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Microstructure refinement of cast high-Si Al alloy via laser remelting

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High-Si Al alloys are suitable materials for thermal management applications such as electronic packaging because they possess low density, high thermal conductivity, low coefficient of thermal expansion and high specific strength. Casting is the cheapest and the most convenient method to fabricate high-Si Al alloys. However, the low solidification rate of the casting process leads to the formation of coarse primary Si and needle-shaped eutectic Si, which result in poor mechanical properties, impeding their applications. Laser remelting of the cast high-Si was attempted to refine the microstructures through rapid melting and solidification. There are large numbers of studies about laser remelting on low-Si Al alloys, but the information on high-Si Al alloys is limited. In this work, laser remelting was conducted on a cast high-Si Al alloy with 50 wt.% Si (Al-50Si) to achieve the microstructure refinement. Results show that the distribution of much finer primary Si particles was uniform in the matrix in the fully remelted region after the laser remelting. In addition, the laser remelting process was found to be effective in eliminating porosity in the as-cast microstructures. Microhardness of the laser remelted regions increased significantly due to the microstructural refinement.

1. Introduction

High-Si Al alloys have been widely used in aerospace and electronic packaging due to their low density, good wear resistance and low coefficient of thermal expansion. In recent years, high-Si Al alloys with fine microstructures and desirable material properties have been prepared by spray forming, powder metallurgy and selective laser melting, but these process methods are usually expensive. Casting is almost the cheapest method to fabricate high-Si Al alloy, but the presence of coarse and irregular primary Si phase due to the low solidification rate, impedes their applications.

In the last few years, laser remelting has been used to achieve the microstructural refinement of Al-Si alloys to improve the hardness, wear resistance and corrosion resistance due to the very high cooling rate [1]. Most of the current studies on laser remelting of Al-Si alloys are focusing on low-Si range, few work has been carried out on high-Si Al alloys which contain large amount of primary Si particles. In this work, laser remelting via a 6 kW fiber laser was performed on an as-cast Al-50Si alloy.

2. Experimental procedures

Al-50wt% Si (in weight percentage) alloy was prepared using commercial pure Al (99.9%) and pure Si (99.9%) by casting through an induction furnace. 0.5 wt% phosphorus was added in the melt as grain refiner via Al-3P master alloy. Then the melt was poured into a graphite mold. The as-cast Al-50Si alloy was ground by sand papers prior to laser remelting.

Laser remelting on an as-cast Al-50Si alloy was performed using a 6 kW fiber laser with a beam size of a few hundred micrometers. The laser head was inclined 30 degrees to avoid the reflection damage on the laser head. The laser power was selected at 1500 W, and the scanning speed was set at 1500 mm/min and 3000 mm/min. During the laser remelting process, argon was used as shielding gas with a flow rate of 20 L/min to avoid the oxidation.

The specimen was hot mounted, ground and finally polished using colloidal silica suspension. The cross-section microstructures of the specimen were observed using an optical microscope (Olympus MX40) and a field emission scanning electron microscope (SEM; JEOL-7600). Prior to the SEM observation, the sample was etched by Keller's reagent. Elemental distribution analysis was carried out using energy dispersive spectroscopy (EDS). Microhardness measurements were performed on the cross-sections using a Vickers microhardness tester (Future-Tech FM-300e). The indenter load and the dwell duration were set at 200 gf and 15 s, respectively. In each area, at least 5 indents were collected to get the average microhardness value and standard deviation.

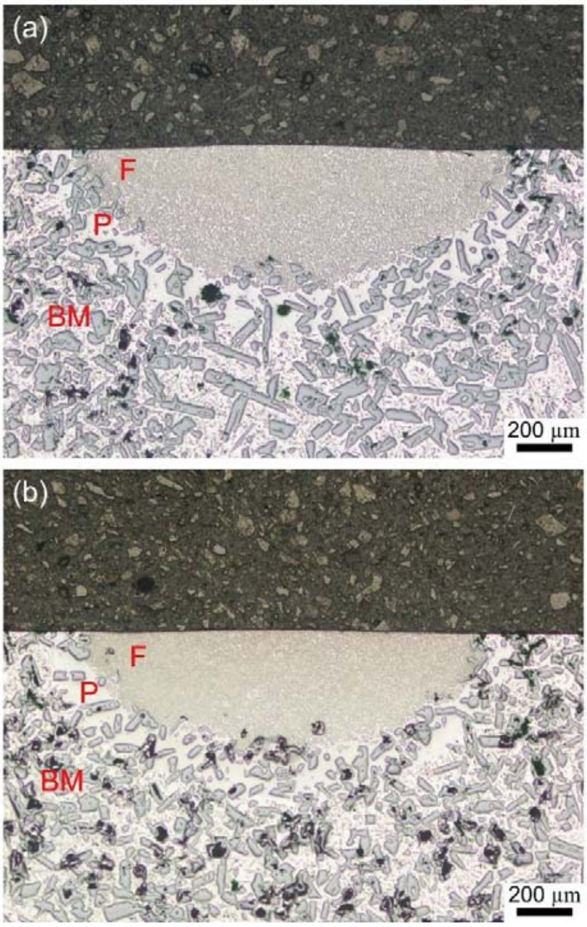

Fig. 1 Optical micrograph showing the cross-section microstructures of as-cast Al-50Si alloy after laser remelting at different scanning speeds: (a) 1500 mm/min, and (b) 3000 mm/min.

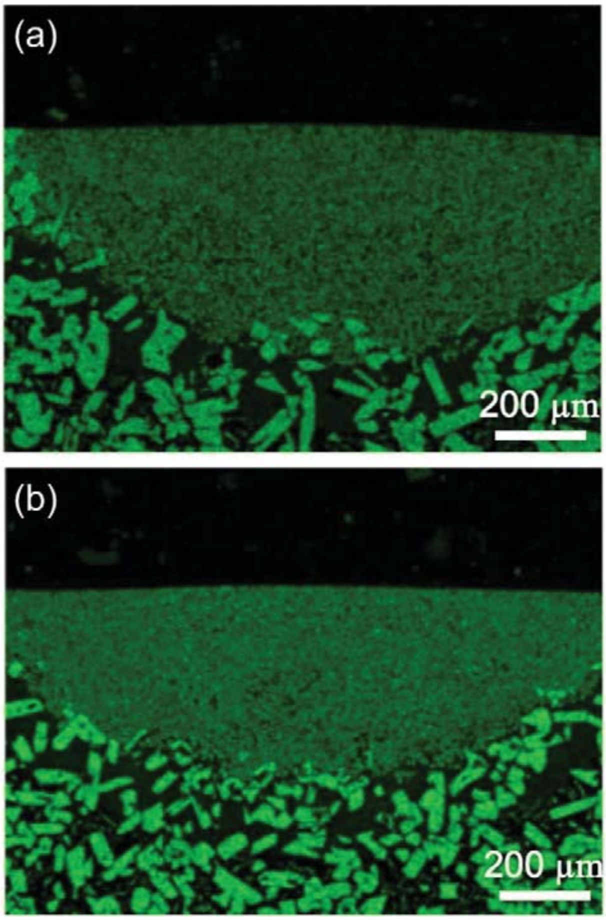

Fig. 2 EDS maps of Si in the laser remelted areas and base materials: (a) 1500 mm/min, and (b) 3000 mm/min.

Table 1 Dimension of the remelted tracks

Scanning speed	1500 mm/min	3000 mm/min
Width (µm)	1860	1720
Depth (µm)	690	630

3. Results and discussion

In the base material (BM), the microstructure consists of coarse polygonal primary Si particles, needle eutectic Si and Al matrix as shown in Figure 1. Some cracks occurred in the primary Si particles and a high percentage of porosities was also observed in the microstructure of base material. After laser remelting, the remelted tracks are in semielliptical shape and can be identified as two different regions which are fully remelting area (F) and partially remelting area (P). In the fully remelted region, the whole area was heated above liquidus temperature and completely melted, most of the casting defects were eliminated in this region. On the other hand, outside the fully remelted area, the region was at lower temperatures and was only able to partially melt the matrix. Due to the insufficient melting, there were some porosities and coarse primary Si particles in the partially remelting area.

The melt pool of the remelted tracks is affected by the scanning speed, and the dimensions of the remelted tracks including fully remelting area and partially remelting area are listed in Table 1. It can be seen that higher scanning speed would result in smaller remelted track due to the less heat input.

The distribution of Si particles plays a significant role in the mechanical properties and thermal-physical properties of Al-Si alloys. Figure 2 shows the Si element maps measured by EDS after laser remelting. In both scanning speeds, Si was homogeneous dispersed in the Al matrix in the fully remelted regions. The uniform distribution of Si particles would be beneficial to improving the hardness and impact toughness of Al-Si alloys [2].

To study the microstructure further, high magnification SEM images of the remelted track are shown in Figure 3. The microstructure of fully remelted area contains fine crack-free primary Si particles surrounded by fine Al dendrites with eutectic Al-Si as shown in Figure 3a. The size of primary Si particles in this region was below 10 µm which is significantly lower than that of cast state.

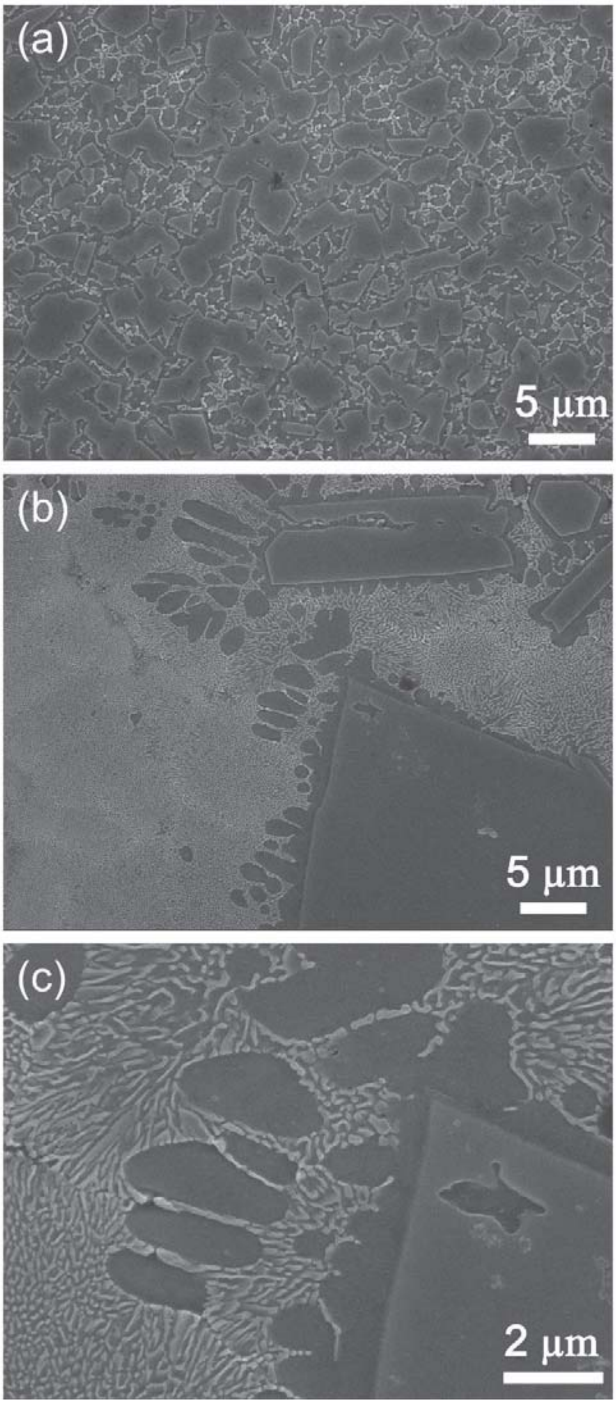

Fig. 3 SEM images showing the microstructures of as-cast Al-50Si after laser remelting at 3000 mm/min.

As shown in Figure 3b and 3c, the microstructure of the partially remelted area contains the coarse primary Si particles and much denser eutectic Si compared to the fully remelted area. The fine Al dendrites have high affinity to the primary Si particles in this area, while the fine Al dendrites were uniformly distributed in the fully remelted area.

Beside the refinement of primary Si particles in the fully remelted region, the size and morphology of eutectic Si also changed significantly after laser remelting. In the base materials, the eutectic Si was in elongated needle shape, which would deteriorate the mechanical properties of high-Si Al alloys. After laser remelting, the eutectic Si needles was refined to fine fibrous shape in the fully remelted area (Figure 3b) and to globular and fibrous shape in the partially remelted area (Figure 3c).

The formation of non-equilibrium microstructure in the remelted regions can be summarized as follows. The as-cast Al-50Si alloy was heated up rapidly to melt by laser. Then during solidification, the primary Si phase with higher melting point would nucleate and grow first accompanied by the ejection of Al to the adjacent melt. With the sudden decrease of Si content and increase of Al content near the Si-nucleation site in the melt, the chemical composition of the surrounding melt shifts to the hypoeutectic side in the coupled zone [3].

The microhardness of the as-cast Al-50Si alloy was measured to be 77 ± 11 Hv. It is noted that the microhardness was performed in the area without the presence of coarse primary Si particles in the base materials. Due to the nature of brittleness of coarse primary Si particles, the cracks are occurred when the indentation covers the coarse primary Si particles and makes it difficult to get the valid microhardness value. After laser remelting, the average microhardness of the fully remelted area was enhanced to 218 ± 8 Hv for 1500 mm/min and 224 ± 10 Hv for 3000 mm/min. This could be attributed to the homogeneous distribution of fine primary Si particles and the reduction of porosities in the fully remelted area. In the partially remelted area, the microhardness of Al-50Si alloy decreased to 159 ± 25 Hv for 1500 mm/min and 156 ± 8 Hv for 3000 mm/min. It is expected the softening of the material would occur in the partially remelted areas since more eutectic structure and less hard primary Si was formed in the microstructure.

4. Conclusions

In this study, an as-cast Al-50Si alloy was surface melted using a high power fiber laser. The microstructures and microhardness before and after laser remelting were carefully characterized. Remarkable microstructure refinement was achieved after laser remelting including the elimination of the most casting defects in as-cast Al-50Si alloy and the refinement of coarse primary and eutectic Si phase. The microhardness of the Al-50Si alloy was improved significantly after laser remelting, and this is attributed to the microstructural refinement due to the rapid solidification rate.

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