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Short Communication

Metallurgical structure of A356 aluminum alloy solidified under mechanical vibration: An investigation of alternative semi-solid casting routes

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ABSTRACT

This study investigated the effects of mechanical vibration during solidification on the metallurgical structure of hypoeutectic aluminum–silicon A356. A series of casting trials were conducted. Emphasis was placed on the morphological changes of the primary aluminum phase of the as-cast alloy, which was subjected to different levels of mechanical vibration at various values of pouring temperature and solid fraction. It was found that the average grain size of the primary phase became relatively finer and more globular as the degree of vibration increased. This suggested that during the solidification process, dendrites that formed normally in the liquid alloy were subsequently disturbed and fragmented by the mechanical vibration introduced into the melt. This effect was enhanced when the vibration was introduced into an alloy with a larger solid fraction, as was observed with solidification at lower pouring temperatures. In addition to the macrostructure examination, semi-solid properties were also assessed and reported using the Rheocasting Quality Index. It was shown that the introduction of mechanical vibration into the A356 melt with adequate solid fraction prior to complete solidification successfully resulted in an as-cast structure featuring semi-solid morphology.

1. Introduction

It is well accepted that microstructure is one of major factors that defines the mechanical properties of aluminum alloy [1]. For general casting applications, refining so as to achieve equiaxed and fine grains will increase fluidity [2,3], reduce hot cracking [4], and reduce microporosity [5]. Non-dendritic structures will be obtained if the solidification is well grain-refined for hypoeutectic Al–Si alloy. Semi-solid processing is an attractive process for obtaining globular structures and for minimizing the porosity and segregation problems of conventional casting. However, a specific shear force from external source in semi-solid processing is needed. This is due to the thixotropic characteristics of SSM billets having high viscosity at low stresses but a decreased viscosity when an increased stress is applied [6].

Many new techniques have been developed for creating semi-solid structures since the inception of semi-solid processing; for example, electromagnetic stirring [7], ultrasonic vibration [8,9], low temperature casting [10], and gas bubble purging [11]. In this study, A356 aluminum alloy was studied because of its wide variety of applications and because its chemical composition is far below the Al–Si eutectic composition, meaning it has a wide solidification range suitable for semi-solid processing.

In this study a robust method for introducing mechanical vibration was developed, at lower cost than ultrasonic vibration. Wu et al. [12] recently introduced mechanical vibration during isothermal holding period of A356 aluminum alloy to prepare semi-solid slurry. A similar method was also reported by Taghavi et al. [13]; however, they focused only on vibration frequency and time. The effects on microstructures of mechanical vibration acceleration, pouring temperature, and isothermal holding temperature at various solid fractions have been investigated here.

2. Experiment

Table 1 summarizes nominal compositions of the A356 alloy ingot used in the present study. The alloy was melted using an induction furnace. For all casting trials, the molten metal was subjected to flux treatment with 0.5 wt.% cleaning and covering flux. Argon purging was used to reduce dissolved hydrogen. In each case, the degassing time was 2 min using a flow rate of 5 L per minute at 0.2 MPa.

To introduce the mechanical vibration, a special setup of apparatus was developed as schematically illustrated in Fig. 1. A stainless steel cup, as shown in Fig. 2, was employed as a mold to cast specimens for further metallurgical investigation. The setup was equipped with a salt bath to allow isothermal holding of the melt at a specific temperature to obtain the designed solid fraction. A thermocouple, temperature controller, and data logger were connected to the salt bath to monitor and control the temperature.

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Table 1
Chemical analysis of the A356 aluminum alloy used in the present study.

Element	Si	Fe	Mn	Mg	Ni	Zn	Sn	Pb	Ti	Al
wt.%	7.13	0.135	0.005	0.331	0.001	0.013	0.012	0.009	0.111	Balanced

The vibration source is a device equipped with a magnetic coil that operates at a frequency of 55 Hz, and can generate different magnitudes of mechanical vibration acceleration by varying supplied voltage. Values of the voltage supplied to the vibration source and the corresponding magnitudes of acceleration (compared to earth's gravity: *g*) are shown in Table 2. In the present study, the corresponding magnitudes of acceleration define the degrees of vibration. These varying degrees of mechanical vibration were introduced into the melt at solid fractions of 13% and 40%. The casting trials, covering solidification conditions at 13% and 40% fractions of solid, were carried out by pouring the liquid alloy at pouring temperatures of 620, 630, and 650 °C into the stainless steel mold, immersing that mold in a salt bath maintained at 580 °C, and then introducing the mechanical vibration to the melt until the melt temperature dropped to 608 ± 2 °C for the 13% solid and 588 ± 2 °C for the 40% solid. The fraction of solid at various temperature was calculated based on the Scheil's equation, and assuming linear liquidus and solidus lines having partition coefficient at 0.13 [14]. Subsequently the stainless steel mold with the specimen inside was suddenly immersed in water at 30 °C with vigorous agitation.

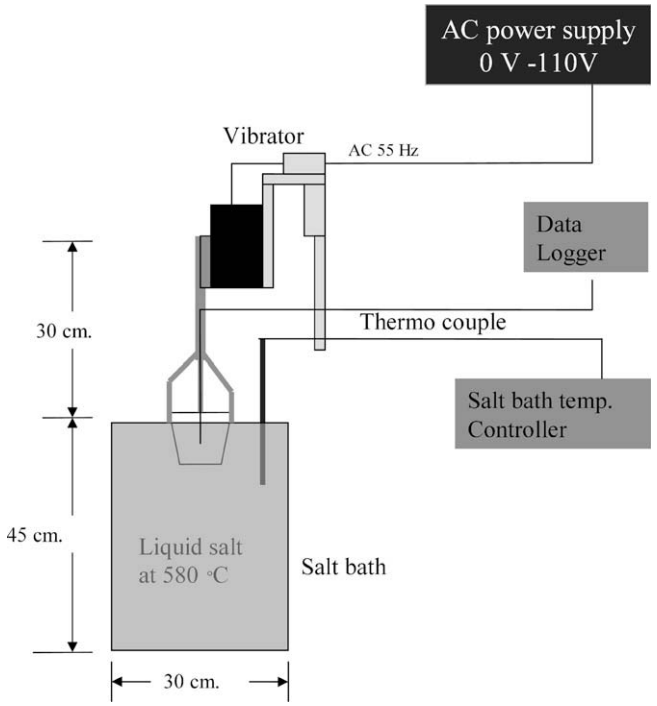

Fig. 1. Schematic illustration of the apparatus used in the present study (not to scale).

Table 2
Series of casting trials defining the conditions, i.e. pouring temperatures, solid fractions, and vibration acceleration levels.

Pouring temperature (°C)	Fraction of solid (wt.%)	Magnitudes of acceleration (Earth's gravity: *g*)
650	13	0.00
		0.25
		0.80
		1.90
	40	0.00
		0.25
		0.80
		1.90
630	13	0.00
		0.25
		0.80
		1.90
	40	0.00
		0.25
		0.80
		1.90
620	13	0.00
		0.25
		0.80
		1.90
	40	0.00
		0.25
		0.80
		1.90

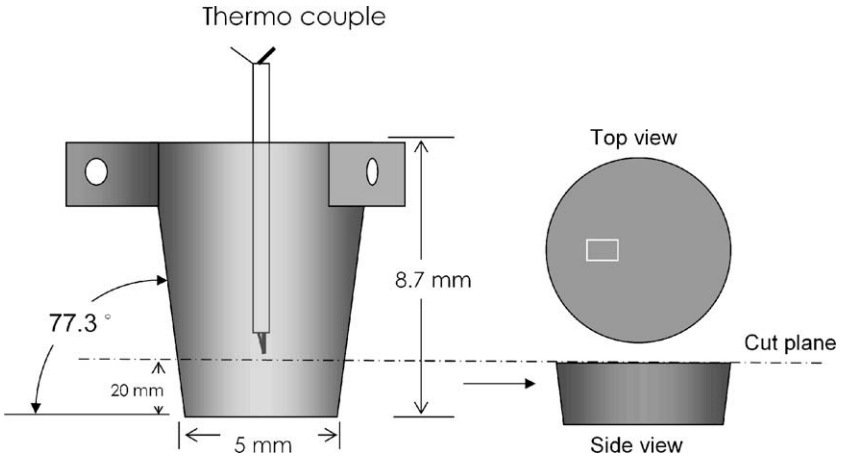

Fig. 2. Stainless steel cup and the plane for microstructure examination.