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Short communication

Structure of in situ Al/Si functionally graded materials by electromagnetic separation method

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Abstract

The aim of this paper is to investigate the structure of in situ Al/Si functionally graded materials by electromagnetic separation method. The research shows that the structure of Al/Si (hypereutectic) sample produced by this method changes from Al–Si hypereutectic structure with a great number of primary Si particles to Al–Si eutectic structure to Al–Si hypoeutectic structure with a great number of primary Al dendrites from one side of the sample to the other. Moreover, the hardness of the sample and the volume fraction of primary Si particles have gradient character in the sample.

1. Introduction

Functionally graded materials (FGMs) are characterized by continuous, smooth variations in composition and/or microstructure, which eliminate the well-defined interface of dissimilar materials when they are put together and avoid local stress concentration of the workpiece. So they provide a solution to many applications that are required to have varied properties in one part [1,2]. Now more and more attention is being paid to the research on FGMs, and a large variety of production methods has been developed, including: powder metallurgy, chemical vapour deposition, physical vapour deposition, centrifugal casting, etc. [1,3].

But these methods are complicated and costly. The process of in situ FGMs by electromagnetic separation method is a new developing production method based on the electromagnetic separation technique [5–7], which produces FGMs by usual casting under the electromagnetic field (DC electric field with steady magnetic field). Therefore, the advantages of this method are lower cost and time saving, and it can produce thermodynamically stable systems based on the in situ nucleation and growth of the reinforcements from the parent melt. The aim of this paper is to investigate the structure distribution of hypereutectic Al/Si FGM sample by electromagnetic separation method.

2. Principle

When the melt containing the primary particles is exposed to the electromagnetic field, the electromagnetic force is induced in the melt and scarcely acts on primary particles due to their lower electric conductivity. By the reaction of the electromagnetic force induced in melt, the particles are pushed to the direction opposite to that of the electromagnetic force, as shown in Fig. 1. The force acting on the particles is named electromagnetic Archimedes force [4,5]. The electromagnetic Archimedes force acting on a spherical particle can be written as

$$F = -\frac{3}{2}\frac{\sigma_1 - \sigma_2}{2\sigma_1 + \sigma_2}\frac{\pi d^3}{6}|J \times B|, \quad (1)$$

where σ_1 is the electrical conductivity of the melt, σ_2 the electrical conductivity of the particle, d is the particle diameter, J the current density, B the magnetic flux density, and the negative sign suggests that the direction of the electro-

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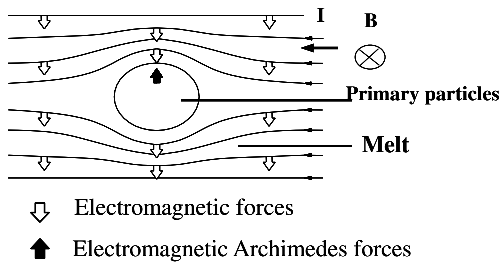

Fig. 1. Principle of electromagnetic separation method: B is the magnetic field and I the electrical current.

magnetic Archimedes force on the particle is opposite to the direction of the electromagnetic force [5–7].

In the solidification of Al–25 wt%Si melt (hypereutectic composition), primary Si particles are formed from the melt at the temperature below the liquids, primary Si particles move in the direction of the electromagnetic Archimedes force when they are exposed to the electromagnetic field. With the decreasing of the melt temperature, primary Si particles are continuously formed and regularly distribute along the direction of the electromagnetic Archimedes force. In situ Al/Si FGMs can be produced by adjusting the electromagnetic field and the melt cooling rate. The principle of the process is schematically shown in Fig. 2.

3. Experiments

The equipments of the experiment are same with work [5], which mainly include an electromagnet with power supply, a direct current power supply, a casting mould made of firebrick and two resistance furnaces. The studied material is hypereutectic Al–25 wt%Si alloy with additional elements Ti. And its nominal composition is Al–25 wt%Si-3.75 wt%Ti. The alloy was melted in the resistance furnace and poured into the casting mould in the electromagnetic field. The process parameters are as following: the pouring temperature is 810 °C, the preheat temperature of the casting mould is 400 °C, the electromagnetic force $|J \times B|$ is about 5×10^4 N/m^3, and the melt cooling rate is about 20 K/min. Samples are prepared for microscopy using standard techniques. Microstructures are examined by optical microscope. Macrostructure of the sample is obtained using a high resolution scanner after etching in 0.5 vol% FH reagent.

4. Results and discussion

Fig. 3 shows the macrograph of in situ Al/Si FGMs sample by electromagnetic separation method. It is obvious that the sample includes two parts: particle packed regions which include region A and region B and particle free regions which include region C and region D. Fig. 4 shows its microstructure, pictures (a), (b), (c) and (d) are the microstructures of regions A, B, C and D (shown in Fig. 3) of the sample, respectively. It is seen that the microstructure of region A and region B is Al–Si hypereutectic structure with a great number of primary Si particles, and its length is about 17 mm. The microstructure of region C is Al–Si eutectic structure, and its length is about 6 mm. The microstructure of region D is Al–Si hypoeutectic structure with a great number of primary Al dendrites, and its length is about 7 mm. These show that the microstructure of Al–Si hypereutectic sample by electromagnetic separation method changes from hypereutectic structure to eutectic structure to hypoeutectic structure from one side to the other. This shows that all primary Si particles are pushed to the particle packed regions by electromagnetic Archimedes force.

Fig. 5 shows the microstructures around interface I between regions B and C and interface II between regions C and D. Fig. 5(a), (b) and (c) show the microstructures from region B to region C around interface I, and Fig. 5(e), (d) and (f) show the microstructures from region C to region D around interface II. It is known that the microstructures from region B to region C and from region C to region D are both smooth transitional.

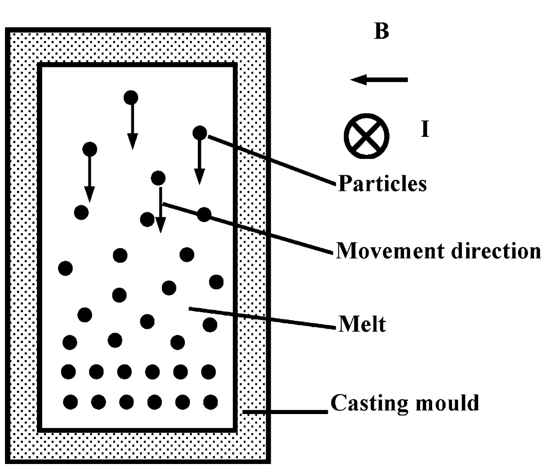

Fig. 2. Principle of the process of in situ FGMs by electromagnetic separation method: B is the magnetic field and I the electrical current.

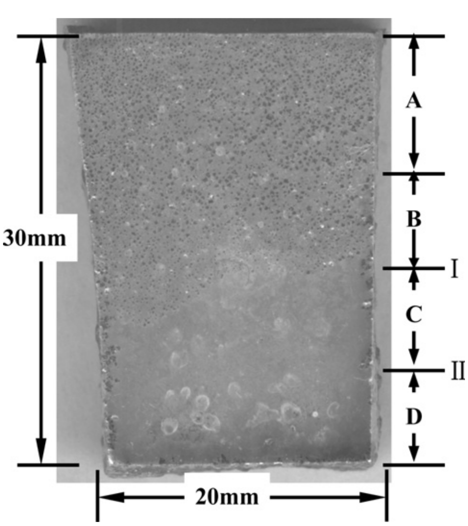

Fig. 3. Macrograph of hypereutectic Al–Si FGM sample by electromagnetic separation method.