Materials and Design 30 (2009) 115–121

Contents lists available at ScienceDirect

Materials and Design

journal homepage: www.elsevier.com/locate/matdes

Study on the ability of mechanical vibration for the production of thixotropic microstructure in A356 aluminum alloy

F. Taghavi [a,b,*], H. Saghafian [a], Y.H.K. Kharrazi [a]

[a] *Department of Materials and Metallurgical Engineering, Iran University of Science and Technology, Narmak, Tehran 16846-13114, Iran*
[b] *Engineering Department, Maad Kimiya Farayand Consulting Engineers, Jordan, Tehran 19689-53691, Iran*

ARTICLE INFO

Article history:
Received 17 November 2007
Accepted 16 April 2008
Available online 25 April 2008

Keywords:
Mechanical vibration
Thixotropic microstructure
A356 alloy

ABSTRACT

In the present paper, efficiency of mechanical vibration for producing semisolid slurry with thixotropic microstructure in an A356 aluminum alloy was studied. The effects of vibration frequency and time were investigated on the size and morphology of α-Al phase and grain refinement degree. It was observed that thixotropic microstructure could be obtained in the Al alloy by applying mechanical vibration. It was also found that size and morphology of α-Al phase were strongly affected by vibration frequency and time.

1. Introduction

The year 2007 marks the 36th anniversary of the introduction of semisolid metal processing concept. The original experiment leading to the discovery of rheocast process was performed in early 1971 by Spencer [1] doing her PhD thesis under supervision of Flemings at MIT University. Since then, investigators have performed many studies about semisolid metal processing. Today, semisolid metal processing has been posed as a modern and advanced technology in manufacturing of engineering components. This modern technology offers several advantages over conventional technologies such as casting, forging and powder metallurgy. Semisolid metal processing enables us to manufacture complicated shape components with near-net wall, good mechanical properties and high dimension tolerance accuracy.

Semisolid metal processing uses solid–liquid slurries. These solid–liquid slurries have been formed under external forces between dies, named thixoforming or injected into die cavity, named thixocasting process. Semisolid slurries show two rheological behaviors, thixotropy and pseudoplasticity. Thixotropic behavior is the change of semisolid viscosity with shearing time in a constant shear rate or transient viscosity, while pseudoplastic behavior is the change of semisolid viscosity with shearing rate or steady state viscosity [2–4]. Semisolid metal processing is based on these two rheological behaviors. Therefore, comprehensive understanding of semisolid rheological behaviors is required for successful development of semisolid metal processing. The factors affecting on semisolid rheology can be divided into two groups: metallurgical factors and technological factors [5]. Metallurgical factors that influence rheological behavior are solid fraction of semisolid slurries [6,7], temperature [5], size, morphology, distribution of solid particles in liquid matrix [7–11] and chemical composition of alloy [12]. Among these factors, size and morphology of solid particles in semisolid slurries have the strongest effects on rheological behavior of semisolid slurries [2–4]. Based on reported literatures about semisolid metal forming, resistance to flow in semisolid slurries containing solid particles with dendrite morphology, when it is sheared during forming or injecting into die cavity, is higher than semisolid slurries containing solid particles with rosette or spherical morphology in a constant solid fraction. On the other words, when semisolid slurry is sheared, solid particles with dendrite morphology get locked by each other. It results in formation of large solid particles in liquid matrix. These agglomerated particles have more resistance to flow and semisolid slurry containing of these particles flow under shear, hardly. In contrast, semisolid slurries containing globular particles easily flow under shearing condition [4,13]. Due to these problems, some researches started to produce semisolid slurries with fine and globular particles. These semisolid slurries with fine and globular solid particles have been assigned as thixotropic microstructures. These investigations led to creation of new technologies for the production of required feedstock materials in semisolid metal forming. Today, semisolid metal processing has been posed in two groups:

- Production of semisolid slurries with thixotropic microstructures as feedstock materials for semisolid metal processing.
- Forming or casting of produced semisolid slurries with thixotropic microstructures.

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* Corresponding author. Address: Engineering Department, Maad Kimiya Farayand Consulting Engineers, Jordan, Tehran 19689-53691, Iran. Tel./fax: +98 2188796101.
E-mail address: taghavi_farshid@yahoo.com (F. Taghavi).

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doi:10.1016/j.matdes.2008.04.034

In recent years, many methods have been introduced for the production of semisolid slurries with thixotropic microstructures. These methods can be divided into two groups [4]:

- Methods which are using melts agitation such as stir cast, electromagnetic stirring and inclined plate.
- Methods without melt agitation such as low pouring temperature and partial remelting, SIMA and addition of chemical refiners.

Application of vibrational energy is one of the methods in which melt agitation is used to produce thixotropic microstructures. Chernov [14] was the first person who made use of vibration in the year 1878. He vibrated mould during solidification of steel and observed refining of primary austenite phase in final microstructure. In other works on application of vibrational energy in metals processing [14–28], it was revealed that vibrational energy has strong effects on final microstructures of cast components.

Based on vibration sources, there are three types of vibrational energy: mechanical vibration, sonic and ultrasonic vibration, and electromagnetic vibration. Among these three types of vibrational energy, only electromagnetic vibration is used for producing thixotropic microstructures in industrial scale. However, high costs, inhomogeneous microstructure in radial direction of produced ingots and presence of primary solid phases with non globular morphologies (but none-dendrite) are the essential problems of this technology. These problems can lead to an increase in isothermal holding time during reheating and partial remelting stage in thixoforming or thixocasting processes and inhomogeneous properties in components produced by semisolid metal processing [4]. Recently, attentions to application of ultrasonic vibrations for the production of thixotropic microstructures have been increased [25–28]. High costs, low durability of ultrasonic transducers and formation of air gap at the blew of transducer surface which leads to reflection of ultrasonic waves, are some of the problems in this technology. Until now, application of mechanical vibration to produce thixotropic microstructures has been studied much less than electromagnetic or ultrasonic vibrations by investigators. Most performed research [14–24] are devoted to application of mechanical vibrations during solidification in high cooling rates and low vibration times in order to grain refinement and creation of equiaxed grains in solidified microstructures. In this research, effect of mechanical vibration on the size and morphology of primary solid phase in A356 aluminum alloy for the production of thixotropic microstructure has been investigated.

2. Experimental procedures

Chemical composition of A356 aluminum alloy used in the current research is shown in Table 1. In order to hold molten metal at a constant temperature, a Ni–Cr electrical resistance coil with 18 Ω electrical resistance was used to supply the required heat. Also a NiCr/NiCrFe-type K thermocouple and an ATBIN-Sinuous C/06-10-21-30/40 proportional thermostat were installed for controlling required heat input. To avoid contacting of coil and mould, coil was put into thin layers of ceramic bricks. The outer body of the coil was insulated with three layers of asbestos to decrease heat loss from outer side of the coil. A vibrating table with constant amplitude of 0.2 mm was used for mould vibration. In the present research, mechanical vibration was exerted into the melt by means of mould vibration in vertical direction. Fig. 1 shows schematically the installation and used equipment set up. A steel cylindrical mould with 50 mm in diameters and 100 mm in length was used. Dycote 39 made by FOSECO CO. was used to cover inner side of the mould. This cover is made of fine titanium oxide particles that facilitate the removal of solidified ingot from the mould and prevent chilling effect of the mould wall.

Table 1
Chemical composition of A356 alloy used in experiments

Al (%)	Si (%)	Mg (%)	Fe (%)	Cu (%)	Mn (%)	Zn (%)	Other elements (%)
92.47	6.58	0.326	0.290	0.199	0.0150	0.0470	<0.1

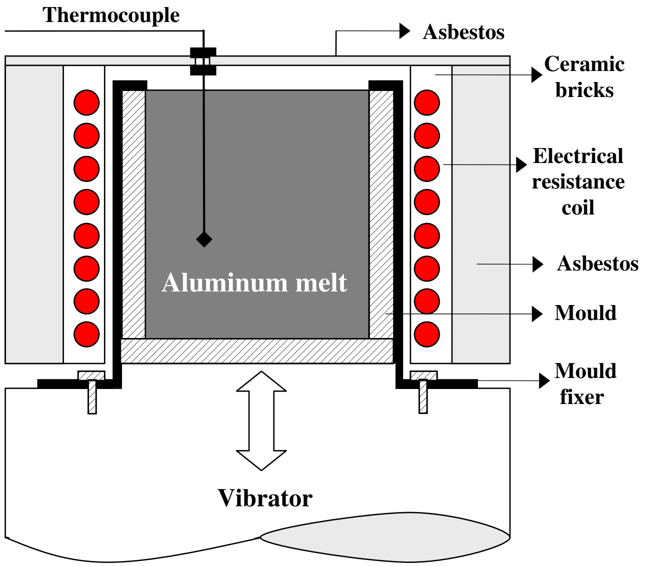

Fig. 1. Schematic view of made system and equipments setup used in experiments.

A356 aluminum alloy (1.5 kg) was put in a silicon carbide crucible and melted by an electric resistance furnace. Coil was placed around the mould and heated to 600 °C simultaneously. When melt temperature was reached to 700 °C, vibrator was turned on and molten alloy was poured into the heated mould. After pouring, thermocouple was put into the molten alloy to monitor and control the temperature and then, surface of mould and coil was covered with two layers of asbestos to avoid cooling or solidification of melt surface.

In this research, a combination of vibration during solidification and isothermal vibration of semisolid alloy (two stages) was used. Fig. 2 illustrates schematic melt cooling curve under solidification and vibration conditions at a constant vibration frequency. At first stage, vibration was applied while the melt was being cooled from 700 °C to 600 °C, at a cooling rate of 0.33 °C/s. When, temperature of melt reached to 600 °C, vibration was continued isothermally at second stage for various times at the same frequency. Vibration time during cooling from 700 °C to 600 °C was 5 min. The frequency and time of vibration examined were

- 5, 10, 15, 20 and 30 min total vibration times (it is necessary to note that 5 min is related to the period vibration applied between pouring temperature and 600 °C and the rest are the periods of isothermal vibration at 600 °C, as illustrated in Fig. 2).
- 10, 20, 30, 40 and 50 Hz vibration frequencies.

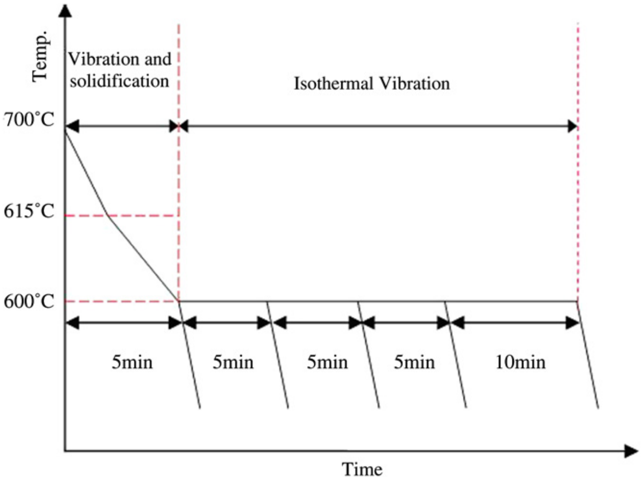

Fig. 2. Schematic diagram of cooling curve and stages of applied mechanical vibration into the melt.