal stirring, as the alternative processes, thus it doesn't destroy the protective aluminium oxide present at the surface of the melt, avoiding its introduction in the liquid aluminium and keeping its protecting effect against atmospheric contaminants. Moreover, the cavitation effect promotes the removal of non metallic inclusions from the melt, playing a major contribution to obtain high sanity castings.

2 Experimental Technique

Degassing tests of a AlSi9Cu3 alloy were performed using both the ultrasonic technique and the rotary impeller degassing. Melting was performed on a 5 litre SiC crucible, in an electrical resistance furnace. Melting temperature was 720 ±10ºC.

Rotary impeller degassing was performed using argon and nitrogen as purging gases. Gas was introduced at 4 bar, using a cylindrical diffuser head, with an impeller rotation speed of 200 rpm.

Ultrasonic degassing was performed using the equipment shown in Figure 1. The ultrasonic device consists mainly of an ultrasonic generator, a transducer, a horn and a acoustic radiator to transmit ultrasonic vibration to the melt. The transducer is capable of converting up to 1,2 kW of electric energy at a resonant frequency up to 25 kHz. Degassing tests were conducted using 750 W at a frequency of 19,9 kHz. The resonator was introduced in the melt on a length of 50 mm.

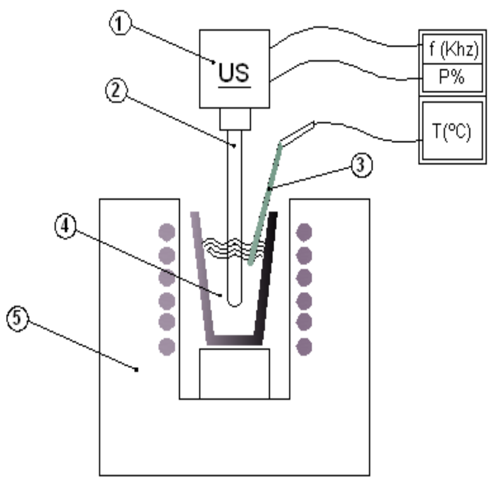

Figure 1 – Ultrasonic degassing apparatus: 1) US generator; 2) Radiator; 3) Thermocouple; 4) Liquid metal; 5) Furnace.

In both processes, samples for hydrogen content and alloy density evaluation, using the "*Straube Pfeiffer*" test, were taken before degassing, and every 1 minute after starting degassing, for 8 minutes. After solidification, samples were vertically sectioned in the middle and polished to reveal the presence of porosities.

3 Results

In Figures 2 and 3 density and hydrogen content of test samples are presented graphically, for both degassing methods and different degassing times.

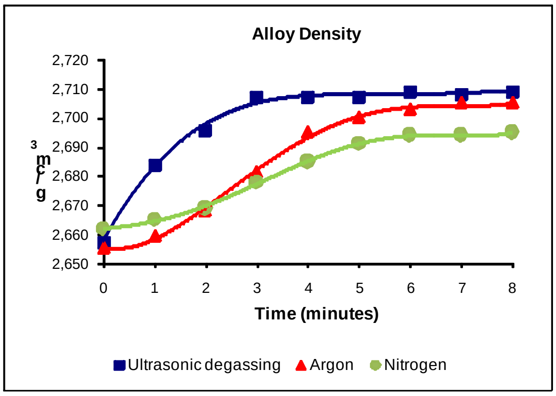

Figure 2 - Evolution of the test samples density with degassing time, for different degassing techniques.

In what concerns to the test samples density, the maximum value (2,707 g / cm^3) was obtained after 3 minutes degassing time, using the ultrasonic degassing technique, although after 2 minutes it was already 99,8% (2,701 g / cm^3) of that value (see Figure 2). For longer degassing times density remains constant, and the difference / balance to the theoretical alloy density is possibly due to solidification defects. That density corresponds to the minimum hydrogen level measured in the samples (0,068 - 0,070ml/100g Al).

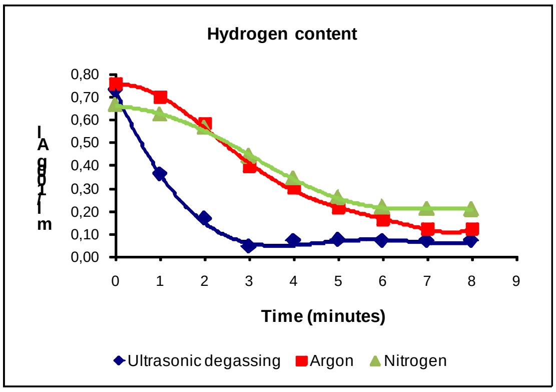

Figure 3 - Evolution of the hydrogen content of test samples with degassing time, for different degassing techniques.

These results agree with the results of other authors, namely Xu *et al.*[5] which refer between 2 and 3 minutes degassing time to achieve maximum density. However, our experimental work was developed using 10 kg of molten aluminium, while those authors refer to melting charges of 2 kg maximum, suggesting that our technique was more efficient than that used by *Xu et al* [5]. According to some authors, after reaching the minimum hydrogen level, density can even start to decrease, as a consequence of a higher tendency of the alloy to develop shrinkage [1]. However for the experimental conditions used on this work, that effect was not detected. Nevertheless, shrinkage is more evident in those test samples of this work that were submitted to higher degassing times.

Figures 2 and 3 suggest that the kinetics of ultrasonic degassing is time dependent, and changes as hydrogen is being removed from the melt. After a high removal rate in the first 2 minutes, the degassing rate slows down until a steady-state hydrogen content plateau is

reached. This behaviour is different from that observed for the rotary impeller degassing method, where the higher degassing rate was found to occur between the 2^{nd} and 4^{th} minutes.
When comparing both degassing methods, it is clearly seen that it is possible to reach a steady-state density and hydrogen content plateau with both techniques, however, the processing time required is much higher when the rotary impeller technique is used. Using ultrasonic degassing, a constant level of hydrogen content and density is reached after 3 minutes, while the steady state plateau is reached only after 7 minutes, using rotary impeller degassing. Nevertheless, results suggest that 8 minutes degassing time using this technique is not enough to reach the best values of hydrogen content and density obtained with ultrasonic degassing (0,068 ml/100g Al and 2,707 g/cm^3, respectively).
Industrial aluminium cast parts usually contain hydrogen contents between 0,15 and 0,30 ml/100g Al, because for lower hydrogen levels the tendency to develop solidification defects is higher. Using ultrasonic degassing, an acceptable hydrogen content of 0,164 ml/100g Al is reached after 2 minutes degassing time, while using rotary impeller degassing, a similar level is achieved only after 6 minutes degassing, using Argon as purging gas. This means that the efficiency of ultrasonic degassing is 3 times higher than rotary impeller degassing.

Conclusions

- Ultrasonic degassing is an effective technique to increase aluminium alloys density and decrease the alloy hydrogen content;
- For a 10 kg melt, the maximum density value (2,707 g / cm^3) and the lowest hydrogen content (0,068 - 0,070ml/100g Al) are reached after 2 minutes supplying acoustic energy;
- When compared with other aluminium degassing methods, like the rotary impeller degassing, ultrasonic degassing is almost 3 times faster than that process;
- For the experimental conditions used on this work, the rotary impeller degassing technique was not able to reach the best values achieved by using ultrasonic degassing, even after 8 minutes processing time.

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