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Improvement in wear resistance of hyper-eutectic Al–Si cast alloy by laser surface remelting

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Abstract

Laser surface remelting of hyper-eutectic Al–20 and 30 mass%Si cast alloys with CO_2 laser beam has been fined to improve the wear resistance of these alloys. A continuous wave CO_2 laser beam with the power of 5kW was irradiated on these Al–Si cast alloy substrates under various defocused distance of laser beam with the argon gas shielding. The microstructure of the laser-remelted layer consisted of fine primary Si particles, primary α-Al matrix phase and fine α-Al–Si eutectic phase. The size of the primary Si particle decreased from 25 to 3 μm with the defocused distance also decreasing. Fine primary Si particles were distributed uniformly in the matrix of the fully remelted layer. The hardness of the laser remelted layer increased gradually with the decrease of the primary Si particle size, which reached 140 HV at about 5 μm in Al–30 mass%Si layer. The wear resistance of the remelted layer increased with increasing the hardness and decreasing the size of primary Si particle. The wear resistance of the remelted layer in Al–30 mass%Si cast alloy was better than that of the Al–20 mass%Si cast alloy.

Keywords: Laser beam; Surface modification; Aluminum–Silcon cast alloy; Hardness; Wear resistance

1. Introduction

Al–Si cast alloys are widely used in the automotive industry as popular alloys owing to their excellent castability, weldability and corrosion resistance. Hyper-eutectic Al–Si cast alloys are especially used in tribological applications. Silicon is a hard and wear resistant material. The hardness and wear resistance of Al–Si cast alloys increase with increasing the Si content. However, the machinability and ductility of these cast alloys decrease with the Si content. These problems are caused mainly by the large primary Si particles in cast alloys. Therefore, the Si content is limited up to about 20% mass in commercial applications. Hyper-eutectic Al–Si cast alloys are usually treated with phosphorus to refine the primary Si particles [1]. The size of Si particles, however, is about 30 μm at the minimum size in conventional gravity casting process [2].

Laser surface modification is ideally suited to refining the microstructure by rapid melting and solidification, and changing the concentration of Si in the surface of substrate alloys by alloying. In the laser surface alloying process, the Si content of the alloyed layer can be increased up to 80% mass [3,4]. The hardness and wear resistance of the laser alloyed layer increased with increasing the Si content [3,5].

On the other hand, in the laser melting process, the size of the primary Si particle in hyper-eutectic Al–high Si cast alloy can be reduced from 30 to 10 μm due to rapid solidification [6]. The wear resistance of the laser-melted layer was higher than that of the substrate [6]. But the influence of the size of primary Si particle on wear resistance is not clear.

Therefore, in the present work the authors investigate the laser surface remelting of hyper-eutectic Al–Si cast alloy to improve the surface hardness and the wear resistance by refining the primary Si particle. The microstructures of the laser-remelted layers are charac-

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terised in detail, and the relationship between the size of primary Si particle and wear resistance is discussed.

2. Materials used and experimental methods

2.1. Materials used

As substrate specimens hyper-eutectic Al–20 and 30 mass%Si cast alloys refined with phosphorus addition were made by a high pressure casting process into a column of 80 mm in diameter and 100 mm in height, and cut into 10 mm in height for laser remelting. The sizes of the primary Si particles of these cast alloys were 25 and 40 μm in Al–20 and 30 mass%Si cast alloys, respectively.

2.2. Laser remelting process

The specimen was coated with carbon to increase absorption of the laser beam. The multi-mode continuous wave CO_2 laser beam with a maximum power of 5.5 kW was used for laser remelting. The laser beam was irradiated under defocusing conditions. A focal point of the laser beam was set up for the specimen. A defocused distance between focal point and specimen surface was varied from 10 to 40 mm. The diameter of the laser beam was 1.5 to 4 mm at each defocused distance. The laser-remelted layer was produced with overlapping tracks. The overlapping fraction of each laser track was set at 25 and 50% to that of the beam diameter. The laser beam power and the travelling speed was set at 5 kW and 100 mm/s, respectively. Argon gas flowed from two directions of the laser beam axis and about 45° against it. The microstructure of the laser-remelted specimen was examined using optical microscopy, scanning electron microscopy (SEM), energy dispersion X-ray analysis (EDX) and X-ray diffraction (XRD). The hardness of the laser-remelted layer was measured using the Vickers hardness tester. The wear resistance of the laser remelted layer was evaluated by the Ogoshi type wear test, as an abrasive wear test with a rotaing counter roller made of SUJ2 (650 HV) at a rotating speed of 1.14 m/s, load of 20.6 N and silding distance of 66.6 m.

3. Results and discussion

3.1. Characteristics of microstructure of laser remelted layer

The surface morphology of the laser remeled track was smooth even on the overlapped area. The width of the single track increased with increasing the defocused distance (Ddf) from 2 to 6 mm. The depth decreased from 0.9 to 0.4 mm as increasing Ddf, but the depth at Ddf+10 mm was lower than that at Ddf+20 mm due to the loss of heat input into specimen by the absorption of plasma. Therefore, the melted region decreased with increasing Ddf. Decreasing the Ddf increases laser energy density by decreasing the laser beam spot diameter. This probably increases peak temperature in the melted region. It is considered that the cooling rate increases as the Ddf decreases. In this study, the cooling rate calculated, by using the dendrite arm spacing method [7], was high as 5×10^4 to 4×10^5 (K/s).

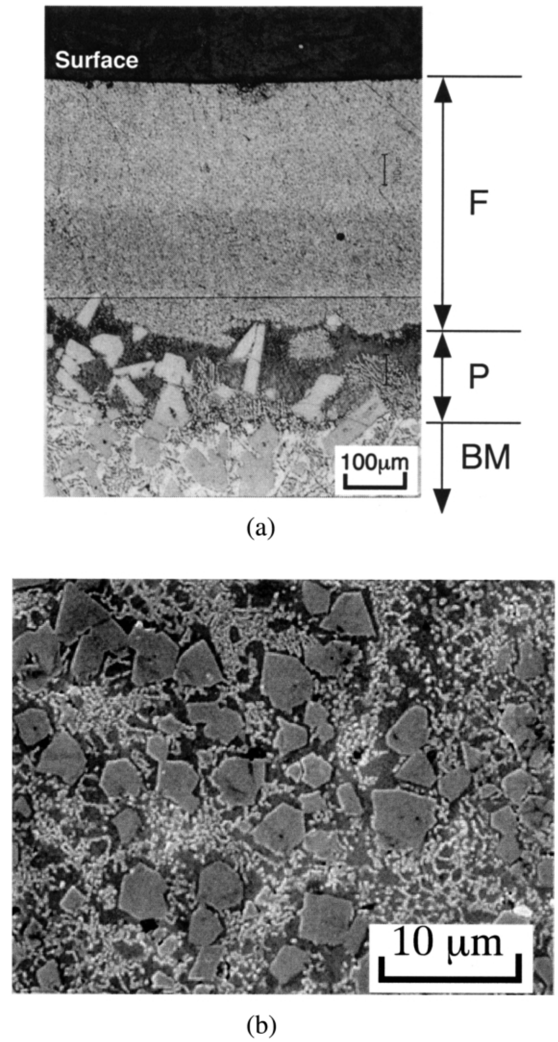

Fig. 1. Typical microstructures of cross section of laser remelted layer in Al–30% Si cast alloy. (a) Cross sectional microstructure of remelted layer at defocused distance (Ddf) of 10 mm; (b) primary Si particles within fully-remelted layer in (a). *F*; fully-remelted layer, *P*; partially-remelted layer, *BM*; as cast structure.

Fig. 1a shows the typical microstructure of the cross-section of the laser remelted layer in Al–30 mass%Si cast alloy. The microstructure consisted of fine primary Si particles, primary α-Al phase and fine (α-Al)–Si eutectic phase. The surface area of the remelted layer (*F*) was fully remelted by heating over liquidus temperature. The next area, below the surface area, was the

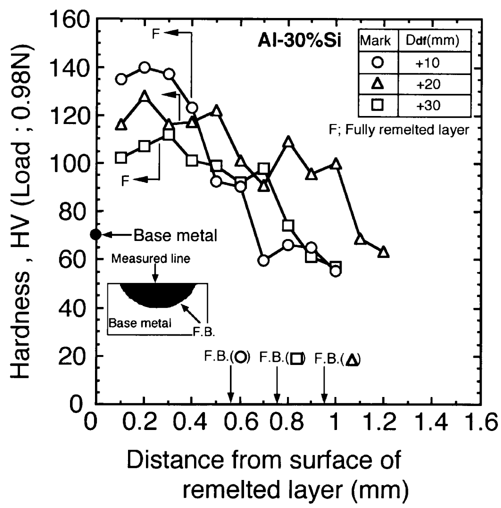

Fig. 2. Hardness distributions of remelted layers in Al–30%Si cast alloy at various defocus distance of laser beam.

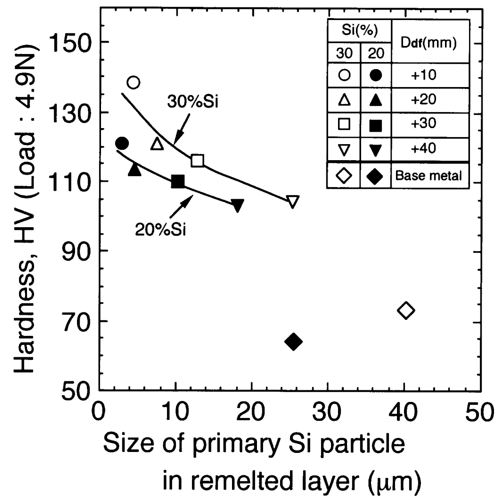

Fig. 3. Effect of primary Si particle size on hardness of fully-remelted layer.

partially-remelted layer (P), in which the matrix was selectively remelted, but the original primary Si particles in the base metal was only partially-melted. Thickness of the fully remelted layer decreased with increasing Ddf. The microstructure of the fully remelted layer is shown in Fig. 1b. Primary Si particles and eutectic phase were very fine due to rapid solidification inherent to the laser remelting process. The Si particles were well dispersed in the remelted layer, and their mean size was 5 μm as shown in Fig. 1b and increased with Ddf. Moreover, at small values of Ddf in Al–30 mass%Si alloy, fine α-Al phase was preferably formed around fine primary Si particles and, thus, the eutectic phase reduced.

3.2. Effect of primary Si particles on hardness and wear resistance

Fig. 2 shows the hardness profiles in cross-section of the laser remelted layer in Al–30 mass%Si cast alloy under various Ddf. The hardness of the fully-remelted layer with fine Si particles was higher than those of the partially-remelted layer and the base metal, and it decreased as the Ddf increased. Fig. 3 shows the relationship between the size of the primary Si particle and the hardness in the fully-remelted layer. The size of primary Si particles decreased with the Ddf as mentioned in Section 3.1. The hardness increased as the size of Si particles decreased and reached about 120 HV and 140 HV for Al–20 and 30 mass%Si alloys, respectively. Moreover, the hardness for Al–30 mass%Si alloys was higher than that for Al– 20mass%Si alloys. It is well known that the hardness of metal matrix composite (MMC) depends on the volume fraction of hard particle [8–10].

Fig. 4 shows the relationship between the primary Si particle size and its volume fraction. The volume fraction of primary Si particle increased with its size decreasing. Moreover, the volume fraction of Al–30 mass%Si alloys was higher than that of Al–20 mass%Si alloys. Therefore, the hardness of the remelted layer depended on the size of primary Si particles and its volume fraction.

Fig. 5 shows the relationship between the size of the primary Si particle and the specific wear, *Ws* for the remelted layer. The *Ws* means the wear loss in units of contact pressure. The value of *Ws* decreased with decreasing the primary Si size. Thus, the wear resistance of the remelted layer was improved with decreasing the primary Si size. This dependency means that the wear

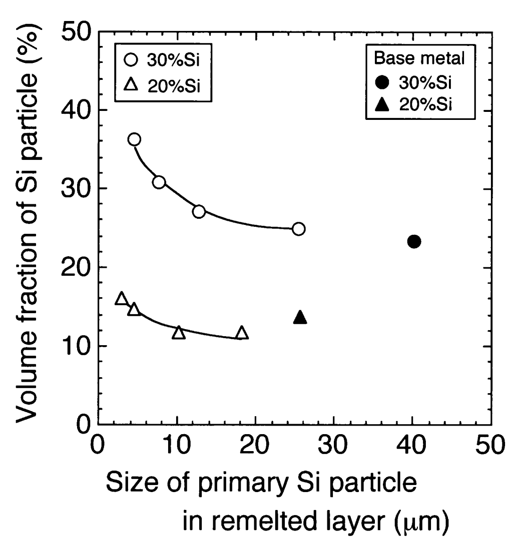

Fig. 4. Relation between primary Si particle size and volume fraction of it in the remelted layer.

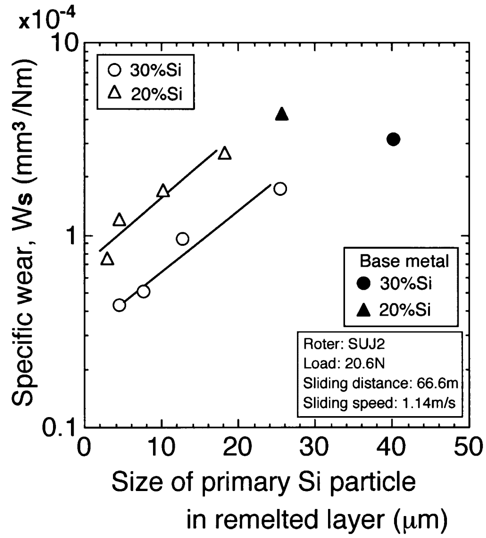

Fig. 5. Effect of primary Si size on specific wear of remelted layer measured by the Ogoshi type abrasive wear test.

resistance increased with the hardness of the remelted layer. The wear resistance of Al–30 mass%Si alloy was better than that of Al–20 mass%Si alloy, because the volume fraction of the primary Si particle of Al–30 mass%Si was higher than that of the 20 mass%Si alloy. Therefore, it is consider that the high volume fraction of the fine primary Si particle provided greater wear resistance.

4. Conclusion

The surface of hyper-eutectic Al–20 and 30 mass%Si cast alloys was remelted to improve the wear resistance by laser surface melting process. Effect of the primary Si particle of the remelted layer on the hardness and the wear resistance was investigated. The main conclusions are obtained as follows:

1. The size of primary Si particles in the remelted layer decreased with decreasing the defocused distance of the laser beam. A minimum diameter ~ 3 μm can be obtained, and was much smaller than that of the base metal, ~ 30 μm.
2. The hardness of the remelted layer increased as decreasing the primary Si size and reached a maximum of 120 HV and 140 HV for Al–20 and 30 mass%Si cast alloys, respectively.
3. The wear resistance of the remelted layer increased as the primary Si size decreased, and was better with a high volume fraction of Si particles.

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