Formation of Aluminum-Boride Dispersed Hardened Layer on Aluminum Plate Surface by Laser Alloying with Boron Powder†

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One of serious drawback in the properties of aluminum materials as engineering materials is its very low anti-wear property. This prevents the wider application of aluminum materials to the industrial parts which is suffered from some kinds of the wear.

It is well known that surface hardening is one of the methods to improve the wear resistance of metals. For ferro-materials, low costly and convenient process for surface hardening to improve the wear property are already established. For example, quench hardening using martensite transformation and some thermo-chemical diffusion penetration processes such as carburizing and nitriding, are well known processes, and a thick surface hardened layer with several hundreds micrometer (μm) to milimeter (mm) order in thickness and Hv400-1500 in hardness is obtained easily.

On the contrary, up to now, there is no established process of the surface hardening for aluminum materials, especially to make the thick and hard layer as same as obtained in ferro-materials.

Some recent reports showed the possibility to make such a thick hardened layer on aluminum surface by using some techniques, that is, laser alloying process with ceramic powder[1,2] and rapid solidification process by electron-beam surface melting[3].

In this report, the authors tried to make a surface hardened layer by using the laser alloying process with boron powder. According to the Al-B binary phase diagram[4], boron reacts with molten aluminum and make hard aluminum borides, AlB_{12}, AlB_{10} and AlB_2. When the adequate quantity of boron is fed into the molten puddle on aluminum plate surface during laser irradiation, aluminum boride will be made and dispersed densely in melted aluminum matrix in the surface melted zone, of which hardness will show a considerable increase in comparison with that of the base aluminum plate.

An aluminum plate used is an industrial pure aluminum (A1070) plate. A specimen size for the laser alloying is a rectangular plate with a 45mm in width × 100mm in lenght × 10mm in thickness. A shallow groove, 6mm wide and 0.5mm depth, was machined on its surface along a center line longitudinally as shown in **Fig. 1**. Boron powder (amorphous state, 0.1-0.5 μm in diameter) was preplaced into the groove by using an ethyl alcohol as a binder. The layer thickness of the preplaced boron powder was about 0.5mm (amount of boron, about 67mg/cm^2) . A test specimen was set in a chamber purged with argon gas and a cw CO_2 laser with a ring mode was irradiated on the preplaced boron powder layer in the groove. Laser irradiation conditions are as follows : laser power, 3.0kW ; specimen traveling speed, 100mm/min ; shielding gas, argon (50 l/min) ;beam diameter, 5.0mm. In order to avoid the formation of plasma flare beam was defocused and to promote the mixing between boron powder and molten aluminum the beam oscillation with 5 Hz in frequency and 2.5mm in amplitude was applied perpendicularly to the traveling direction of the specimen.

Figure 2 (a) and **(b)** show the specimen surface before and after the laser irradiation, respectively. The alloyed layer was obtained on the whole regions of the groove, but the surface of the alloyed layer was not so smooth in this condition used.

Figure 3 shows the typical microstructures of the cross-section of the alloyed layer. The layer thickness was about 350 μm and there was no cracking in the alloyed layer and also the alloyed layer/aluminum base plate boundary.

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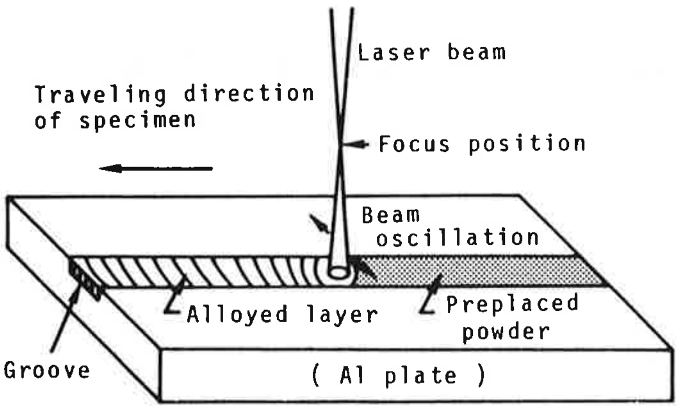

Fig. 1 Schematic illustration of laser alloying process

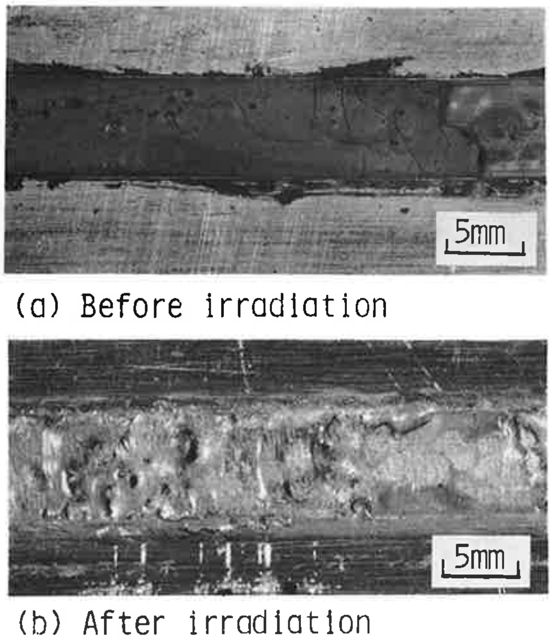

Fig. 2 Appearances of specimen surface before and after laser irradiation

The most part of the alloyed layer consisted of the microstructure as shown in (a) and (b) , higher magnification in (a) . The comparably large, square-like compounds with mean diameter of 30 μm were dispersed densely in the molten aluminum matrix. The mean hardness of these parts reached to 550-900 Hv (load, 4.9N) , much higher than that of the base aluminum, Hv30, and equal to that of the hardened layer of ferro-materials by the conventional surface hardening processes as mentioned above as same as the layer thickness. The hardness of the compound itself showed very high value, Hv2900-3450 (mean value, Hv3150 in load 0.98N) .

The alloyed layer near the edge of the groove showed the structure as (c) and (d) , higher magnification of (c) . Very fine compounds in several μm in diameter was dispersed and not so dense in comparison with (a) . Therefore the hardness of this part was Hv190-290 (load, 4.9N), not so hard as (a) , but also much harder than the base aluminum. This is due to the increase in the ratio of the amount of the molten aluminum to the mixed boron powder in it.

Figure 4 shows the X-ray diffraction pattern from alloyed layer surface by Cukα radiation (40kV, 20mA) . This result shows the compound formed in the alloyed layer is α-AlB_{12}, and AlB_2 was not detected by X-ray dif-

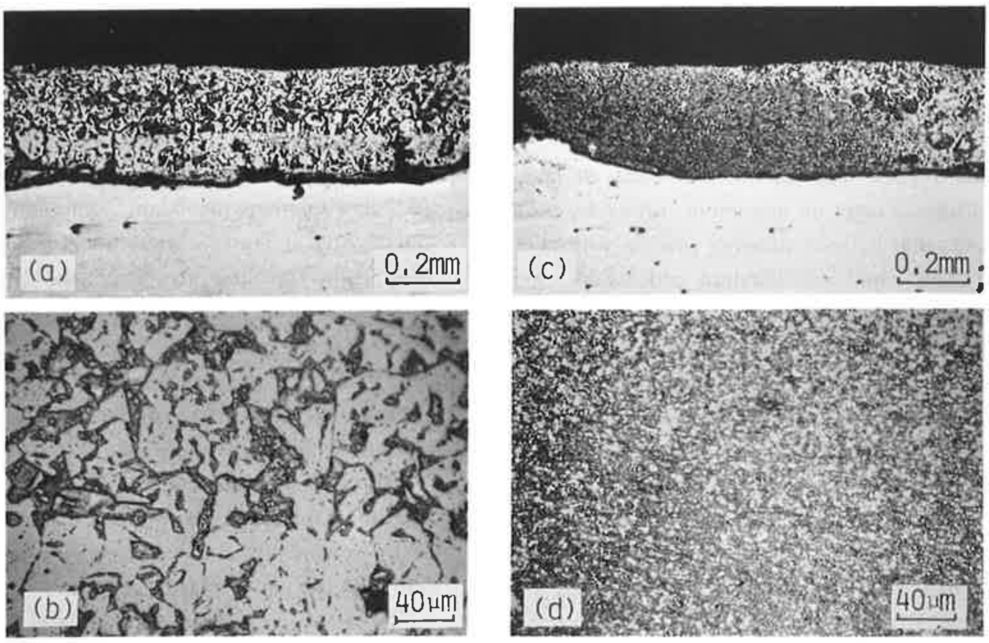

Fig. 3 Microstructures of the crosssection of the boron-alloyed layer: (a) and (b) , center of the groove; (c) and (d) , near the edge of the groove

fraction. As the Al-B binary phase diagram[4)], stable borides at room temperature are α-AlB_{12} and AlB_2 .α-AlB_{12} is formed in higher temperature than 975°C as a primary phase in the molten aluminum and AlB_2 is formed below this temperture. By a more detail observation a plate-like compound, which is considerd to be AlB_2, was occasionally observed in the alloyed layer.

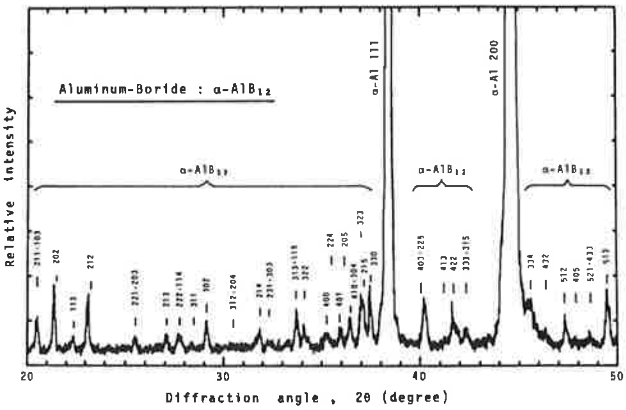

Fig. 4 X-ray diffraction pattern from the boron-alloyed layer surface

As concluding remarks, it is made clear by this report that the laser alloying process with boron powder can open the new technology for surface hardening of aluminum materials with mm order in hardened layer thickness and 500Hv and more in hardness.

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