O-95

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Microstructure Refinement in Al-7%Si Alloys Solidified by an Electromagnetic Stirring Technique

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In the present study, we poured the Al-7%Si aluminum melt into a ceramic crucible that was then set in a rotating electromagnetic field. Solidification of the melt was accomplished while the rotating magnetic field was imposed and thus electromagnetic stirring (EMS) could be produced. The structure development versus reverse EMS imposition time, *t*, has been observed, revealing that the longer imposition time will result in the finer primary solid solution phase. The refinement mechanism is discussed when considering fluid flow and uncoupled movement behavior between the primary solid and the remaining liquid.

Keywords: *Aluminum alloy, solidification, structure, electromagnetic stirring, grain refinement.*

1. Introduction

A grain-refined structure is always desired during casting as the processing cost of an aluminum alloy billet with a refined structure can be substantially reduced in the subsequent treatment and moreover, it can improve the performance of the alloy. Although TiB_2 compound has been proved to be quite effective in refining Al alloys [1], these two rare-metal elements increase the production cost. Moreover, the unstable supplying market may make the Al industry subject to a high risk. Therefore, it is critical to develop new techniques, by which Al billets with grain-refined structures can be produced while no refining additives are required. In the present study, we employed the EMS technique to yield grain refined structures for a bulk aluminum alloy ingot, by which no rare metals are externally added. The microstructure development as a function of processing parameters has been observed and the refinement mechanism is discussed when considering the EMS-induced melt flow and the displacement behavior between the primary solid and remaining liquid.

2. Experimental procedure

To generate a rotating electromagnetic field, a three-phase induction motor was used and the rotor was removed to produce a hollow space. The molten Al-7%Si aluminum alloy was placed into the space to solidify while EMS was imposed. Here it should be noted that by switching over the sequence of the alternating current, one can readily alter the rotating direction of the magnetic field and thus change that of Lorentz force accordingly. The movement direction of the crystallizing melt in the crucible can also be changed by switching over the phase sequence of the three-phase alternating current, i.e., from clockwise (CW) to counterclockwise (CCW) and vice versa. For the present study, we employed an inverter to change the phase sequence of the three-phase alternating current. The EMS imposition time could be well controlled with a timer. Fig. 1 indicates the EMS imposition pattern in the present study.

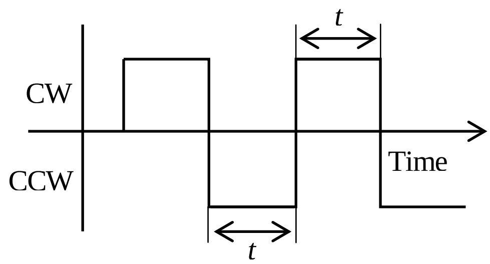

Fig. 1 The EMS imposition pattern versus time

The polarized optical microstructures were observed along the traditional metallographic method after the electrolytic corrosion was carried out.

3. Results and discussions

In order to reveal the influence of EMS on structure formation, we first show the microstructure solidified under the usual casting state without EMS, as depicted in Fig. 2. One can see that it consists of developed coarse dendrites. Fig. 3 shows two microstructures of the alloy solidified at (a) t = 0.2 seconds and (b) t = 0.5 seconds, respectively. It can be discerned that in comparison with that solidified at the casting state, the structure solidified at t = 0.2 seconds

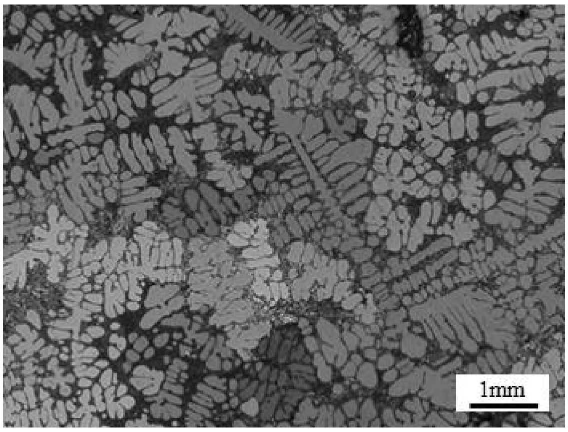

Fig. 2 Microstructure solidified without EMS

consists of some fine particles. When the reverse imposition time is further extended to t = 0.5 seconds, as revealed in Fig. 3(b), the microstructure almost consists of fine equiaxed grains and no traces of complete dendrites can be identified. One can readily become aware that using the EMS processing can refine the structure and the longer imposition of the reverse time can result in equiaxed fine grains.

As far as the refinement mechanism is concerned, two principal reasons are considered. The first is that EMS can induce fluid flow that has been well documented [2]. The primary mechanism concerning refinement is that fluid flow can lead to thermosolutal convection that originates fragmentation by local remelting of higher order of dendritic arms and thus resulting in grain-refined structures.

The second reason concerns the movement behavior of the solid and liquid during EMS processing. The electromagnetic torque of a conductor in a magnetic field is reversely proportional to its electrical resistivity. For simplicity, the electrical resistivities of the Al solid solution and the remaining liquid can be approximated to that of pure solid and liquid aluminum, respectively, which are 110n Ω m for solid and 242nΩ m for liquid [3]. Hence, one can deduce that the electromagnetic torque produced upon the solid is about twice of that upon liquid. Considering that there is little difference in density between the solid and liquid, it is clear that the body force upon the solid is about twice of that the liquid. Therefore, the solid can be driven to move with a larger acceleration and thus covers a longer distance in comparison with the liquid. So, uncoupled movement occurs between the mobile leading solid and the sluggish remaining liquid, making solute distribution boundary layer unstable and thus difficult to produce

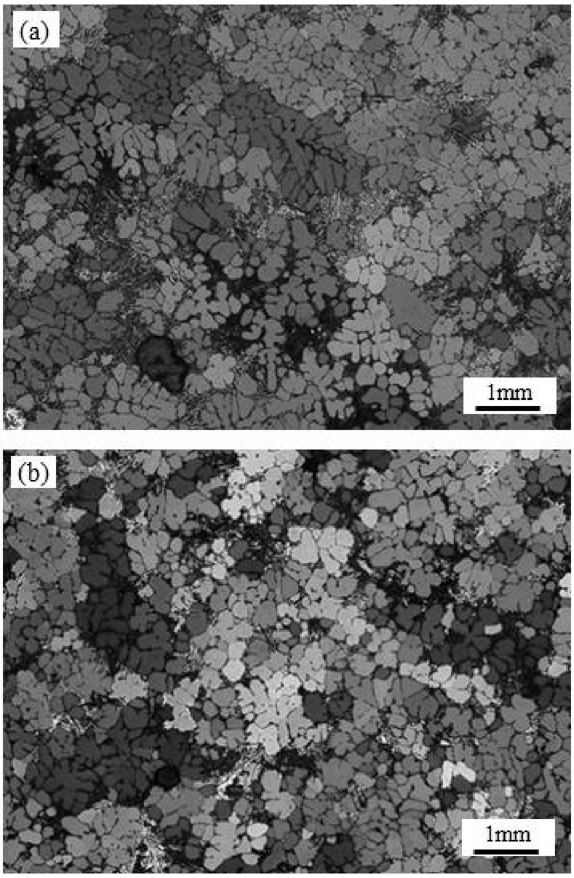

Fig. 3 Two microstructures solidified with EMS at the imposition time of (a) t = 0.2 and (b) t = 0.5 seconds, respectively.

constitutional undercooling zone to yield dendrites.

Meanwhile, the longer imposition time may lead to more severe turbulent fluid flow and furthermore, yield considerable uncoupled displacement behavior, which may result in finer equiaxed grains.

4. Conclusions

The EMS technique has been proved to be effective in refining the microstructure of the Al-7%Si alloy. The refinement can be attributed to fluid flow and uncoupled movement between the solid and liquid, and thus promoting the fragmentation of dendrites to yield refined structures during EMS processing.

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