The combined effect of melt stirring and ultrasonic agitation on the degassing efficiency of AlSi9Cu3 alloy

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Abstract

The combined effect of high intensity ultrasound and melt stirring on the degassing of AlSi9Cu3 using simultaneously the novel MMM (Multi-frequency Multimode Modulated) ultrasonic technology, and low frequency mechanical vibration to promote melt stirring, was studied. Different mechanical vibration frequencies, melt temperatures and processing times were tested and their influence on the degassing efficiency evaluated and compared with the results of the single MMM ultrasonic degassing technique. Fixed ultrasonic parameters (frequency and electric power) were used, according to the best results obtained in former experimental works developed by the authors. For the experimental conditions used in this research, it was found that melt stirring significantly improves degassing efficiency, and such improvement depends on the metal temperature and the mechanical vibration frequency. The experimental results suggest that combining melt agitation and ultrasonic vibration it is possible to achieve almost the aluminium alloy theoretical density without increasing the processing time.

Keywords: Casting; Porosity; Metals and Alloys; Metallurgy

1. Introduction

One of the most efficient, fast and environmentally friend degassing method of Al alloys is based on the supply of ultrasonic energy to the molten metal in order to induce cavitation [1,2,3]. 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 [4] which intensifies mass transfer processes and accelerates the diffusion of hydrogen from the melt to the developed bubbles. 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 [4].

During the last years some of the authors developed an improved ultrasonic degassing apparatus (MMM - Multi-frequency Multimode Modulated technology) characterized by synchronously exciting many vibrating modes through the coupled harmonics and sub harmonics in solids and liquid containers to produce high intensity multimode vibrations that are uniform and repeatable [2,5] which avoid the creation of stationary and standing waves, so that the whole vibrating system is fully agitated, improving the degassing process.

However, ultrasound loses its oscillation energy and sound intensity along the path in a melt. If this loss is significant the intensity rapidly falls to the cavitation threshold and cavitation ceases, decreasing the degassing effect [4,6]. The displacement and the intensity of a plane ultrasonic wave decreases exponentially with the propagation path x, according to expressions (1) and (2) [4]:

$$A = A_0\, e^{-\propto x} \qquad (1)$$

$$I = I_0\, e^{-\propto x} \qquad (2)$$

where A is the displacement, I the intensity and is the sound absorption, or attenuation, factor. Among other factors the absorption of ultrasound depends on the viscosity of the melt, thus on the metal temperature,and its thermal conductivity.

Ultrasonic degassing performed so far has been running in a stationary volume of metal [2,3,7]. As a consequence of attenuation cavitation decreases gradually as the distance to the radiator increases, and cavitation only develops on a limited volume of molten metal. To attenuate this effect,a modification to the original ultrasonic apparatus was made, in order to simultaneously induce a gentle stirring motion in the melt which would increase the volume of metal developing cavitation.

This paper presents the experimental study developed to evaluate the capability of the combined/simultaneous effect of melt stirring and ultrasonic agitation on the degassing efficiency of AlSi9Cu3 alloy over the single ultrasonic degassing technique.

2. Experimental procedure

The main components of the new version of the MMM ultrasonic system used in this research consist of a high power ultrasonic converter, an acoustic wave-guide and radiator, a low frequency mechanical vibrator coupled to the radiator by a helicoids interface, and a sweeping-frequency, adaptively modulated waveform generated by an MMM ultrasonic power supply (Fig.1).

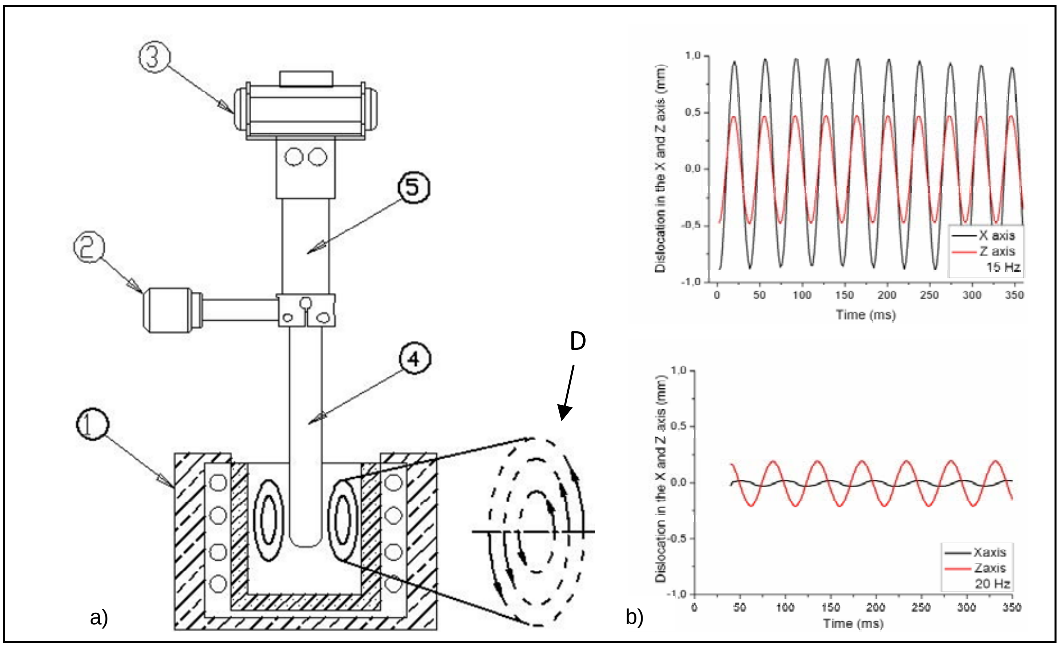


Fig.1 – a) Degassing apparatus including 1.furnace; 2.ultrasonic transducer; 3.low frequency mechanical vibrator; 4.radiator; 5.helicoids interface. b) Dislocation of the ultrasonic radiator under different mechanical vibration frequencies.

The equipment is fully controlled through Windows compatible software developed by MPI. Optimal ultrasonic parameters (sweeping and fswm = frequency shift with modulation) for the selected resonant frequency and electric power are adjusted in order to produce the highest acoustic amplitude and the largest frequency spectrum in the metal, which is monitored with a specifically implemented feedback loop.

The effect of the helicoids interface on the melt dynamics was evaluated in water, using a translucent container, since the water viscosity is similar to that of molten aluminium at 700ºC [4]. For that purpose, the movement of the radiator for various vibration frequencies was measured by a high speed digital Photron, FastCam APX RS video camera capable of 10,000 fps at 1Mpixel. Appropriate illumination is required and two high intensity beams were strategically placed in the vicinity of the viewing area. The video sequences were recorded at 1000 fps and a subsequent image analysis TEMA Motion software enabled the determination of the motion as a function of time. A mark was placed on the radiator surface and a scale was in view in order to calibrate the frames. From the position time series, the velocity and acceleration can be derived.

The specimen vibrations induce an oscillatory motion of the surrounding fluid. The radiator was placed in a circular vessel, 170 mm in diameter, filled with water. In order to reduce optical distortion, this was placed inside a square vessel filled with water. This way the mismatch of refractive indexes at the curved interface is reduced. The velocity field was measured by a two component DANTEC Laser Doppler Anemometry (LDA), with a spatial resolution of approximately 1 mm. The Doppler signals are processed in the frequency domain by Burst Spectrum Analyzers. 20 µm polystyrene tracer particles are used as a diffracting medium for the laser beams. For each position in the fluid, the mean velocity is statistically determined from 3,000 samples. In this way, the velocity profile in the vicinity of the radiator is determined.

4 kg melting stocks of AlSi9Cu3 were melted in a resistance furnace equipped with a 170 mm diameter and 180 mm height SiC crucible. Melt temperature was controlled within an accuracy of ±10ºC. Degassing was carried at 650 and 700ºC for 1, 3 and 5 minutes, using 19.8 kHz ultrasonic frequency,750 W electric power and 15, 20 and 30 Hz mechanical vibration frequencies, using a 60 mm diameter radiator made of a titanium-based material. Results evaluation was based in the measurement of samples density, which is directly related to the samples hydrogen content. The RPT test and the apparent density measurement method were used to evaluate the samples density [1,8]. Degassing efficiency η was calculated from equation (3), where D is the theoretical alloy density (2.74 kgxdm^{-3}), and Di and Df are the initial and final alloy densities, respectively.

$$\eta = \frac{Df - Di}{D - Di} \times 100 \qquad (3)$$

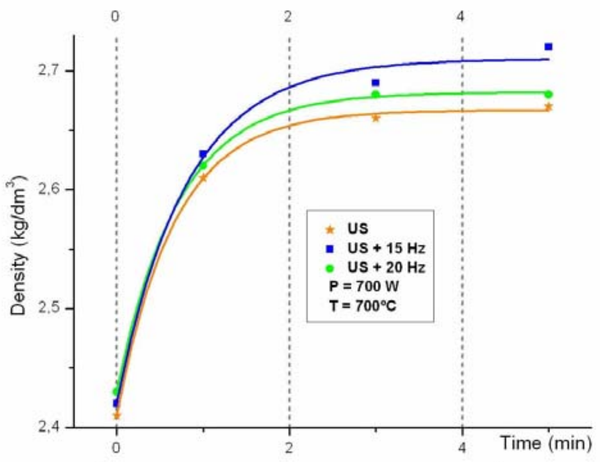
3. Results and Discussion

From the experiments conducted in water it was concluded that the low frequency vibrator promotes a helicoids motion of the ultrasonic radiator (Fig. 1b) that, in turn, induces an oscillatory motion in the water (a up and down loop movement was detected – Fig.1 – Detail D). The amplitude of the radiator dislocation in both z and x axis strongly depends on the mechanical vibrator frequency. Amplitudes close to 2 mm and 1 mm in x and z axis, respectively, were registered for 15 Hz frequency, and 0.1 and 0.4 mm, respectively, for frequencies on the range 20 to 30 Hz (Fig 1b).

The effect of low frequency vibration in the fluid dynamics under these experimental conditions is not fully understood yet, namely the reason why an inversion in the relative amplitudes in z and x components occur when frequency increases from 15 to 20 Hz. More experimental work is being developed in this particular field,to understand the dynamical behavior of this particular vibration system and to characterize its capability to degas aluminum melts, and to understand the degassing mechanisms that are associated.

i) Effect of mechanical vibration frequency and processing time on degassing improvement

Figure 2 shows the effect of vibration frequency to promote melt stirring on the samples density and degassing efficiency, for different processing times at 700ºC, using simultaneously 19.8 kHz ultrasonic frequency on the acoustic radiator.



	US	US+15Hz	US+20Hz
$\eta_{1min.}$ (%)	61	66	61
η_{final} (%)	79	94	83

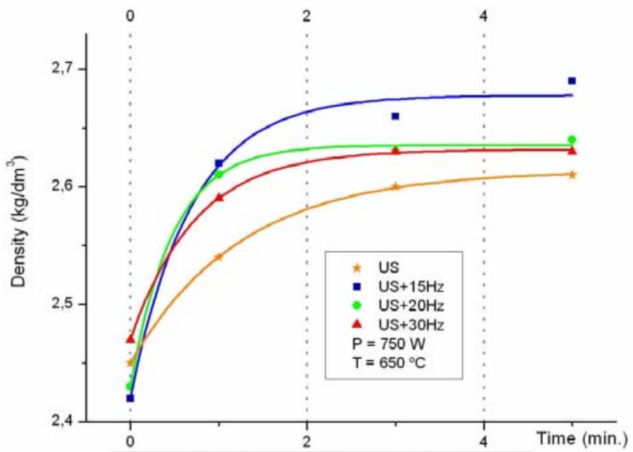
Fig.2 – Density and degassing efficiency of the AlSi9Cu3 alloy as a function of mechanical vibration frequency and processing time, for 700ºC melt temperature.

The maximum alloy density (2.72 kgxdm^{-3}) is 0.05 kgxdm^{-3} higher than that obtained by USD,and was achieved after 5 minutes degassing, using 15 Hz for melt stirring. That value is very close to the theoretical alloy density (2.74 kgxdm^{-3}), and represents a degassing efficiency of 94% . For 20 Hz frequency, the maximum alloy density was 2.67 kgxdm^{-3} which represents 85% degassing efficiency. In both cases, an improvement over single ultrasonic degassing (USD) is clear,although much more significant for 15 Hz vibration frequency (Fig.2). The difference to USD becomes more important as the processing time increases, because the number of H_2 molecules in the metal is continuously decreasing, thus the effect of melt stirring on its approach to cavitation bubbles is more effective.

It is also clear from Fig.2 that the kinetics of degassing is not changed by combining simultaneously ultrasonic and low frequency vibration, when compared with single USD [2,3,8]. The improvement in the degassing efficiency is due to the motion of the liquid metal that forces a greater volume of liquid to pass at distances from the acoustic radiator where cavitation develops, making it easier hydrogen removal. Best results achieved for 15 Hz mechanical vibration deal with the higher dislocation amplitude of the acoustic radiator when compared with 20Hz vibration frequencies (Fig.1b) that promoted more intense liquid motion.

ii) Effect of the melt temperature on degassing improvement

The improvement on the degassing efficiency using the new combined technique over the traditional USD was much more effective for low melt temperatures (compare Figs 2 and 3).



	US	US+15Hz	US+20Hz	US+30Hz
$\eta_{1min.}$ (%)	31	62	57	46
η_{final} (%)	55	84	69	60

Fig.3 – Density and degassing efficiency of the AlSi9Cu3 alloy as a function of mechanical vibration frequency and processing time, for 650ºC melt temperature

At low temperatures three factors impair the capability of the USD process: *a)* as temperature decreases the acoustic waves attenuation factor strongly increases; *b)* the mobility of hydrogen atoms in the liquid metals decreases, slowing down the diffusion of hydrogen from the liquid to the cavitation bubbles; *c)* lower melt viscosity makes more difficult the pulsation of cavitation bubbles, their coagulation and floating to the surface. The first two drawbacks can be overtaken by stirring the melt,as melt agitation increases the volume of metal where cavitation develops, thus increasing hydrogen removal,and the low mobility of hydrogen atoms is compensated by liquid motion.

At 650ºC the maximum alloy density achieved using 15Hz mechanical vibration frequency to promote melt stirring was 2.68 kgxdm-3, corresponding to 84% degassing efficiency. As it happened for 700ºC melt temperature, degassing efficiency increased less for higher mechanical vibration frequencies because liquid motion is not so intense. The maximum alloys densities achieved for 20 and 30 Hz where approximately 2.63 kgxdm^{-3}. When compared to USD, the combined degassing process lead to a maximum increase of 0.08 kgxdm-3, and degassing efficiency increased from 55 to 84%.

The alloy density steady-state plateau is lower for lower degassing temperatures because below 700ºC the pulsation and development of cavitation bubbles is more difficult, and melt stirring cannot fully compensate such drawback.

4. Conclusions

- Melt stirring is an effective way to improve ultrasonic degassing of aluminium alloys, increasing both the alloys density and the degassing efficiency;
- For fixed ultrasonic parameters, the degassing efficiency and the maximum alloy density depend on the melt temperature and the frequency of the mechanical device used to promote melt stirring;
- For the ultrasonic parameters and setup used in this research, maximum efficiency (94%) and alloy density (2.72 kgxdm^{-3}) were achieved for 700ºC and 15 Hz vibration frequency, decreasing for higher frequencies and lower temperatures.

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