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Grain size control in Al–Si alloys by grain refinement and electromagnetic stirring

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ABSTRACT

The present study concerns the directional solidification of grain-refined and non-refined Al–7 wt.% Si alloys under the influence of a travelling magnetic field (TMF). Upwards and downwards travelling fields have been applied to provide a forced convection within the solidifying melt. The formation of a fine equiaxed structure is favoured by both the addition of grain refining AlTi5B1-particles and electromagnetic stirring as well, whereas the addition of grain refiners into the melt appears to be more efficient for achieving a reduction of the mean grain size. A minimum grain size has been observed of the electromagnetic agitation of a grain-refined alloy. A melt stirring by a sufficiently high magnetic field provides a homogeneous grain size distribution in the sample volume, but, gives rise to the formation of segregation zones.

1. Introduction

The adjustment of fine grain morphologies has been approved to be a crucial issue for improving characteristics and properties of cast and wrought aluminium alloys. Several methods are known to achieve grain refinement in solidification processes: add-on of grain refiners [1,2], rapid cooling conditions [3], mechanical or electromagnetic stirring [4–6], or ultrasonic treatment [7].

Grain refiners are already widely used in the foundry industry as a very effective method to achieve grain refinement in aluminium alloys. Benefits can be obtained in a various manner such as a better feeding to avoid shrinkage porosity, reduction of hot tearing, improvement of strength and fatigue life. Grain refinement is usually realized through addition of Al–Ti or Al–Ti–B master alloys. The initiation of a forced melt flow during solidification has been shown as another successful way in non-refined alloys to achieve grain-refined microstructures and a transition from a columnar to equiaxed dendritic growth (CET). Several theories have been proposed to explain the nucleation of equiaxed crystals. The detachment of crystal fragments from the advancing columnar front is intensively discussed to serve as a decisive mechanism for grain multiplication [8]. Secondary arms of columnar dendrites may be detached as a result of an enrichment of solute in the liquid between the arms [9,10]. Such a local solute pileup can occur because of dendrite ripening, but, liquid flow may contribute to such remelting scenarios by convective transport of heat and solute into the interdendritic zone. Furthermore, the flow is supposed to accomplish a subsequent transport of the fragments into the undercooled regions adjacent to the solidification front allowing for nucleation and growth of equiaxed grains.

AC magnetic fields provide a contactless method to control the flow inside a liquid metal. A number of studies have already been reported concerning the impact of rotating magnetic fields (RMF) [11–14] or travelling magnetic fields (TMF) [15–18] in solidifying metals. Only a few studies have been reported until now with respect to the interplay between grain refinement and electromagnetic stirring of the melt. Zaidat et al. [19] considered the directional solidification of Al–Ni alloys under the influence of a travelling magnetic field and observed a disturbance of the equiaxed microstructure, which usually occurs in refined alloys without stirring, by the forced convection. The authors suppose an influence of the TMF-driven flow on the nucleation of the refining particles. They suggest a filtering effect by the mushy zone in which the biggest most effective refining particles are transported into the mushy zone where they are blocked within the interdendritic space. Liu et al. [20] studied the effect of strontium addition and electromagnetic stirring on the microstructure of AZ91 alloy. They found that a combination of strontium alloying and electromagnetic stirring reduces the grain size significantly. On the basis of results obtained from a DTA analysis the authors explained the refinement by an increase of the undercooling and the nucleation temperature of the primary α phase. Jin et al. [21] published a study

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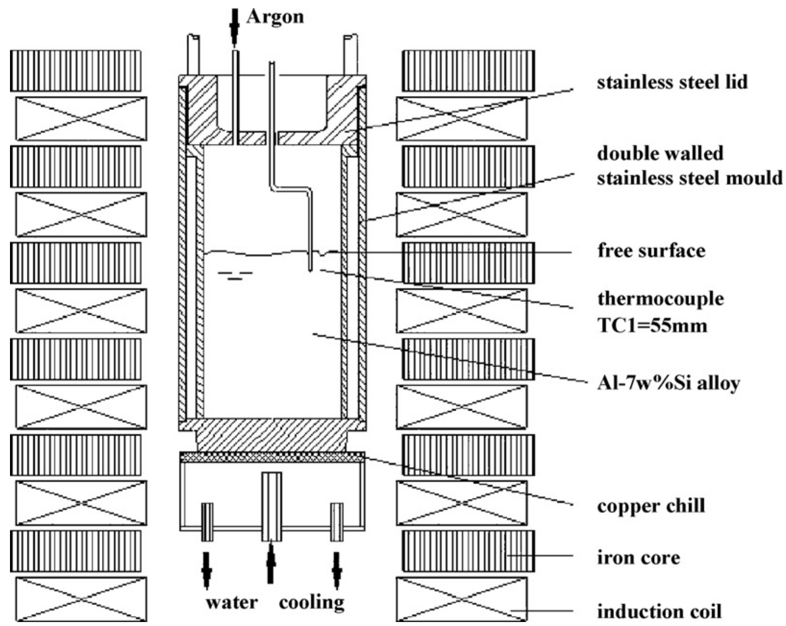

Fig. 1. Schematic view of the experimental set-up.

with respect to the structure formation in the superalloy IN100 under the application of a rotating magnetic field. The inner wall of the mould was coated with the inoculant $CoAl_2O_4$ in order to prevent a columnar grain growth from the mould. It was shown, that an increase of the magnetic field strength leads to a finer grain structure and increases the fraction of equiaxed grains.

The present study is focused on the use of grain refining particles and electromagnetic stirring to control the grain size in AlSi7 alloys. The experimental set-up used for the solidification experiments and the procedure for the metallographic analysis will be described in Section 2. Section 3 presents the experimental results with a special focus on the obtained grain size and the substructure within the grains. Aspects concerning the effect of TMF stirring and grain refiners on the grain morphology are discussed in Section 4. Finally, the outcome of this work is concluded in Section 5.

2. Experimental procedures

2.1. Solidification experiment

Solidification experiments were performed using an Al–7 wt.% Si alloy prepared from 99.7% Al and 99.98% Si according to the designated composition. A part of the raw alloy was modified with 400 ppm Ti by adding AlTi5B1. The Al–7 wt.% Si samples were solidified directionally from the bottom in a double-walled, cylindrical stainless steel mould. The inner wall of the mould was coated with boron nitride (BN). The mould has an internal diameter of 50 mm and a height of 100 mm. The mould is furnished with a lid made from stainless steel. The schematic drawing of the experimental setup can be found in Fig. 1.

Preparatory specimens were cast from Al–7 wt.% Si alloy. Fifteen minutes before pouring, at a temperature of 700 °C, AlTi5B1 was added to a part of the specimens. After solidification, the specimens were machined until they achieved a predetermined weight of 315 g. This weight corresponds to a filling height of 60 mm for the liquid in the mould.

For the solidification experiment, these grain-refined and non-refined preparatory specimens were melted inside the steel mould using an electrical furnace. After approximately 60 min at a temperature of 700 °C, the complete melting was

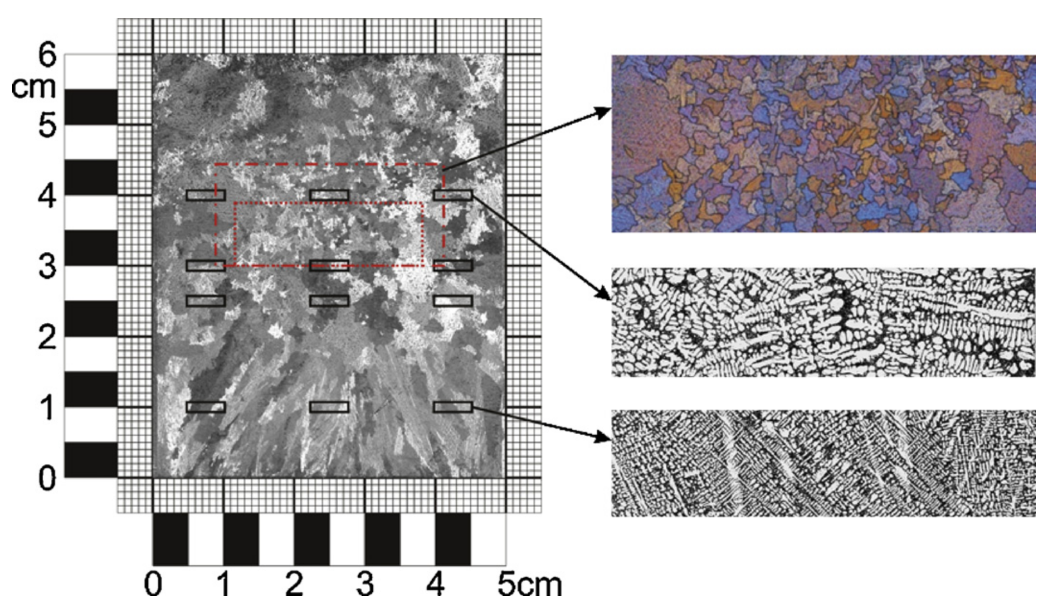

Fig. 2. Longitudinal section of a solidified sample showing the locations of inspection windows for quantitative examinations of the grain morphology.