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Effects of electromagnetic stirring and superheat on the microstructural characteristics of Al–Si–Fe alloy

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Abstract

Semisolid metal (SSM) processing is getting momentum to be the preferred fabrication route for near or net-shaped castings. For SSM processing of Al–Si alloys, there are two important microstructural features which influence the properties of finished products. These are the size and morphology of the primary α-Al phase and the eutectic matrix which consists of silicon, aluminum, and intermetallic phases. The presence of iron is beneficial to reduce the soldering effects in permanent mold castings, but it is unfavorable due to formation of a range of intermetallic phases. The casting parameters play an important role in avoiding the segregation of thin platelets of Fe-intermetallic, which is detrimental to mechanical properties. In this context, it is of particular interest to see the effects of melt stirring on the formation of eutectic silicon flakes and iron-based intermetallics during SSM processing.

The effects of process parameters such as cooling rate and superheat are investigated on the morphology and size distribution of eutectic silicon and iron-based intermetallics during application of electromagnetic stirring (EMS). It is concluded that melt stirring not only alters the morphology of α-Al phase to rosette or globule shape, but also refines the eutectic silicon and iron-intermetallics.

Keywords: Stirring; EMS; Eutectic silicon; Iron-intermetallics; Superheat; CET

1. Introduction

Semisolid metal (SSM) processing is one of the most convenient methods for fabricating near or net-shaped castings. It takes advantages of the unique flow behavior of prepared raw material slugs within the mushy zone. Such bilateral combination exhibits both solid and slurry like behavior. It means that as a solid, the material preserves its structural integrity and self standing characteristic in the form of billet while by applying shear force, the material flows easily as a slurry and fills die cavity in a progressive manner. Comparing to the other high productive casting processes, it takes advantages of lower porosity and shrinkage voids, lower processing temperature, less mold erosion, and higher die life [1–3].

Technologies for SSM processing can be generally divided into two basic groups; rheo-routes and thixo-routes. The rheo-route involves preparation of SSM slurry from liquid phase and its direct transfer into a die or mold for component shaping. The term "slurry-on-demand", SoD, has recently been coined in industry to describe slurry making operations that take place in the cast shops, thus providing a constant supply of slurry for shaping operations. The thixo-route is involving the preparation of a feedstock material having an equiaxed or globular structure which is reheated to temperatures between solidus and liquidus (mushy zone) to generate a semisolid structure and finally the prepared feedstock is injected into the mold. A detailed review of SSM processes is explained elsewhere [4].

One of the most popular alloys for SSM processing is aluminum alloys due to their wide solidification range, relative lower melting points, superior formability, and better mechanical properties. Generally a desired structure in all SSM processes is defined as a structure free of dendrites, spherical solid particles, and minimum or no entrapped eutectic. Therefore, globule morphology is the most concerned issue being sought while other variables almost neglected.

In semisolid casting of Al–Si alloys, the morphology and size of silicon is a paramount issue for improving the mechan-

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ical properties while on the other hand, the presence of silicon, impurities, and alloying elements such as Fe, Mn, Cu, Zn, Mg, and Ti may result in some complications in the microstructure due to the formation of intermetallic phases.

Iron is one of the most common and perhaps the most significant alloying or impurity elements in Al–Si alloys; either added intentionally to promote certain characteristics or otherwise as an unwanted impurity. The Fe-addition imparts two distinct features; on one hand, it forms different intermetallics together with Al and Si, which most of them regarded considerably harmful to the mechanical properties of the finished product and on the other hand, it reduces the interaction of molten aluminum alloys with permanent molds, i.e., soldering or die sticking, due to formation of a thin layer of intermetallics at the interface between the die and the castings during solidification [5–7].

In the SSM processes, impurities and alloying elements are rejected into the liquid and solidified under shear forces and rapid cooling. Therefore, it is of technical and technological importance to study the possible microstructural changes, particularly evolution of silicon and iron-intermetallic phases and those of the other intermetallics phases, and their possible effects on the mechanical properties of the as-cast products.

The present article is part of a comprehensive study on the structural evolution in SSM processing. The aim of the current work is to evaluate the effect of cooling rate, pouring temperature, and stirring on the morphology and distribution of eutectic silicon and iron-intermetallics.

2. Experimental procedure

Binary Al–7% Si alloys were prepared by melting 99.7% commercially pure aluminum in a SiC crucible in an electric resistance furnace. Addition of silicon and iron was carried out at 720 ± 5 °C using pure silicon and Al–25% Fe master alloy. The chemical composition of the melts is given in Table 1.

For achieving different cooling rates, two different molds were used. For higher cooling rate, a copper mold with a water cooling jacket and for the lower cooling rate, CO_2 bonded silica sand mold was used to produce ingots of 76 mm in diameter and 300 mm long. The entire configuration was placed in an electromagnetic stirring machine, EMS (Fig. 1). For these series of experiments, the frequency was set to 50 Hz and the current was 100 and 30 A for copper and sand molds, respectively (stirring was stopped around 400 °C in EMS samples).

Table 1
Chemical analysis of the melt (wt.%)

Si	6.7–6.9
Fe	0.8–0.81
Al	Balance

For the superheat variation, pouring temperature was changed between 630 and 690 °C. The cooling rate in the copper and sand molds for the conventional ingot (with no stirring) was about 4.8 and 3.3 $°C\,s^{-1}$, respectively. The cooling rates were calculated in the liquid state above the liquidus temperature. The cooling rate in the sand mold is relatively high at the beginning of the pouring which is due to the large volume of sand compared to the liquid metal. However, after the initial rapid heat dissipation, the bulk liquid temperature decreases slowly due to low heat diffusivity of sand mold. As a result, the sand could absorb significant amount of heat after filling the mold. The cooling rate is then reduced in the mushy zone. For the experiments with no stirring, the liquid was poured into the same molds and allowed to air-cool. The samples with no stirring will be referred as "*conventional*" in the remaining of this paper.

The metallographic specimens were cut transversely at 200 mm from the bottom of the billets and then mounted, ground, and polished down to 0.05 μm colloidal silica. Image analysis technique was employed to measure parameters such as the circular diameter, number density, length and width for both iron-intermetallics and eutectic silicon. For the reason of having a representative of the structure, the entire data were obtained from image processing of the resulting microstructure between the center and wall surface of the billets. Grain and globule size were measured using linear intercept method on the anodized specimens.

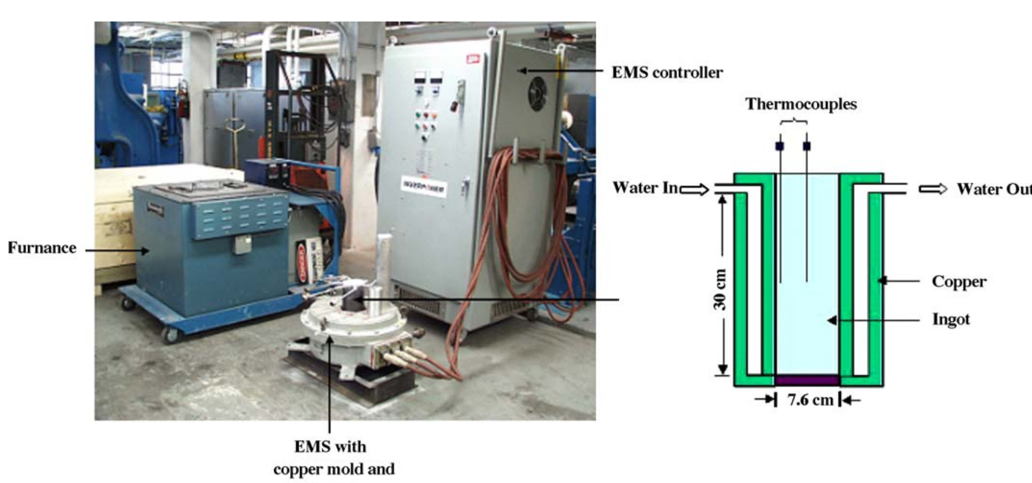

Fig. 1. (a) Casting facilities and (b) schematic details of the water-cooled copper mold.