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# Casting A356+SiCp with ultrasonically treated melts: Effect reinforcement and processing in the microstructure

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**Abstract**

Low mass fractions (0.05 wt%) of SiC micro sized particles have been added to an A356 melt and dispersed by ultrasonic vibration to study their impact on the microstructural morphology of cast samples. It is shown that the ultrasonic melt treatment at 680°C can promote a homogenized distribution of the reinforcement while also degassing the melt and induces a moderate grain refinement. Even though SiC may act as a nucleant, its use did not induce a significant grain refinement relatively to ultrasonically treated unreinforced melts. Adding SiC microparticles, however, seems to enhance Eutectic Si modification, although it contributes to its slight coarsening at the expense of $Mg_2Si$.

## 1. Introduction

A356 is widely used light casting alloy, being used in an extensive range of industries and applications. While the processing of this alloy has been thoroughly studied, recently, there seems to be an interest in the manufacturing of MMCs that use A356 as matrix. Indeed, these studies usually report the casting A356 alloys with ceramic reinforcement as a viable route to produce complex geometry parts with enhanced mechanical properties (Yadav et al. 2021).

Although most studies address the impact of ceramic reinforcement, such as SiC microparticles, in the MMC yield/UTS strength, elongation and fatigue (Verma and Khvan 2019), there seems to be an absence of literature on the impact of these compounds on the microstructural details of the matrix. The high reinforcement volume fractions actually overshadow the study on this effect, thus, it is frequently not suitable to draw conclusions on this particle-matrix interaction.

Here, we analyze residual SiC additions (0.05 wt%) to study the effect of this compound on the microstructure of an A356 alloy with ultrasonically treated melts. This study is particularly useful, given that ultrasonic melt treatment has recently been shown as a promising route to

deagglomerate and disperse ceramic reinforcement within Al alloy melt and produce MMC components (Grilo et al. 2020).

It is shown that the ultrasonic melt treatment can uniformly disperse the SiC reinforcement, refine the $\alpha$-Al and modify the Eutectic Si. The addition of SiC microparticles in low contents increases the Eutectic Si modification, however, it also generates its coarsening.

## 2. Materials and Methods

A356 alloy (2 kg) was molten and homogenized at 720°C, before being cooled into a semisolid state at 600°C. SiC microparticles (7±3 $\mu$m, 0.05 % in weight), previously pre-heated at 300°C, were added and the temperature was risen to 680°C. A SiAlON sonotrode was inserted in the melt when a 620°C temperature was reach, being used in On-Off cycles every 2 min to promote ultrasonic vibration until 680°C (20.2 kHz with 600 W of electric power) and disperse the reinforcement. The melt was finally poured into a pre-heated (250°C) steel die to produce cylindrical specimens (14 mm diameter and 150 mm length). A similar protocol was also performed without adding SiC microparticles to produce standard alloy samples.

Microstructural details were characterized by optical microscopy (Leica DM2500M) and scanning electron microscopy with energy dispersive spectroscopy (FEI Nova 200). The melting behavior of $\alpha$-Al, Eutectic Si and $Mg_2Si$, was characterized by Differential thermal analysis (DTA, TA instruments SDT 2960) in an inert atmosphere by increasing the temperature to 700 °C with a 10°C/min rate.

## 3. Discussion

Figure 1 shows micrographs of the two types of produced samples, i.e. samples with ultrasonically treated melts (A356+US, Figure 1a)) and samples whose melts were ultrasonically treated while SiC reinforcement was also added (A356+0.05 wt%SiC+US, Figure 1b)). Figure 1c) and Figure 1d) show magnifications of, respectively, Figure 1a) and Figure 1b).

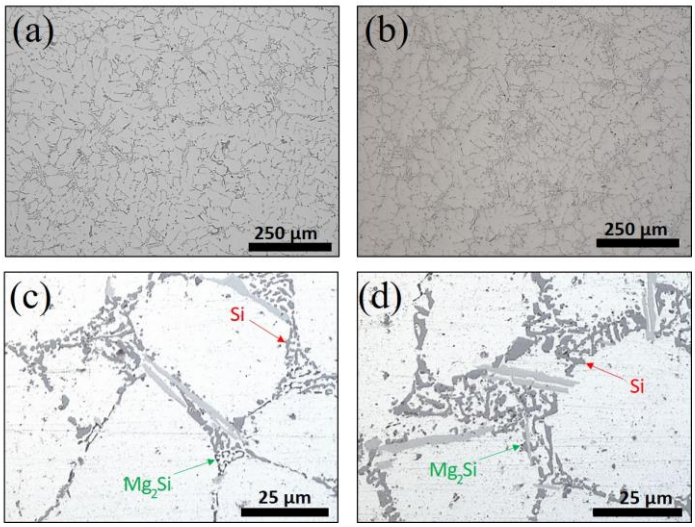


**Figure 1**: Optical micrographs of (a) A356+US and (b) A356+0.05wtSiC+US samples and their respective higher magnification are presented in (c) and (d)

It may be observed that the morphology of the $\alpha$-Al in the samples is similar, i.e. these are presented in globular and rosette-like morphologies, implying that both have been refined. Table 1 shows no significant difference in grain size and circularity. Given that both SiC and ultrasonic melt treatment induce grain refinement (Bae and You 2020), it is proposed that the latter has a more prominent effect. Considering the 0.05 wt%SiC addition, and the lack of statistically significant differences in the $\alpha$-Al grains, the reinforcement does not seem to

generate any additional refinement. Table 1 also shows that the 0.05 wt% SiC addition promotes a slight increase in the average length and aspect ratio of the Eutectic Si (Figure 1 d)), relatively to the samples without reinforcement (Figure 1 c)). It is apparent that there is also a dispersion of the $Mg_2Si$ in samples with 0.05% SiC.

**Table 1**: Geometrical details on α-Al and Eutectic Si of the samples

| | | A356+US | A356+0.05 %SiC+US |
|---|---|---|---|
| α-Al grains | Size (μm) | 38±14 | 39±15 |
| | Circularity ( - ) | 0.7±0.2 | 0.7±0.2 |
| Eutectic Si | Length (μm) | 3.9±1.8 | 4.2±2.4 |
| | Aspect ratio ( - ) | 3.0±1.6 | 3.1±2.0 |

SiC particles are not easily observeable by optical microscopy (Figure 1a)). Figure 2 displays a secondary electron SEM micrograph of an A356+0.05 wt%SiC+US sample that highlight the SiC particles. The EDS spectra (Z1 and Z2) highlight the main composition of the microstructure, respectively, the α-Al matrix and a SiC microparticle.

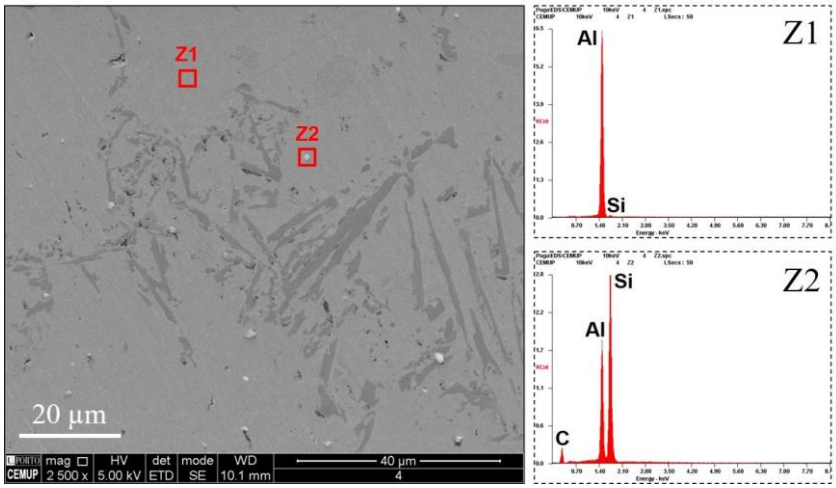


**Figure 2**: Detail of (a) SEM microstructure with EDS spectra in the α-Al matrix (Z1) and SiC particle (Z2)

The microstructure of the cast samples was further detailed by thermal analysis. Figure 3 presents the heating DTA of both samples, showing that the addition of SiC in an A356 melt promotes a change in the endothermic peaks (Table 2), impacting both dissolution energies and peak temperatures of the Mg2Si, Eutectic Si and α-Al, according to those previously identified by Wang et al. (2017) and Niu, Mao, and Wang (2019).

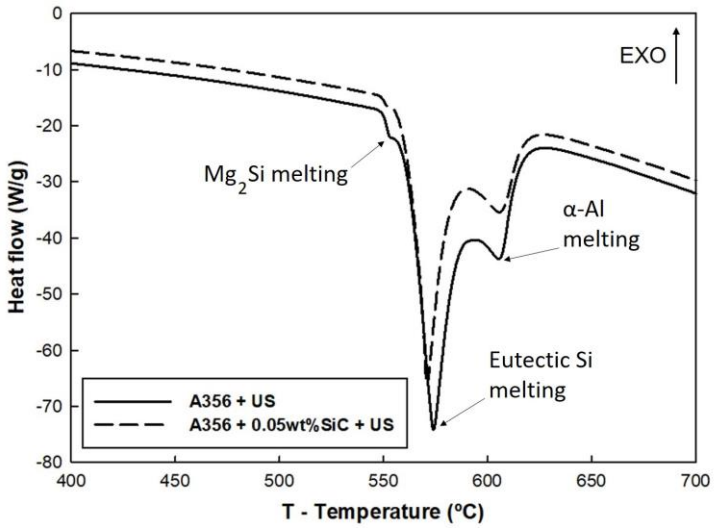


**Figure 3**: Heating DTA of A356+US and A356+0.05wt%SiC+US samples

**Table 2**: Detail of dissolution energies and peak temperatures from DTA

| | Dissolution energy (J/g) | | Peak temperature (°C) | |
|---|---|---|---|---|
| | A356+US | A356+0.05 wt%SiC+US | A356+US | A356+0.05 wt%SiC+US |
| $Mg_2Si$ | 1.5 | 0.5 | 552.8 | 551.4 |
| Eutectic Si | 358.2 | 380.7 | 574.0 | 571.0 |
| α-Al | | | 606.3 | |

It is highlighted that the addition of SiC generates a decrease in the dissolution energy (-1 J/g) of Mg2Si, while the dissolution peak also occurs at a lower temperature (-1.4°C). However, the energy to dissolve both α-Al and Eutectic Si is increased (+22.5 J/g). Given that there is no significant difference in the size/shape of the α-Al (Figure 1 and Table 1), the higher dissolution energy is promoted by the Eutectic Si coarsening (Table 1).

The coarsening is proposed to be caused by the addition of SiC particles, as these act as Eutectic Si refinement and modification (Jiang and Yu 2019), as the temperature peak of the unfreinforced sample is aligned with those reported by Gottardi, Pola, and La Vecchia (2015). In addition to the ultrasonic vibration induced modification, the SiC dispersoids further enhance the heterogeneous nucleation and modification of the Eutectic Si. This is supported by a decrease in the peak temperature for the Eutectic reaction (-3°C), which is characteristic of a Eutectic Si chemical modification (Chen, Ma, and Chen 2012; Barrirero 2019). Additionally, the low energy required to melt the Mg2Si hints that the elemental Si needed to precipitate this phase was spent in the coarsening of the Eutectic Si.

## 4. Conclusions

It is shown that ultrasonic melt treatment is an efficient route to cast A356 samples with well-dispersed micro-scale SiC reinforcement. Although SiC is known to promote grain refiner, the addition of low fractions of micro-sized SiC does not significantly impact the refinement of an A356 alloy with ultrasonically treated melt. Instead, the residual amount of SiC particles was able to enhance Eutectic Si modification, however, there is also the coarsening of these phases at the expense of the $Mg_2Si$ precipitation.

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