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Effect of ultrasound treatment of AlSi5 liquid alloy on corrosion resistance

A. Arrighini, M. Gelfi*, A. Pola and R. Roberti

The application of power ultrasound to liquid alloys can be a simple and cost effective method to induce both degassing and grain refinement in a single step, without the need of inert gas or inoculants additions. In this paper, the treatment of liquid hypoeutectic AlSi5 alloy by ultrasound waves and its effects on microstructure were investigated. The corrosion behavior of ultrasound treated samples was compared to that of the non-treated ones by means of immersion and electrochemical tests. It was observed that the ultrasound treated alloy offers better quality, higher mechanical properties and improved corrosion resistance, as a consequence of a more uniform distribution of the solute.

1 Introduction

Castings characterized by homogeneous and fine microstructure offer higher mechanical properties. As known, grain size is inversely proportional to the number of active nuclei inside the liquid metal [1, 2], which can be increased by grain refinement methods, such as nucleants addition (i.e. TiB_2) [3]. However, the use of this technique involves high and continuous costs to the foundries that, in the case of aluminum alloys, must be added to those for the metallic bath pre-treatment for hydrogen removal. Degassing is performed by injecting inert gas bubbles (argon or nitrogen) within which the hydrogen atoms diffuse and can be removed by floatation [3]. This technology needs both technical and economical arrangement and management of inert gas tanks which involve increases in production costs.

A potential alternative to these methodologies is represented by the power ultrasounds (US) applied to the liquid bath, which seem to guarantee simultaneously nucleation and degassing [4]. The introduction of high-power ultrasonic vibration into a liquid alloy leads to cavitation and acoustic streaming. Ultrasonic waves produce cavitation phenomena in liquids and the creation, growth and collapse of bubbles, that can also generate very high impact forces; these ones have a dynamic role during the nucleation because the high pressures fragment the rising crystals, by breaking dendritic structures and by increasing the nucleation centres [5], while the acoustic flow induces a vigorous stirring of the bath, homogenizing the alloy. Cavitations phenomena originate also a rapid development of hydrogen bubbles, causing their following coalescence and flotation on the liquid metal surface and, therefore, promoting the alloy degassing [4, 6].

Moreover, waves clean the low wettable surfaces of the non-soluble non-metallic particles unavoidably present in the liquid metal; by means of ultrasound treatment the wettability increases and heterogeneous nucleation is favored, without the need of expensive inoculants.

Research has already been done by authors in order to evaluate the effect of US treatment on degassing and grain refinement of aluminum and zinc alloys [7, 8].

The aim of this paper is to complete the characterization of US treated aluminum alloys by evaluating their corrosion resistence. As known, the corrosion behavior of a foundry alloy is strongly influenced by grain size and microstructure morphology, by the anodic or cathodic character of the present phases and also by the solute distribution [9, 10]. Therefore, the microstructural variations induced by US treatment, in term of size and morpology of aluminum primary phase, silicon particles and intermetallics, are expected to have a strong influence on corrosion resistance. To study this effect immersion and electrochemical tests were performed.

2 Experimental procedure

The experiments were carried out on a hypoeutectic Al-Si alloy produced from commercially pure elements, in order to strictly evaluate the effect of US treatment on microstructure avoiding the influence of any other parameter (i.e. nucleants agents, modifier, etc..). According to spectroscopy analysis, the resulting composition was: 4.52% of silicon, 0.17% of iron, 0.006% of manganese, titanium, magnesium, copper, and zinc <0.02%, rest aluminum.

For this experiment, about 1 kg of alloy was melt in a refractory crucible. A part of this alloy was treated by US at

A. Arrighini, M. Gelfi, A. Pola, R. Roberti
Dipartimento di Ingegneria Meccanica e Industriale, Università degli Studi di Brescia, via Branze 38, 25123 Brescia (Italy)
E-mail: marcello.gelfi@ing.unibs.it

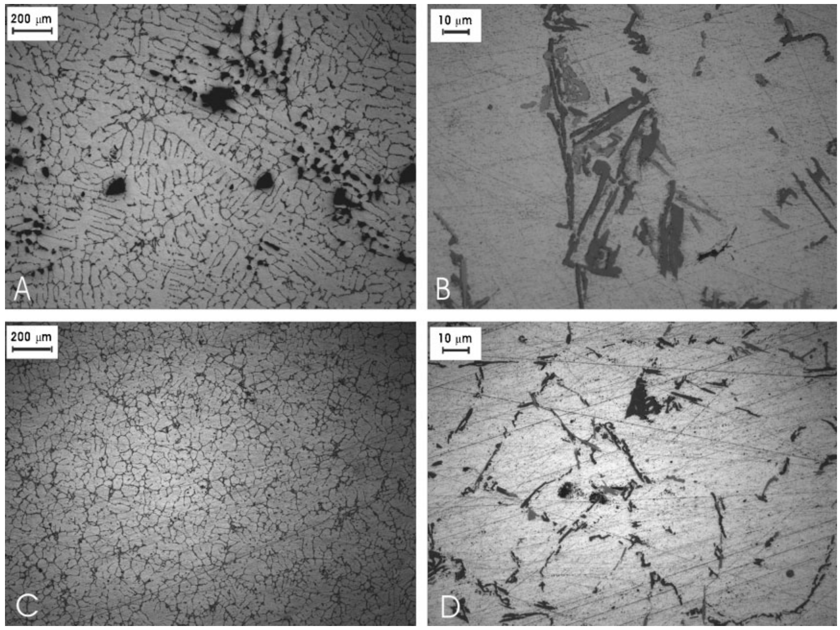


Figure 1. Optical images at low and high magnification of microstructure of NUST (A–B) and UST (C–D) samples

30–40 °C above the liquidus temperature and cast into a laboratory gravity die to produce small disks ($\Phi = 40$ mm, $H = 15$ mm). The rest of the alloy was cast into the same dies without any treatment, obtaining two sets of samples named respectively: UST (US Treated) and NUST (Not US Treated).

Nowadays, no off-the-shelf ultrasound equipments suitable for this specific application are industrially available; therefore, a US device was purposely manufactured, as already described in previous works [7].

UST and NUST samples were subjected to immersion corrosion tests for 450 h in a 5% sodium chloride solution at 50 ± 2 °C.

Electrochemical corrosion tests were also carried out on square section specimens (1 cm^2) machined from the cast disks, in a 0.5 M sodium chloride aqueous solution at 25 °C. The AMEL 7050 potentiostat used for the polarization experiments was set in the 3 electrodes standard configuration: platinum counter electrode (CE), saturated calomel reference electrode (SCE), and working electrode (WE). The polarization curves were collected, after at least 30 min of immersion into the solution, by stepping the potential at a scan rate of 0.16 mV/s from 200 to +200 mV with respect to open-circuit potential. Using an automatic data acquisition system, the potentiodynamic polarization curves were plotted and both corrosion rate and potential were estimated by the Tafel extrapolation method. For treated and non-treated castings, minimum three tests were performed.

In order to assess the effect of US treatment on castings microstructure, metallographic investigations were carried out on samples surfaces and sections by means of optical microscope (Reichert-Jung MeF3) equipped with QWin image analyzer, and by means of scanning electron microscope LEO EVO 40, both in secondary electrons and backscattering mode, equipped with an EDS (Energy Dispersive Spectroscopy) probe.

Finally, Vickers microhardness was measured, applying a 300 g load for 15 sec, in order to evaluate the castings mechanical performance.

3 Results and discussions

As shown in Fig. 1, the NUST samples have a dendritic microstructure, typical of foundry products, characterized by the presence of gas and micro-shrinkage porosity.

The application of US to the liquid alloy, for a proper time [7], produced a finer and more homogeneous microstructure. The UST samples are free from hydrogen porosity and characterized by almost rounded aluminum-rich primary phase surrounded by the eutectic. Moreover, the lack of dendrites, whose arms can interconnect and obstruct the eutectic liquid feeding, prevents from the formation of shrinkage micro-porosity.

Concerning the interdentritic phases, both UST and NUST samples have the same eutectic silicon and (Al, Fe, Si) intermetallic particles, characterized by needle and Chinese script morphology.

In order to evaluate the refining effect of US treatment, the size of interdendritic particles was measured, because directly related to grain size [11]. Measurements were carried out on 10 areas of the samples, in order to average the effect of different cooling rate in the various casting sections. The US treatment has the main refining effect on the silicon eutectic particles, which present a three times lower average size in UST samples compared to the NUST ones (12.8 μm *vs.* 30 μm). It also must be noticed that in the ultrasound treated alloy the data dispersion is strongly reduced ($\sigma = 5$ μm *vs.* $\sigma = 13$ μm).

Similar results were observed for the (Al, Fe, Si) intermetallic particles. NUST samples have intermetallics with a maximum size almost twice (45.7 μm *vs.* 27.4 μm). UST data are still

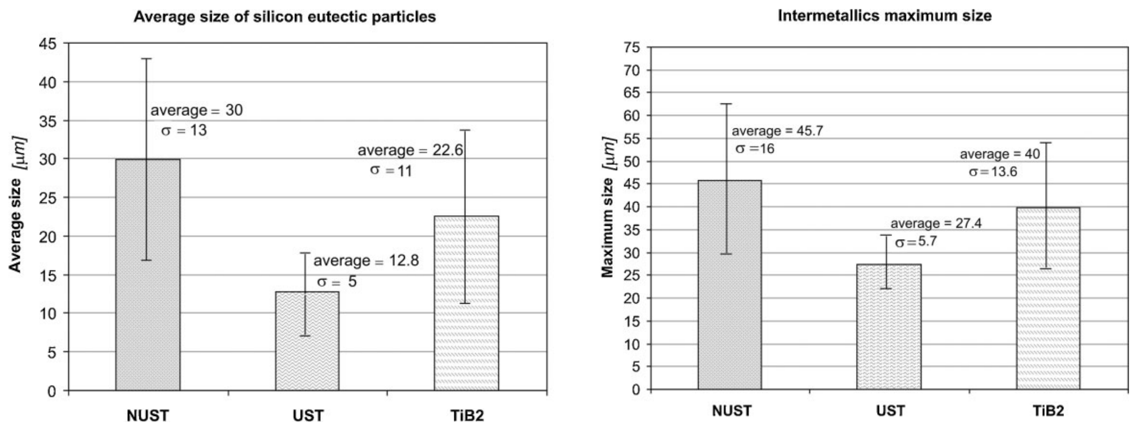


Figure 2. Intermetallics and silicon particles size

characterized by lower dispersion ($\sigma = 5.7\ \mu m$ *vs.* $\sigma = 16\ \mu m$), confirming the homogenizing effect of the treatment.

To compare the microstructure refining effect of power ultrasounds treatment with that of traditional methods, the same measurements of eutectic silicon and intermetallic particles were finally performed on an AlSi5 alloy refined by TiB_2 addition. The results, plotted in Fig. 2, show the comparison between NUST, UST, and TiB_2 refined samples and demonstrate that the ultrasound treatment produces a better microstructural refinement than the conventional method.

Vickers microhardness measurements show higher and less scattered results for UST samples with respect to the NUST ones (48 ± 1.3 HV *vs.* 43 ± 3 HV), still as a consequence of finer and more homogenous microstructure.

Considering the finer microstructure of UST samples, it was expected to find a worse corrosion behavior according to literature [10, 12]. It is well known that in Al-Si alloys silicon and intermetallic particles play a cathodic effect with respect to the aluminum matrix, inducing localized corrosion in the eutectic regions. A finer microstructure has a higher number of interface aluminum/particle, i.e. a higher number of preferential corrosion sites, with a consequent reduction of corrosion resistance.

Anyway, the electrochemical corrosion tests gave opposite results. The UST samples show a higher corrosion resistance with respect to the NUST ones (Fig. 3), even if the silicon and intermetallic particles are smaller. In particular, for the NUST samples the mean corrosion current density (i_{corr}) calculated by means of the Tafel extrapolation is equal to $1.50 \pm 0.21\ \mu A/cm^2$, in agreement with literature [12], while for the treated alloy i_{corr} is only $0.30 \pm 0.01\ \mu A/cm^2$.

Moreover, the UST samples show a higher corrosion potential. This difference cannot be related to experimental inaccuracy, considering that tests were repeated several times and that all the samples were obtained from the same melt (i.e. same chemical composition).

The good corrosion resistance and the more noble potential of UST alloy can only be explained considering the homogenizing effect of ultrasound treatment, which promote a more uniform solute redistribution.

Considering that these alloys are affected by galvanic corrosion on a microscopic scale, a better distribution of elements can reduce the potential difference in the microstructure and the occurrence of selective corrosion phenomena. This seems to be confirmed by the polarization curve shape for

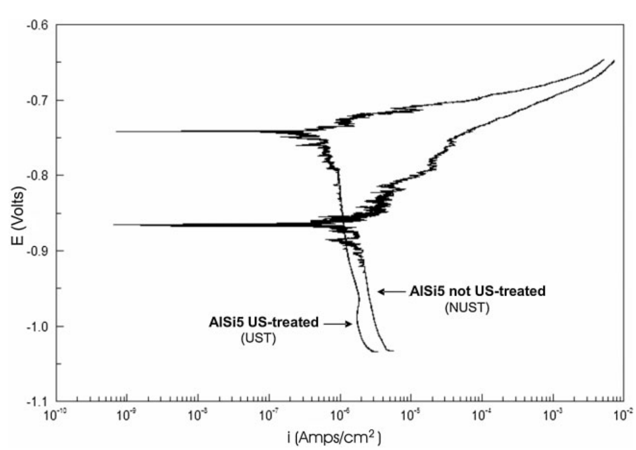
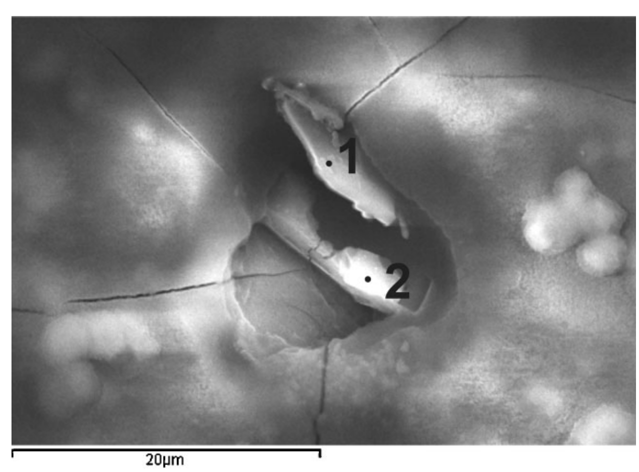


Figure 3. Examples of polarization curves for NUST and UST samples



Spectrum	O	Al	Si	Fe
1	20.76	32.07	32.63	14.54
2	24.11	9.19	66.69	

Figure 4. Cathodic effect of silicon and intermetallic particles in stimulating corrosion of aluminum matrix

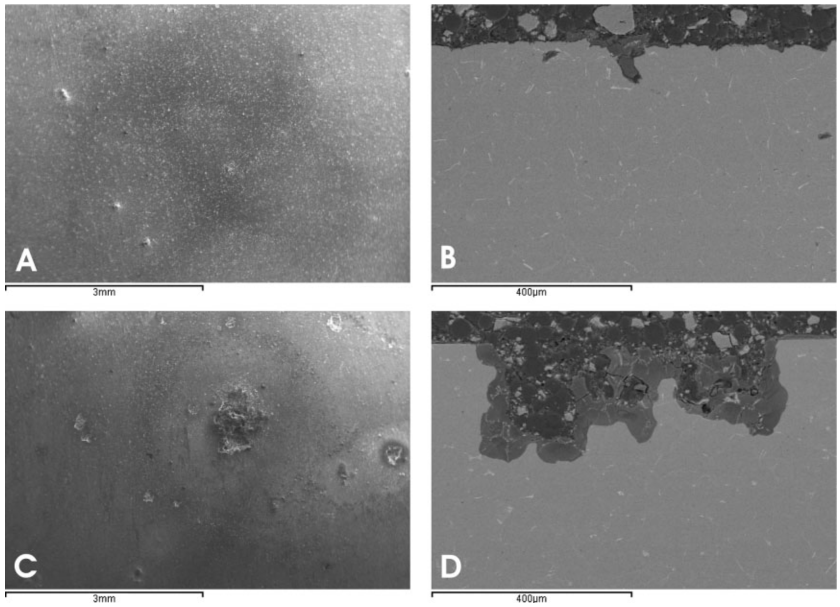


Figure 5. Surfaces and sections of UST (A–B) and NUST (C–D) samples after 450 h 5% sodium chloride immersion test

the NUST sample which show an increased and vibrating current between the free corrosion potential and the pitting potential (approx. from −850 mV to −750 e mV), that likely indicates a selective dissolution of some compounds. As the UST sample is more homogeneous, the dissolution starts next to the pitting potential.

These observations are in agreement with the corrosion morphologies noticed on samples surfaces after 450 h of immersion in 5% sodium chloride solution. As expected, for both samples, corrosion occurs preferentially in the eutectic regions, stimulated by the presence of cathodic silicon and intermetallic compounds (Fig. 4). In the UST sample, the presence of a great number of small intermetallics produces a higher pit density than in the NUST one (14.9 ± 1.1 pits/mm^2 *vs.* 11.1 ± 3.0 pits/mm^2). As a consequence, on the UST sample the pits are shallow and uniformly distributed, while on NUST sample the attack is strongly localized, producing deep pits, which justify the higher current densities measured during the polarization test (Fig. 5).

4 Conclusion

In this paper, the effect of the ultrasound treatment of liquid AlSi5 alloy on castings quality and corrosion resistance was studied and compared to that of non-treated samples.

Metallographic investigations show that US treatment has a strong effect in reducing porosity and especially in refining and homogenizing the microstructure.

Concerning the electrochemical corrosion tests, the US treated alloys have a better corrosion resistance and a higher corrosion potential, probably as a consequence of a more uniform distribution of the solute. This hypothesis seems to be confirmed by immersion tests, which show that on UST samples surfaces the corrosion is less localized.

5 References

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