# Study of the effect of ultrasounic treatment in porosity and mechanical properties of cast parts

M. da Silva, S. Cruz, X. Planta, J. Tort, G. Aguirre

Ultrasonic treatment has gained interest as aluminium melt degassing treatment lately due to its environment friendly feature. This paper describes the effect of ultrasonic degassing in preparing melt for different aluminium alloys for permanent mould casting and high pressure die casting. Efficiency of ultrasonic degassing is compared with conventional lance degassing, by direct measurements of hydrogen concentration in the melt with a Hycal probe and by reduced-pressure test in different stages of the casting process. Significant reduction in dross formation along was shown for ultrasonic degassing as compared with conventional lance degassing. The mechanical properties, microstructure and porosity level of components produced by high pressure die casting and permanent mould casting after both degassing techniques are determined. It is observed that the degassing efficiency of one and other degassing method depends on the treated aluminium alloy. The results show that the components produced after ultrasonic degassing treatment have similar hardness, tensile properties, porosity level and microstructure as the components degassed with conventional lance degassing. However, ultrasonic treatment seems to have an effect on porosity distribution, reducing the amount of big pores and distributing the porosity more homogenously.

**KEYWORDS:** AULTRASONIC DEGASSING, HYDROGEN CONTENT, HIGH PRESSURE DIE CASTING, PERMANENT MOULD CASTING

## INTRODUCTION

Ultrasonic degassing of liquid metals has long history. As early as in the 1940s Esmarch et al. studied the degassing of Al–Mg alloys by sonic vibrations induced by contactless electromagnetic stirring and vibrations in the crucible [1]. Starting from the 1960s laboratory and pilot-scale trials of ultrasonic degassing for foundry and later wrought alloys have been performed and summarized by G.I. Eskin [2]. Indeed, already early investigations conducted by Altman et al. [3] demonstrated that the removal of hydrogen from aluminium alloys depends greatly on the acoustic power transferred to the melt and on the development of cavitation.

The efficiency of ultrasonic degassing is a function of input ultrasonic power, melt temperature, melt flow, and alloy composition. The fundamental studies on these issues have been published elsewhere [2, 4].

Despite successful industrial trials in the 1960–1970s, ultrasonic degassing was not adopted as a mainstream technology due to arrival of Ar-assisted degassing. In

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recent years, however, the intrinsic features of ultrasonic degassing stipulated comeback interest to this technology that may answer the current environmental challenges. In addition, new level of ultrasonic technology makes its application easier.

This paper reports the results of pilot-scale trials of ultrasonic degassing using a prototype specifically designed for the application, applied to two of major foundry technologies, i.e. high-pressure die casting and permanent mould casting.

## EXPERIMENTAL PROCEDURE

Ultrasonic degassing treatments were conducted for 20 min for AlSi7Mg and 10 min for AlSi9Cu3(Fe). The treatment was conducted in a crucible holding furnace with a capacity of 400 kg filled up with about 300kg. The temperature of the alloy was 690±20°C for AlSi9Cu3(Fe) alloy and 725±20°C for AlSi7Mg alloy during the degassing treatment. The experiments were conducted using a prototype specifically designed to treat large volumes of molten aluminium. An image of the prototype is shown in Fig. 1. The ultrasonic equipment used in the experiments was composed of: a 5-kW USGC-5-22 MS ultrasonic generator, a 5-kW MST-5-18 water-cooled magnetostrictive transducer, a titanium booster, all supplied by Reltec (Russia), and a niobium tip (Fig. 1). During the treatment the sonotrode was moved with the prototype over the surface of the melt. Between 4 and 4.5 kW of power in the range of 17-18 kHz were applied in the molten metal. Alternatively, a 20 min degassing treatment with a porous graphite lance bubbling N2 was introduced in the same amount of metal, with the same temperature and composition.

**Fig.1** - Experimental set-up used in the experiments, general view of the prototype (left) and detail of the ultrasonic generator and wave-guiding equipment (right).

Measurements of the hydrogen with a Reduced Pressure Test (RPT) (MK, Germany) were made before and after the degassing treatment, 15 minutes and 1 hour after the treatment. Additionally, the hydrogen content was directly measured with an Hycal probe. After the degassing treatment, the melt was used to cast components using a High Pressure Die Casting (HPDC) unit (Bühler Evolution 53D), AlSi9Cu3(Fe) alloy, and a mould for Permanent Mould Casting (PMC), AlSi7Mg alloy.

One randomly selected part produced after each degassing treatment by PMC was inspected by computed tomography. Additionally, parts produced by PMC and HPDC were sectioned in order to control their tensile properties and microstructure. In Fig. 2 are presented pictures of the parts, indicating the regions where the specimens were extracted. The tensile properties were determined according to ISO 6892-1 standard.

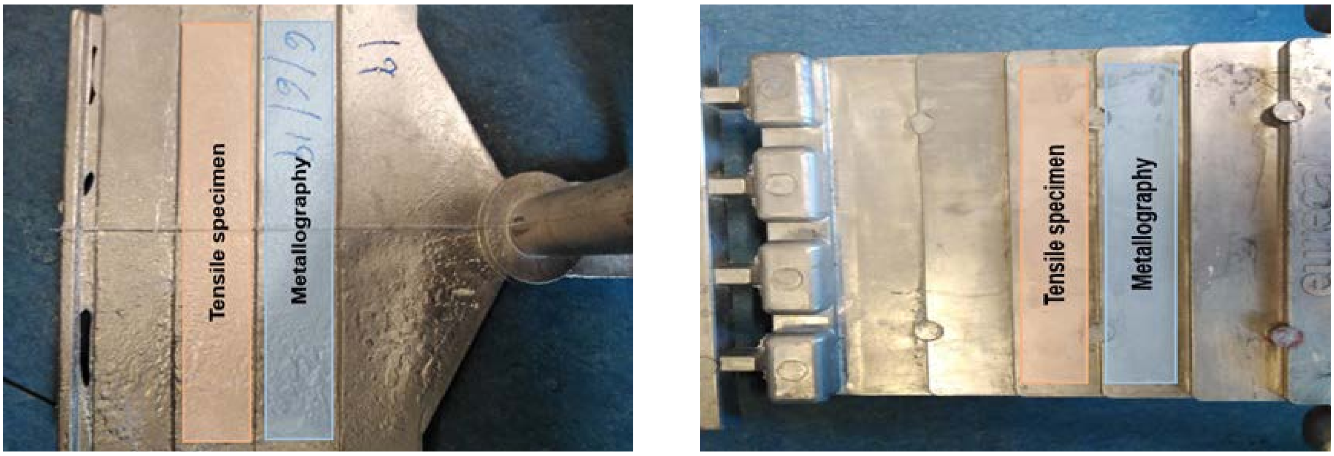


**Fig.2** - Images of a PMC part (left) and HPDC part (right) indicating the regions where the specimens for tensile test and metallographic inspection were extracted.

## RESULTS AND DISCUSSION

### Permanent Mould Casting of AlSi7Mg alloy

In Table 1 are presented the Density Index measured in the ultrasonic degassing treatment and the reference lance degassing. In both treatments the Hycal probe was used to record the actual hydrogen present in the melt during the whole trial. The hydrogen evolution observed in the different tests is presented in Fig. 3. After the treatment, 21 parts were produced for each batch, with a stair shaped permanent mould by gravity casting.

**Tab.1** -D.I index values measured for the lance degassing and ultrasonic treatment of AlSi7Mg alloy.

| Sample number | 20 min lance degassing | 20 min ultrasonic treat. |
|---|---|---|
| Before treatment (1) | 5.65 | 8.69 |
| After treatment (2) | 0.37 | 1.40 |
| 15 min after treatment (3) | 0.47 | 4.10 |
| 1 hour after treatment (4) | 2.48 | 6.98 |
| Ambient temperature | 22.7°C | 13.1°C |
| Relative humidity | 32 % | 92 % |
| Dross weight | 2075 g | 239 g |

It is observed that both treatments are quite effective, considerably reducing the initial Density Index value. After this first drop in the Density index, it increases again, but without reaching the initial value. Lance degassing seems to be more effective than ultrasonic degassing, but the reduction with ultrasonic treatment is also very significant. In addition, can be observed that ambient humidity was much higher in the day where ultrasonic treatment was conducted, leading to a faster regassing of the metal, once the degassing treatment concluded [4].

Regarding the dross formed during the treatment, lance degassing generates almost 10 times the dross that is created with ultrasonic treatment, increasing the dross rate from 0.08 % to 0.69 %. The highly turbulent conditions created by gas degassing generate a disturbance in the aluminium surface that enhance dross formation. On the contrary, ultrasonic processing, creates very small cavities that are turned into bubbles that practically do not break the oxide layer covering the melt surface [5].

Regarding the results of Hycal measurements (Fig. 3), it can be observed that the hydrogen content has a clear relation with the furnace temperature. The natural oscillation of temperature experienced by the melt, due to furnace heating system, is transferred into a similar oscillation on hydrogen value, and the effect of the degassing treatment is hidden by the temperature variation.

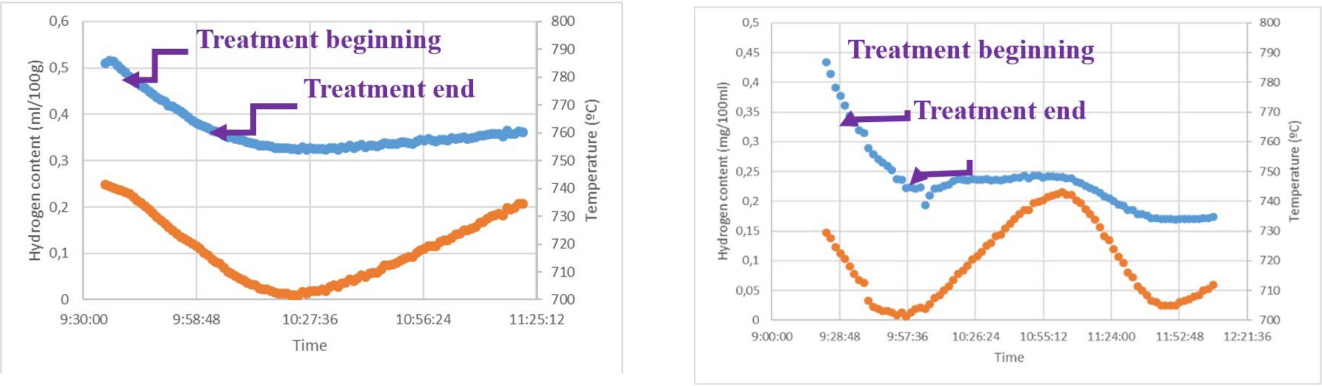


**Fig.3** - Hydrogen evolution measured with Hycal equipment for the utrasonic (left) and lance (right). Blue curve belongs to measured hydrogen concentration and orange to measured melt temperature.

5 PMC parts of AlSi7Mg were selected from each batch for subsequent inspection. A tensile specimen was machined from each of the parts and tested in a universal testing machine. The results are summarized in Table 2.

As can be seen in Table 2, the results obtained with the ultrasonic degassed parts are slightly better than the nitrogen degassed parts. Nevertheless, the difference is in the level of the sum of both standard deviations, not allowing to infer any strong conclusion.

One part produced from the nitrogen degassed batch (N2) and one part produced from the ultrasonic degassed batch (US) were selected for detailed measurement of their porosity distribution with computed tomography. The results with the percentage of pores found for each pore size interval are presented in Fig. 4. The results show that the number of larger pores (with a volume over 0.1 $mm^3$) is clearly higher in the $N_2$ degassed part. This behavior has been observed previously [6], but it is still not clear the mechanism to lead to this more homogeneous pore distribution in the ultrasonic degassed parts. The pores below this size of 0.1 $mm^3$ are much less relevant regarding effect on ductility and other mechanical properties than the biggest ones, as the equivalent size in one single dimension for this volume is 33 μm, a value just over the 29 μm obtained in the SDAS measurement of current material for both degassing routes. Pores below SDAS size do not to have a relevant impact on mechanical properties, as do larger pores [7].

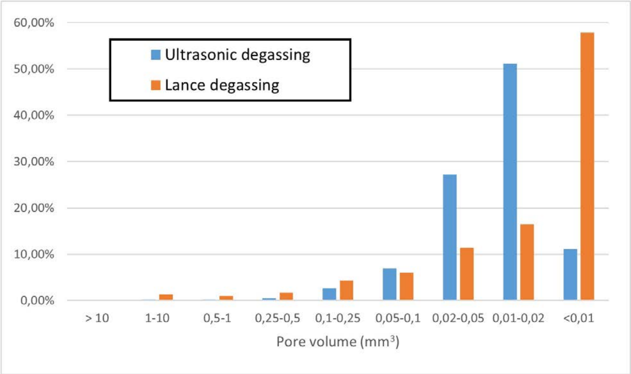
**Tab.2** - Section measured for the tensile specimens and values obtained from the corresponding tensile test.

| | Part number | $R_{p0.2}$ MPa | $R_m$ MPa | $A_{t\,(corr.)}$ % | | Part number | $R_{p0.2}$ MPa | $R_m$ MPa | $A_{t\,(corr.)}$ % |
|---|---|---|---|---|---|---|---|---|---|
| Ultrasonic degassed | US-2 | 117 | 157 | 2.28 | Nitrogen degassed | N2-2 | 118 | 172 | 2.16 |
| | US-3 | 115 | 171 | 3.26 | | N2-5 | 104 | 170 | 3.17 |
| | US-6 | 121 | 174 | 2.23 | | N2-6 | 111 | 169 | 2.78 |
| | US-8 | 117 | 174 | 2.78 | | N2-12 | 112 | 151 | 1.69 |
| | US-10 | 117 | 177 | 3.02 | | N2-13 | 99 | 155 | 2.51 |
| | Average | 117 | 171 | 2.71 | | Average | 109 | 163 | 2.46 |
| | Desvest | 2 | 8 | 0.45 | | Desvest | 7 | 10 | 0.57 |

## HIGH PRESSURE DIE CASTING OF ALSI9CU3(FE) ALLOY

Two treatments were used alternatively in the melt 10 min ultrasonic degassing and 20 min lance degassing treatment. After the treatment the metal was used to produced HPDC components with a HPDC machine.

Reduced Pressure Test samples were taken from the metal before the treatment (1), immediately after the treatment (2), after 15 minutes of idle time (3) and 1 hour after the treatment (4). In Table 3 are presented the results of Density Index obtained for this alloy with both degassing treatments.



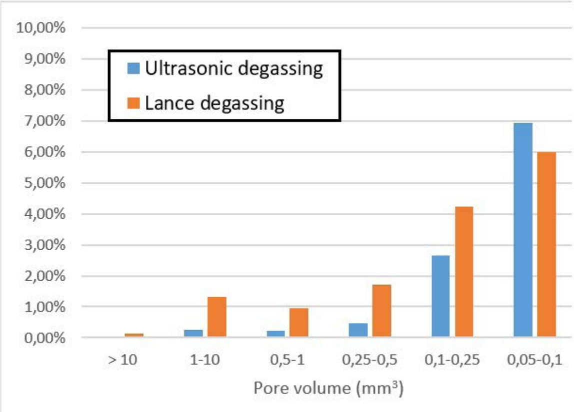


**Fig.4** - Total pore size distribution in percentage of total number of pores for the ultrasonic degassed and lance degassed parts (left) and only considering the pores with a size over 0.05 mm$^3$ (right).

**Tab.3** - D.I index values measured for the lance degassing and ultrasonic treatment of AlSi9Cu3(Fe) alloy.

| Sample number | 20 min lance degassing | 10 min ultrasonic treat. |
|---|---|---|
| Before treatment (1) | 5.14 | 4.17 |
| After treatment (2) | 4.99 | 0.09 |
| 15 min after treatment (3) | 3.08 | 4.50 |
| 1 hour after treatment (4) | 2.43 | 4.74 |
| Ambient temperature | 14.5°C | 16.1°C |
| Relative humidity | 59 % | 75 % |
| Dross weight | 555 g | 240 g |

The lance degassing reduces the density index slightly after the treatment, and degassing continues after production has started. In the ultrasonic treatment a strange value of just 0.09 is obtained immediately after the ultrasonic treatment, but after that the other two remaining samples (3 and 4) shows similar D.I. values than the initial melt. With the obtained results, it seems that the effect of the 10 min ultrasonic treatment in the D.I. is insignificant. Nevertheless, it is observed that both treatments are not very effective with this AlSi9Cu3(Fe) alloy, having a very limited impact on the D.I. value. Regarding the dross formed during the treatment, lance degassing generates more than double of the dross that is created with ultrasonic treatment, increasing the dross rate from 0.08 % to 0.19 %.

As well, as for AlSi7Mg alloy, 5 HPDC components were selected from each production in order to characterize their mechanical properties. The values obtained in the tests for each lot of parts are summarized in Table 4. No significant differences in the obtained mechanical properties are observed between both degassing methods. All the samples present similar values of yield strength, ultimate tensile strength and elongation.

**Tab.4** - Section measured for the tensile specimens and values obtained from the corresponding tensile test.

| | **Part number** | **$R_{p0.2}$ MPa** | **$R_m$ MPa** | **$A_{t\,(corr.)}$ %** | | **Part number** | **$R_{p0.2}$ MPa** | **$R_m$ MPa** | **$A_{t\,(corr.)}$ %** |
|---|---|---|---|---|---|---|---|---|---|
| | 181 | 120 | 243 | 0.5 | | 161 | 121 | 249 | 0.5 |
| Ultrasonic | 186 | 113 | 230 | 1.3 | Nitrogen | 163 | 114 | 229 | 0.7 |
| | 190 | 129 | 267 | 0.5 | | 164 | 125 | 260 | 0.9 |
| degassed | 191 | 126 | 257 | 0.9 | degassed | 169 | 118 | 235 | 0.9 |
| | 193 | 108 | 216 | 0.8 | | 171 | 114 | 225 | 0.8 |
| Average | US | 119 | 243 | 0.8 | Average | N2 | 118 | 240 | 0.8 |
| Desvest | US | 9 | 20 | 0.4 | Desvest | N2 | 5 | 15 | 0.2 |

## CONCLUSIONS

From the results obtained in the present study the following conclusions can be inferred:

- Ultrasonic degassing performed using a single ultrasonic source and a prototype-level setup is able to achieve similar hydrogen content in the melt than a mature, commercially available porous lance for an appreciable melt volume of 300 kg of AlSi7Mg alloy.
- The melt surface is much less disturbed during ultrasonic degassing, as cavitation bubbles are formed within the metal and the flow is directed downwards. As a result, much less dross formation is observed as compared to lance degassing.
- Porosity and mechanical properties of the castings produced after ultrasonic degassing or lance degassing are similar with some tendency of reduction of large pores content after ultrasonic degassing.

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