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Effect of SiC particles on crystal growth of Al–Si alloy during laser rapid solidification

K. Zhang *, G.N. Chen

Materials Center, Institute of Mechanics, Chinese Academy of Sciences, Beijing 100080, China

Abstract

Rapid solidification microstructures of SiC_p/Al–Si composite and the monolithic alloy are comparatively studied through laser remelting process. In the case of composite, particles disturb the orderly arrangement of primary α-Al dendrites observed in the base alloy. The underlying mechanisms are rationalized based on the interaction between the particle and aluminium melt.

Keywords: Composite; Laser processing; Solidification

1. Introduction

Laser rapid solidification of monolithic alloy has been extensively studied and great achievements have been achieved [1]. A thorough work on metal matrix composites, however, does not seem to be existing. This is particularly difficult because the reinforcement frequently alters matrix solidification response [2]. This paper deals with microstructure evolution of SiC_p/Al–Si composite subjected to laser remelting treatment. For comparison, microstructure development of the monolithic alloy is also characterized.

2. Experimental

The experiments are carried out on samples of A356 aluminium alloy and 20 vol.% SiC_p/A356 composite in an as-cast condition. All samples are prepared using an investment mould casting technique under same process parameters. The nominal compositions of A356 alloy are 7 wt.% Si, 0.3 wt.% Mg, 0.1 wt.% Ti, Al bal. The SiC particles have an average diameter of 15 μm.

A continuous CO_2 1.5 kW laser is used for remelting experiments. The diameter of laser beam, d, set at 2 mm, beam powers, P, 400–800 W, and scanning velocities, V_b, 15–60 mm s^{-1} are major parameters. Particle melting and particle/matrix reaction are avoided by a proper combination of P and V_b. Optical microscopic (OM) observations of longitudinal sections taken through the center of laser trace are made. A solution containing 0.5 ml HF and 100 ml distilled water is used to etch metallographic specimens, wherever required.

3. Results

After laser remelting of A356 alloy, the microstructure consists of primary α-Al dendrites and Al–Si eutectic. The dendrites orient themselves closet to the heat flux direction and grow uninterrupted from the bottom of the melt track up to the surface. Raising the scanning velocity, the dendrites become finer but remain in the characteristic of epitaxial columnar regrowth [1]. One typical example is displayed in Fig. 1. It is noted from Fig. 2, however, that the arrangement of dendrites in laser treated composite is somewhat chaotic. An unstable branching dendritic structure is easily observed. This irregular growth behavior is similar to that observed in the case of laser cladded SiC_p/Ti composite and laser alloyed Al_2O_{3p}/Al composite [3,4]. In addition, there are some dendrites terminating at a particle, which indicates strong effect of particle restricted growth.

Experimental results also show that, at any scanning velocities, remelting process results in little redistribu-

* Corresponding author. Tel.: +86-10-62547527; fax: +86-10-62561284.

E-mail address: kzhang@cc5.imech.ac.cn (K. Zhang).

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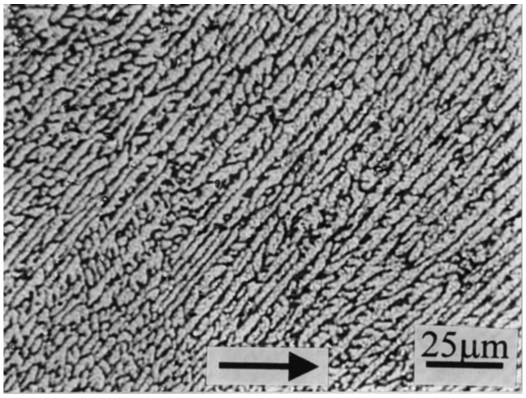

Fig. 1. OM micrograph of laser processed A356 alloy at $d = 2$ mm, $P = 800$ W, $V_b = 60$ mm s^{-1}, showing regular growth of primary phase. The micrograph is taken from the middle of melt track with the laser scanning direction indicated by arrow (etched).

tion of particles. In fact, particle microsegregation characteristic of the original material is preserved in large, as shown in Fig. 3. This means that the particles can be regarded as still during rapid solidification.

4. Discussion

4.1. The mechanisms of chaotic growth

Due to unrevealed grain structure, the exact mechanism of chaotic growth is not clear. However, following extrapolations can be made from existing results.

4.1.1. Non-epitaxial grain development

It is well known that SiC does not act as heterogeneous nucleation site for α-Al [2]. Nevertheless, according to the argument presented by Sekhar and Trivedi [5], particle restricted growth is expected to create sufficient undercooling and time to allow new grains to develop. The finding on Al–Cu–SiC_p by Dutta and Surrapa, especially relevant to this argument, is that columnar growth is favored in particle free region and equiaxed growth in particle-containing region [6]. Moreover, in a recent study on laser rapid solidification, we have revealed greatly refined columnar grains in SiC_p/Al–Zn composite compared to coarse columnar grains in Al–Zn alloy. Therefore, the contribution to disorder growth might be mainly from non-epitaxial grain development, although distortion of subgrain structure may be regarded as another contribution.

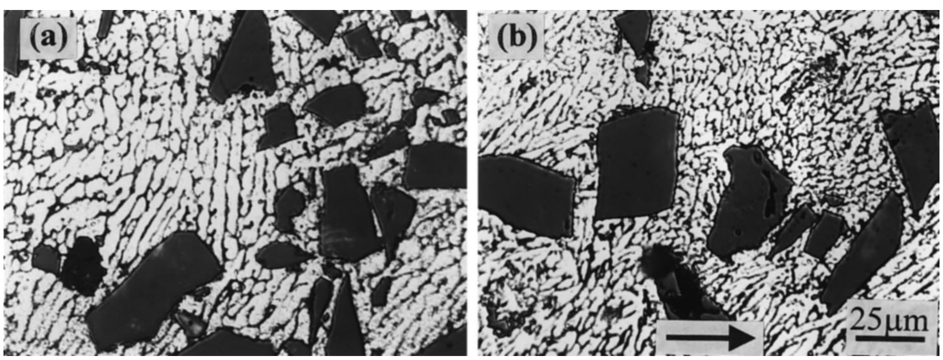

Fig. 2. OM micrographs of laser processed SiC_p/A356 composite at (a) $d = 2$ mm, $P = 400$ W, $V_b = 15$ mm/s and (b) $d = 2$ mm, $P = 800$ W, $V_b = 60$ mm s^{-1}, showing somewhat chaotic growth of primary phase. The micrographs are taken from the middle of melt track with the laser scanning direction indicated by arrow (etched).

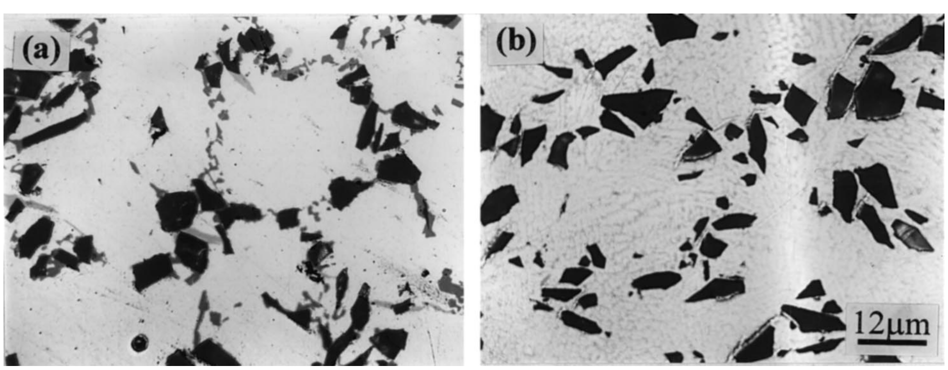

Fig. 3. OM micrographs of SiC_p/A356 composite taken from (a) unmelted zone, showing heterogeneous nucleation of Si on SiC_p pushed into interdendritic regions, and (b) the bottom of fusion zone, showing little redistribution of particles after remelting ($d = 2$ mm, $P = 800$ W, $V_b = 60$ mm s^{-1}, unetched).

4.1.2. Distortion of subgrain structure

Rohatgi et al. [7] and Liu et al. [8] believed that, since the particle acts as a barrier to solute diffusion and heat transfer, disturbed solute field and temperature field ahead of solidification interface may thus contribute to irregular growth in any given columnar grain. If so, disturbed solute field is believed to be the major factor in this work. First, crystal growth of alloy melt is primarily influenced by the solute diffusion rather than thermal conductivity. Second, thermal equilibrium between SiC particle and aluminium melt is rapidly established. In fact, the time delay for the attainment of equilibrium is on the order of 10^{-3} ms [9], whereas the life of molten pool is estimated to be at least around 33 ms.

4.2. The key parameters for chaotic growth condition

Chaotic growth can reduce hot cracking tendency during laser treatment. It is desirable to reveal the following key parameters under which crystal growth can be greatly restricted and then, chaotic growth can be ensured to occur. Note that the effect of single inert particle on crystal growth is taken into account here.

4.2.1. High velocity of solidification

The particle can be pushed by solidification interface if solidification velocity, V_s, is low. In such a case, particle can not restrict crystal growth to a great extent. Indeed, some investigators have observed unidirectional dendritic growth and particle pushment simultaneously in composite weldments [10,11]. In order to make particle keep stationary, V_s should be larger than the critical velocity, V_{cr}, approximately given by ref. [12]. For composite used in this study, the calculated value of V_{cr} is around 4.16 mm s^{-1}. If the relationship of the form $V_s = V_b \cos\theta$ (θ is the angle between V_s and V_b) is accepted and θ is assumed to be 60° [13], V_s ranging from 7.5 to 30 mm s^{-1} are higher than V_{cr} in this study.

4.2.2. Large value of particle diameter

Even though particle can not be pushed by solidification interface, it may be engulfed into any given dendrite (or entrapped into interdendritic region) and restricting effect will be marginal. In order to terminate crystal growth, particle diameter should be larger than λ_1 ($2R_d$), where λ_1 is primary arm spacing of dendrites, R_d is dendrite tip radius [14]. In this study, λ_1 ($2R_d$) on the order of micrometer is much smaller compared to particle diameter.

In addition to solidification velocity and particle diameter, particle volume fraction also can play a significant role in determining the behavior of crystal growth. On one hand, high particle content means a better chance for the crystal growth to be restricted [4]. On the other hand, even in the case of low solidification velocity and particle pushing, high particle density promotes the formation of particle cluster with a large effective size. The restricting effect of particle cluster on crystal growth is thus expected [7].

5. Conclusions

During laser rapid solidification of A356 alloy, the presence of SiC particles may disrupt the usual columnar epitaxial regrowth. This occurs especially under the condition of high solidification velocity and large particle diameter.

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