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Fe–Al composite layers on aluminum alloy formed by laser surface alloying with iron powder

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Abstract

Formation of Fe–Al composite thick layers by using laser surface alloying process with mixture of Al and Fe powders has been investigated to improve the surface hardness and the wear resistance of A5052 commercial Al–Mg alloy substrate. A continuous wave CO_2 laser beam with the power of 2200 W was irradiated to the preplaced mixture powder on the substrate at various defocused distance of laser beam (30–150 mm up on the substrate) at the constant traveling speed (100 mm/min) in the argon gas shielding. The thickness of the laser alloyed layer varied from 0.5 to 7.0 mm. The microstructure of the laser alloyed layer changed with increasing Fe content from hypo-eutectic structure to hyper-eutectic structure with needle-like $FeAl_3$, fine needle-like $FeAl_3$ and finally lump-like Fe_2Al_5 compounds, and their hardnesses were HV100, HV100-300, HV300-500 and HV600-1000, respectively. The alloyed layers with the fine needle-like $FeAl_3$ and Fe_2Al_5 compound structures showed the high hardness, HV300 and HV800, respectively, even at elevated temperatures up to 673 K. The wear resistance of the laser alloyed layer increased with increasing the hardness.

Keywords: Laser beam; Aluminum alloy; Hardness; Wear resistance; Intermetallic compound

1. Introduction

A laser surface alloying process has been used to improve the hardness, wear and corrosion resistances by modifying the alloy composition and microstructure of the material surface [1–5]. The process has a unique characteristic of forming a thick alloyed layer in the order of millimeter in a short time with a small heat affecting to the substrate by using a high energy density heat source [6].

Aluminum alloys are used today for some structural parts in automobiles, railway cars, aircraft, etc., because of their excellent properties, such as low density, high specific strength and good formability. However, their hardness, wear resistance and mechanical properties are poor in comparison to steel. Therefore, it is necessary to produce a thick hardened layer in the order of millimeters to improve the wear resistance for those industries [6]. The authors have carried out the formation of thick hardened layers on the aluminum alloy plate using Cu powder, Cu coated TiC and Al coated Ni composite powders by the laser surface alloying process [7–9]. The hardness of these alloyed layers reached HV200 to 350 without cracks. Gjϕnnes et al. [10] have investigated the characteristics of the microstructure and the hardness of Fe alloyed layer on aluminum alloy. The wear resistance of this layer, however, was not evaluated yet. The Fe–Al intermetallic compounds are expected as new material for high temperature applications due to excellent oxidation resistance, high hardness exceeding HV700 [11] and relatively low cost.

Therefore, the aim of the present work was to produce thick Fe–Al intermetallic compound layers to improve the wear and the heat resistance of the surface of aluminum alloy by the laser alloying process with a mixture of Al and Fe powders.

2. Materials used and experimental methods

2.1. Materials used

The substrate used was 40 inch width × 100 inch length × 8 inch thickness (mm) of A5052 commercial

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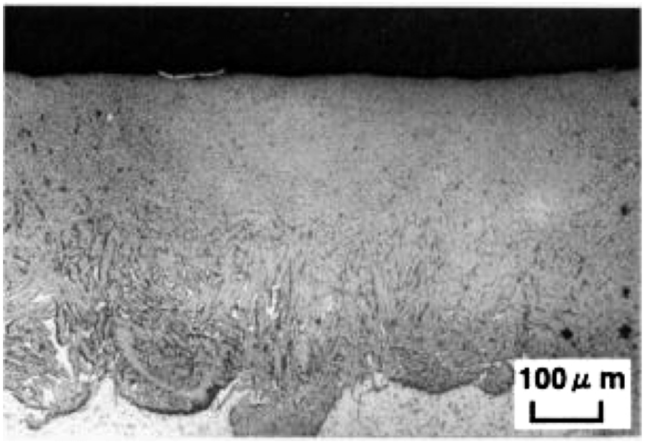

Fig. 1. Typical microstructure of laser alloyed layer with 50 mass%Fe powder.

Al–Mg alloy plate. A shallow groove with 5 inch width×100 inch length×1 inch depth (mm) was machined on the center of the substrate. As alloying material a mixture of Al power (99.9 mass%, diameter <177 μm) and Fe powder (99.9 mass%, diameter < 149 μm) was used at mixture ratios of 20, 50, 70 and 100 mass% of Fe powder.

2.2. Laser alloying process

Alloying powders were preplaced in the groove on the substrate by using acrylic binder and dried on a hot plate. The amount of precoated powder was 250 mg/cm^2. A multi-mode continuous wave CO_2 laser beam with maximum power of 2500 W was used for laser surface alloying. The specimen was set on the copper plate cooled with water in a gas shielding box. The defocused laser beam was irradiated on the specimen oscillating perpendicular to the traveling direction with an oscillating frequency of 10 Hz and amplitude of 5 mm at laser spot size of 2.5 mm. The defocused distance (Ddf) between focal point and the specimen surface was varied from +30 to +150 mm upward the specimen surface. Namely, the spot size of laser beam at the surface of specimen was varied from 2.5 to 9.9 mm. The laser beam power was set constant to 2200 W. Alloying powders were melted by the laser beam. Argon gas was used to shield the melted area with flow rates of 15 l/min in the laser nozzle and 20 l/min in the shielding box. The traveling speed of the specimen was 100 mm/min. The microstructure of the laser alloyed specimen was examined and analyzed using optical microscopy, scanning electron microscopy (SEM), energy dispersion X-ray analysis (EDX), electron probe micro analyzer (EPMA) and X-ray diffraction (XRD). The hardness of the laser alloyed layer was measured at room temperature and elevated temperatures up to 673 K using Vickers hardness tester. Wear resistance of the laser alloyed layer was evaluated by the Ogashi type abrasive wear test with a rotating counter roller made of SUJ2 (HV650) at a rotating speed of 4.36 m/s, load of 20.6 N and sliding distance of 100 m.

3. Results and discussion

3.1. Structure

The alloyed layer was formed with Fe mixture ratio less than 70 mass%. A good layer with smooth surface was obtained at Ddf of +50 to +80 mm. The thickness of this alloyed layer was approximately 1–4 mm, and the thickness reached approximately 7 mm in maximum at Ddf of +100 mm with 20 and 50 mass%Fe powders. Fig. 1 shows the good microstructure with fine needle-like compounds near the surface of the laser alloyed layer at 50 mass%Fe. Fig. 2 shows the typical microstructures of the laser alloyed layer classified into four types: a hypo-eutectic structure (a) and three hyper-eutectic structures (b, c, d). The needle-like (b), the fine needle-like (c) and the lump-like (d) intermetallic compounds were formed in each structure. The needle-like and the lump-like intermetallic compounds were identified as $FeAl_3$ and Fe_2Al_5 by EDX and XRD, respectively. Hypo-eutectic structure (α-Al+ $FeAl_3$) and needle-like $FeAl_3$ were easily formed with 20 mass%Fe powder and Ddf of +80 mm. The fine needle-like $FeAl_3$ compound formed at Ddf of +50 to +80 mm with 50 and 70 mass%Fe powders. These conditions corresponded to the optimum condition to get a smooth surface layer. The lump-like Fe_2Al_5 compound formed at less than Ddf of +50 mm with 50 and 70 mass%Fe

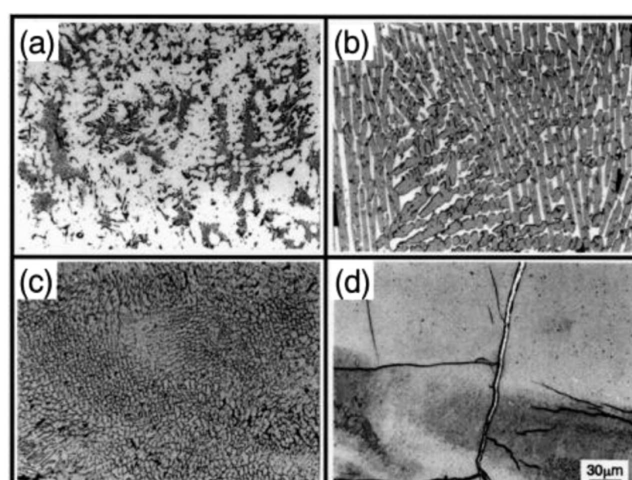

Fig. 2. Classification of microstructures of laser alloyed layer. (a) Hypo-eutectic structure; (b) Needle-like $FeAl_3$ intermetallic compound; (c) Fine needle-like $FeAl_3$ intermetallic compound; (d) Lump-like Fe_2Al_5 intermetallic compound.

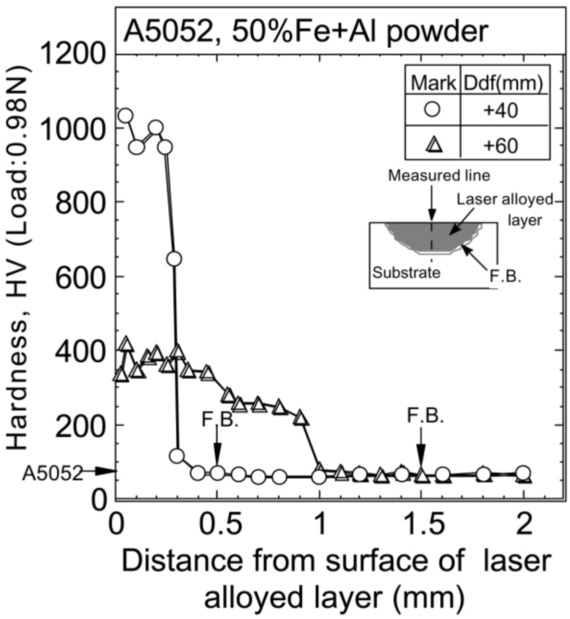

Fig. 3. Hardness profiles of laser alloyed layer at Ddf of +40 and +60 mm with 50 mass%Fe powder.

powders. However, cracking occurred in the Fe_2Al_5 compound. Therefore, a crack free alloyed layer can be obtained with the hypo-eutectic structure and $FeAl_3$ compound hyper-eutectic structure.

3.2. Hardness

Fig. 3 shows the hardness distribution in the cross-section of the alloyed layer at Ddf of +40 and +60 mm with 50 mass%Fe powder. At Ddf of +40 mm, the hardness of the alloyed layer with the lump-like Fe_2Al_5 compound was approximately HV1000. On the other hand, at Ddf of +60 mm, the hardness was HV400 at the top side with the fine needle-like $FeAl_3$ compound and HV200 to 280 at the bottom side with the needle-like $FeAl_3$ compound. The mean hardness of the alloyed layer decreased with increasing the Ddf due to the dilution of the substrate and with decreasing the mixture ratio of Fe powder. This is caused by the decrease of Fe content in the alloyed layer. Namely, increasing the Ddf increases the dilution of the substrate due to the increase in the laser heated area and the effect of thermit reaction. Fig. 4 shows the relation between Fe content measured by EPMA and the hardness of the alloyed layer. The hardness increased with increasing Fe content and reached approximately HV800 to 1000 at more than 45 mass%Fe. However, cracking occurred in the alloyed layer with higher hardness than HV600, because the brittle lump-like Fe_2Al_5 compound was produced in these layers. Fig. 5 shows the characteristic of elevated temperature hardness for each typical structure of the alloyed layer. The hardness of the substrate, the hypo-eutectic structure and the needle-like $FeAl_3$ compound structure decreased with increasing test temperature at more than 473 K and fell to almost the same value at 673 K. The hardness of the fine needle-like $FeAl_3$ compound structure also decreased with increasing temperature in similar manner like the needle-like $FeAl_3$ compound, but the hardness at 673 K was still HV300. Moreover, the hardness of the lump-like Fe_2Al_5 compound structure had an almost constant value, HV800, irrespective of test temperature. Therefore, the fine needle-like $FeAl_3$ compound structure has a good elevated temperature performance.

3.3. Wear resistance

Fig. 6 shows the relation between the surface hardness of the alloyed layer and the specific wear: Ws means the wear loss in units of contact pressure, contact area and sliding distance. The value of Ws of laser alloyed layers decreased rapidly to the half of the substrate value even with small increase in the surface hardness. At more than HV100, in the structure with the intermetallic compounds, the value of Ws decreased monotonically with increasing the surface hardness of the alloyed layer. Therefore, the wear resistance of the alloyed layer improved with increasing the hardness due to the formation of the fine Fe rich intermetallic compounds. This tendency is the same as those of another laser alloyed layers using Cu and Ni-Al powders in our previous studies [7,8].

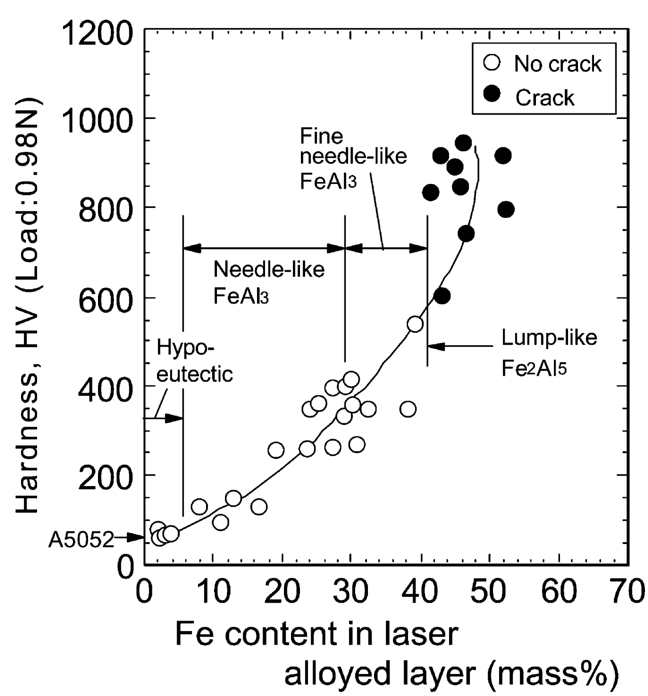

Fig. 4. Relation between Fe content and hardness of laser alloyed layer.

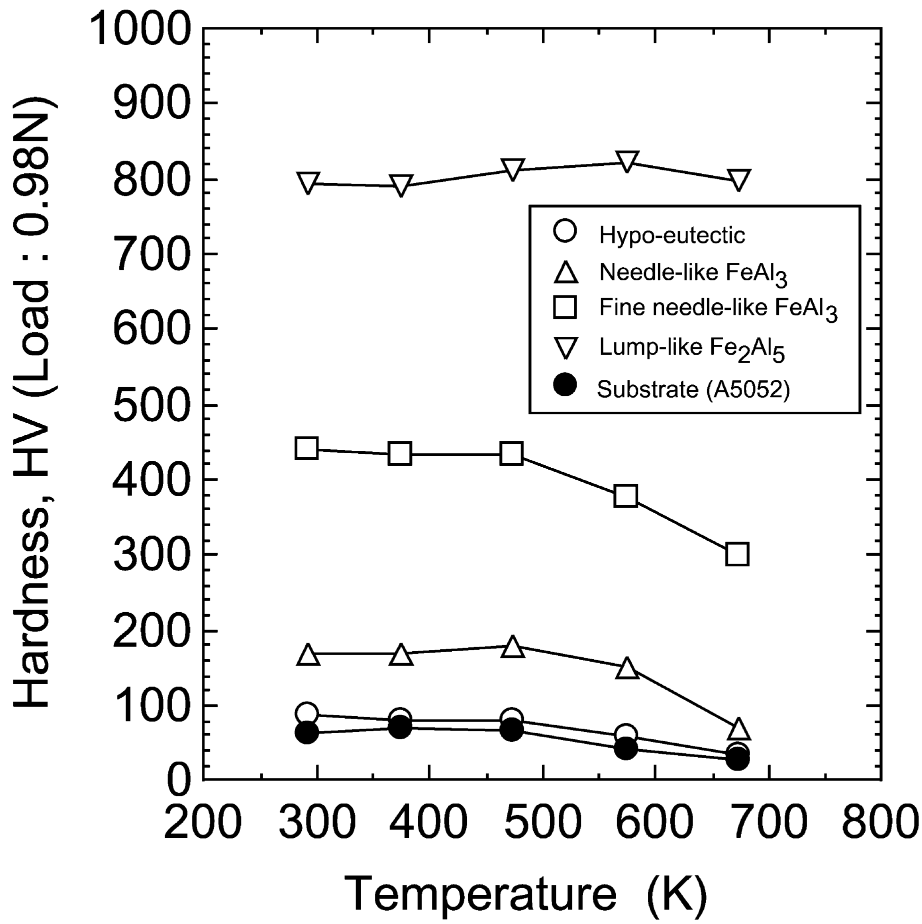

Fig. 5. Elevated temperature hardness of typical structures in laser alloyed layer.

4. Conclusion

The CO_2 laser surface alloying treatment to produce Fe–Al composite thick layer has been examined to improve the surface hardness and the wear resistance of A5052 commercial Al–Mg alloy plate. The main results are:

1. It was possible to form a thick laser alloyed layer up to approximately 7 mm in thickness with smooth surface and high hardness.
2. The microstructures of the alloyed layer were classified into the hypo-eutectic (α-Al+ $FeAl_3$) structure and hyper-eutectic structures of the needle-like $FeAl_3$, the fine needle-like $FeAl_3$ and the lump-like Fe_2Al_5 intermetallic compounds. Cracking occurred in the Fe_2Al_5 intermetallic compound structure.
3. The hardness of the alloyed layer increased with increasing Fe content and reached HV800 to 1000 in the lump-like Fe_2Al_5 intermetallic compound structure at more than 45 mass%Fe. The alloyed layer with the fine needle-like $FeAl_3$ intermetallic compound structure showed good elevated temperature hardness of HV300 even at 673 K.

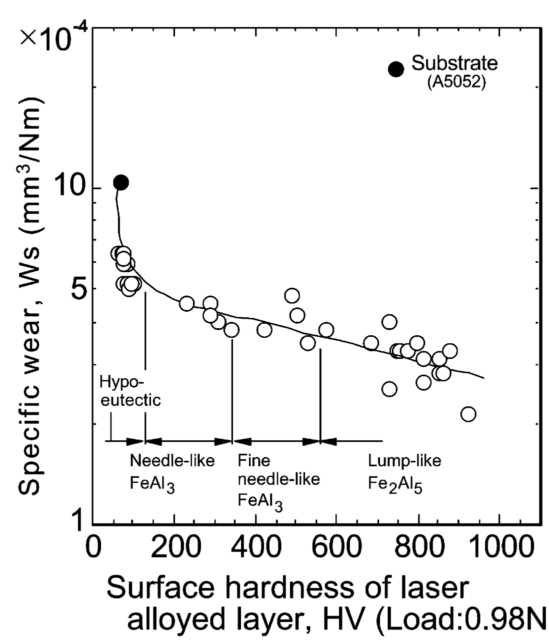

Fig. 6. Relation between surface hardness of laser alloyed layer and specific wear measured by the Ogashi type abrasive wear test.

4. The wear resistance of the alloyed layer increased with increasing the hardness and reached approximately three times that of the substrate at more than approximately HV400.

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