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Effect of ultrasonic degassing on performance of Al-based components

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Abstract: The effect of high intensity ultrasound based on the novel multi-frequency multimode modulated technology on the final density, porosity, mechanical and fatigue properties of an $AlSi_9Cu_3(Fe)$ alloy after different processing time was studied. Reduced pressure test was used to evaluate the density of alloys. The tensile and fatigue tests were used to evaluate the static and dynamic properties for the different time of ultrasonic degassing, respectively. It is found that ultrasonic degassing is effective in reduction porosity as well as to improve the final density of castings. Furthermore, the experimental results suggest that the porosity level does not have a substantial influence on the static properties contrary to what is observed on fatigue properties.

Key words: casting; ultrasound; degassing; porosity; fatigue

1 Introduction

In the last years, the demand of cost-effective high strength castings for application in industries where superior specific strength is a crucial factor, such as the automotive and aeronautical industries, has significantly increased. On this context, Al−Si-based alloys are the most widely used aluminium alloys for shape casting due to their high fluidity and castability, easy machinability and weldability, good corrosion resistance and mechanical properties. CACERES et al [1] stated that high mechanical strength is usually achieved by the addition of alloying elements such as copper and magnesium as they make the alloys heat treatable, in spite of having a tendency to decrease ductility.

AMMAR et al [2] and TENG et al [3] have shown that traditional casting techniques induce high number of defects like porosities, inclusions and coarse microstructure, each of them being characteristic of a specific casting process, which are highly detrimental to the mechanical and fatigue properties of castings. In addition, TANAKA et al [4] also stated that fatigue is considered the most common failure mechanism of engineering components and it is responsible for almost 90% of all service failures attributed to the mechanical causes. Among casting defects, porosity is considered the key factor controlling the fatigue behavior of Al-based castings since they are preferential sites for crack initiation, independent of the loading conditions and the stress applied.

GRUZLESKI and CLOSSET [5] and MEIDANI and HASAN [6] have demonstrated that the main source of gas porosities in aluminium castings is hydrogen, which is the only gas with significant solubility in molten aluminium. For this reason, they stated that the hydrogen content in a molten alloy must be kept as low as possible, especially when dealing with high strength casting alloys for critical applications like aerospace or automobile parts.

Taking the traditional application fields of aluminum alloys into consideration, the porosity and mechanical properties are critical factors in the components performance. Thus, it becomes important to develop techniques for treatment of liquid melt leading to a high sanity and microstructural characteristics that ensure the best possible mechanical performance of components, without environmental impact, more efficient and easier to control than those existing today.

Ultrasonic degassing is a possible way to improve hydrogen removal and thus overtake the drawbacks that occur when traditional methods are applied [7−10]. When a liquid metal is submitted to high intensity ultrasonic vibrations, the alternating pressure above the cavitation threshold creates numerous cavities in the liquid metal which intensifies the mass transfer processes

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and accelerates the diffusion of hydrogen from the melt to the developed bubbles [11]. As acoustic cavitation progresses with time, adjacent bubbles touch and coalesce, growing to a size sufficient to allow them to rise up through the liquid, against gravity, until reach surface promoting degassing of the liquid [11].

The main advantages of ultrasonic degassing are the high degassing rate and the reduced environmental impact of the process. Moreover, cavitation promotes the removal of non-metallic inclusions from the melt, playing a major contribution to obtain high sanity castings.

In this work, the effect of ultrasonic degassing on the final density and porosity is assessed. Furthermore, the type of pores, area fraction, average size and maximum size are assessed and their influence on mechanical and fatigue properties of the $AlSi_9Cu_3(Fe)$ alloy is presented, for different degassing time. Moreover, simple prediction equations for the fatigue limit incorporating the effect of the shape and size of casting defects on the fatigue strength of material were used.

2 Experimental

2.1 Experimental set-up

The experimental set-up (Fig. 1) used in this work consisted of a novel multi-frequency, multi-mode, modulated technology (MMM) ultrasonic power supply unit, a high power ultrasonic converter (1200 W), acoustic waveguide with 30 mm in diameter and 150 mm in length and the acoustic load which consisted of a Sialon acoustic radiator with 60 mm in diameter and 500 mm in length and the liquid metal.

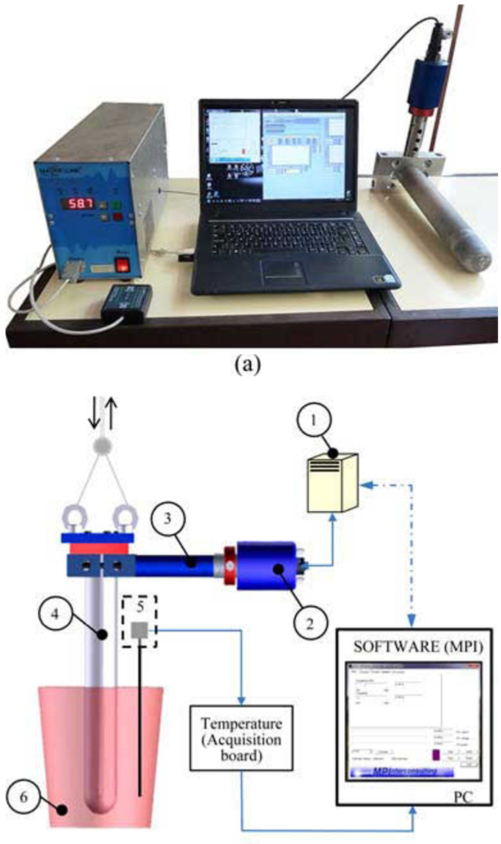
Degassing tests using ultrasonic frequency of (19.8±0.1) kHz at 60% electric power were carried out for each processing condition: no treatment, time of 1 and 3 min, and melt temperature of (700±5) °C. Before degassing and after each degassing period, 15 cylindrical samples with 14 mm in diameter and 110 mm in length were cast on a metallic mold and used for mechanical and fatigue testing. At the same time, 3 samples for alloy density evaluation, using the reduced pressure test (RPT) and the apparent density measurement method were cast.

2.2 Materials

Melting stocks of $AlSi_9Cu_3(Fe)$ alloy (Table 1), weighing 6 kg for each ultrasonic treatment were melted in a resistance furnace equipped with a SiC crucible with 210 mm in diameter and 240 mm in height.

2.3 Microstructural and mechanical characterization

Samples for microstructure characterization were taken from each cast sample by sectioning them perpendicularly to its longitudinal axis at half length.



(b)

Fig. 1 Laboratory unit for ultrasonic degassing (a) and schematic diagram of experimental apparatus (b): 1—Ultrasonic power supply; 2—Transducer; 3—Waveguide; 4—Acoustic radiator; 5—Thermocouple; 6—Liquid

Table 1 Chemical composition of $AlSi_9Cu_3(Fe)$ alloy (mass fraction, %)

Si	Fe	Mg	Cu	Mn	Zn	Sn	Al
9.15	0.66	0.18	2.25	0.26	0.47	0.10	Bal.

They were ground using 1200 SiC paper and polished up to 1 μm. Those samples used for optical microscopy characterization were etched with Keller's reagent to reveal the resulting microstructure.

Optical microscopy (OM) and scanning electron microscopy (SEM) with quantitative metallographic analysis capability were used to evaluate the shape and grain size of constituents. Image-ProPlus software was used to quantify the area fraction of porosities and SDAS in fields of 100x.

For tensile testing, specimens were machined from the as-cast samples according to EN 10002-1:tensile testing metallic materials with a gauge length L_0 of 50 mm and a cross-sectional diameter d_0 of 10 mm. Tensile tests were carried out at room temperature and a strain rate of 0.5 mm/min on a INSTRON testing machine, Model 8874, to obtain yield strength, ultimate tensile strength and strain. At least 12 specimens, with the