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Effect of ultrasonic treatment on the Fe-intermetallic phases in ADC12 die cast alloy

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ABSTRACT

The ultrasonic treatment temperatures were varied from about 100 °C above the liquidus temperature down to the Al–Si eutectic temperature, for different treatment times (0–15 s). The results showed that the ultrasonic melt treatment was very effective to convert the long plate-like Fe-intermetallic phases (up to 200 μm length) to a highly compacted fine polyhedral/globular form (<15 μm size). The critical ultrasonic treatment temperature to affect the morphology of Fe intermetallics was found to be in the range of 596–582 °C. The eutectic Si was mostly not affected by ultrasonic treatments carried out in this study (in the temperature range of 670–581 °C and for up to 10 s). It was also observed that the nucleation undercooling, which is a measure of nucleation efficiency, at the start of solidification was lowered from ~2.9 to ~0.4 °C by ultrasonic treatment. The variation of horn temperature within 20 °C above pouring temperature to 10 °C below it had no noticeable effect. The ultrasonically treated samples showed better tensile properties than the untreated samples, due to the change in morphology of the Fe-intermetallic particles.

1. Introduction

The commercial importance of aluminum–silicon alloys is based on their high fluidity and low shrinkage in casting, brazing and welding applications, in addition to their high specific strength and good corrosion resistance. These alloys are increasingly used in automotive applications to reduce vehicle weight and improve fuel economy. The commercial cast alloys usually contain Fe as impurity or deliberate additions (e.g., to reduce the die soldering in die casting process), which form intermetallic phases with Al, Si and other elements. These phases constitute an important part of the microstructure, because the particles formed during casting may influence the soundness of components and material properties during subsequent fabrication steps or in service. For example, the β-AlFeSi plate-like phase has a detrimental influence on the alloy properties: these platelets act as potential sites for crack initiation that may result in decohesion failures as demonstrated by Narayanan et al. (1994). The β-AlFeSi platelets are also responsible for enhancing the shrinkage porosity in cast Al–Si alloys by reducing the permeability of the dendritic network as demonstrated by Taylor et al. (1999). Thus, controlling the formation, morphology and size of the platelet Fe-intermetallic phases during processing and production of Al–Si alloys is highly desirable.

The detrimental effects of the platelet Fe-intermetallic phases can be neutralized using alloying additions of Mn. This leads to changing the morphology and type of phases, e.g., platelet particles (β-Al_5FeSi) convert to Chinese-script, globular or polyhedral morphologies of the α-$Al_{15}(Fe,Mn)_3Si_2$, as reviewed by Couture (1981). Chromium also has a similar effect. The complex intermetallic phases formed with Fe, Mn and Cr are usually called “sludge”, and have high melting points and high specific gravities. The sludge particles have usually star-like or polyhedral morphology. The sludging tendency (sludge factor) of an alloy can be calculated from the equation reported by Tuttle (1985) and Jostard (1986):

$$SF = \%Fe + 2(\%Mn) + 3(\%Cr) \quad (1)$$

This empirical formula is used as guide in evaluating the effect of furnace bath temperature and alloy chemistry on sludging. For example, sludge factor of 1.6, 1.9 and 2.9% at about 621, 649 and 705 °C are frequently used as mentioned by Tuttle (1985).

Thus, the additions of Mn or Cr can minimize the detrimental effects of the platelet Fe intermetallics by converting them into a large compacted form. However, these compacted particles themselves (in form of large sludge particles) cause several problems. The large particles (due to high additions of Mn and longer holding time of melt at low temperature) settle down to the floor of the melt reducing the furnace capacity, can be incorporated into the

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Table 1
Alloy chemical composition.

Alloy	Weight %									Sludge factor
	Si	Mn	Cr	Cu	Ti	Mg	Zn	Fe	Sr	
ADC12	10.6	0.16	0.04	2.10	0.03	0.23	0.70	0.78	–	1.22

cast parts causing excessive tool wear during machining, and causes loss of Fe, Mn and Cr from the die casting alloy as reviewed by Tuttle (1985). Therefore, a solution is required to avoid the detrimental effects of the platelet Fe-intermetallic particles without introducing the other deleterious effects of sludge.

Recently, some attention was paid to the effect of ultrasonic vibration on modifying and controlling the solidification structure of Al–Si alloys (Brodova et al., 2002; Meek et al., 2006). High-intensity ultrasonic waves (e.g., above 80 W/cm^2) are useful because of their capability to generate important non-linear effects in liquids, i.e., cavitation and acoustic streaming. These effects cause microstructure refining, degassing of liquid metals, and dispersive effects for homogenizing. Cavitation involves the formation, growth, and collapsing of micro-bubbles in liquids under cyclic-high-intensity ultrasonic waves. By the end of one cavitation cycle (about the order of 100 ms), the micro-bubbles implosively collapse producing very high pressures of up to 1000 atm. Cavitations can produce an implosive impact, strong enough to explode bubbles and break up the clustered fine particles and disperse them more uniformly in liquids as shown by Abramov and Lobov (1994).

The ultrasonic melt treatment (UST) was found to be highly efficient in controlling the size and morphology of the α-Al phase in the Al–Si cast alloys. However, the influence of this treatment on other phases, such as the intermetallic phases of Fe, Cu and Mg, has not been thoroughly investigated. The present work aims to evaluate this influence on Fe intermetallics in Al–Si die cast alloys, through qualitative metallographic observations, EDS microanalysis and tensile testing.

2. Experimental

The die cast alloy JIS ADC12 (A383) was used in this study. The alloy chemical composition and the calculated sludge factor are shown in Table 1. The liquidus temperature of this alloy is about 574 °C. Samples of this alloy, ~210 g each, were treated by ultrasonic vibrations at different temperatures in the liquid state. The ultrasonic vibrations were directly applied to the melt in the shot sleeve of the die casting machine, and then the treated melt was injected into the die cavity. The treatment times varied from 0 to 15 s. Mechanical actuator with 630 kgf capacity was used to drive the plunger. Fig. 1 shows schematically the ultrasonic die casting machine and the die cast sample used in this work.

The shot sleeve temperature, as measured at the center point before pouring the metal, was 400–420 °C, and the die temperature was 200–230 °C (for movable and fixed parts). Different horn temperatures were used, ranging from 700 °C to melt temperature, and to 10 °C lower than the melt temperature. Horn was immersed to about 5 mm in the molten alloy during treatment. Pouring temperatures of 680, 640, 620, and 600 °C were investigated in this study. Table 2 shows the experimental conditions of all experiments carried in the present study.

The ultrasonic system used consists of a 600-W generator, a water-cooled 19.5 kHz transducer and Si_3N_4 horn (diameter = 20 mm). The ultrasonic intensity used was about 190 W/cm^2. Majority of experiments were done with vibration amplitude of 30 μm as measured on horn surface at 620 °C in air. Microstructures were studied using optical and SEM microscopies, and EDS

Table 2
Experimental conditions used in the present study.

No.	Pouring temperature (°C)	Ultrasonic treatment time (s)[a]	Horn temperature (°C)	Comments[b]
Solidification in shot sleeve[c]				
1	680	0	–	Solidified in shot sleeve
2	680	54 s during solidification	700	Solidified in shot sleeve
3	640	0		Solidified in shot sleeve
4	640	41 s during solidification	660	Solidified in shot sleeve
5	600	0		Solidified in shot sleeve
6	600	32 s during solidification	620	Solidified in shot sleeve
Die casting experiments				
7	680	15	700	Partially solidified in shot sleeve
8	680	10	700	Die cast
9	680	6	700	Die cast
10	680	2	700	Die cast
11	640	6	660	Die cast
12	640	2	660	Die cast
13	640	0	–	2 s holding in shot sleeve, die cast
14	640	4	640	Die cast
15	620	4	620	Die cast
16	620	4	610	Die cast
17	600	2	620	Die cast
18	600	0	–	2 s holding in shot sleeve, die cast
19	600	4	600	Die cast
20	680	15	700	40 μm amplitude, partially solidified in shot sleeve
21	680	10	700	40 μm amplitude, die cast
22	680	6	700	40 μm amplitude, die cast

[a] Ultrasonic vibrations turned on and horn placed in position immediately before pouring the molten alloy.
[b] Experiments were done with vibration amplitude of 30 μm, if nothing else mentioned.
[c] Cooling data were recorded during solidification in the shot sleeve (down to 500 °C).