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Improvement in wear property of Aluminum by laser cladding of Al_3Ti/ceramics composite layers

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Abstract

For the improvement of wear property of Al, formation of Al_3Ti/TiB_2 or /TiC composite layers was tried on Al surface by laser cladding.

With increasing the volume fraction of ceramics in the clad layer, it needed higher laser power to obtain sound clad layer. But control of laser power to suppress the dilution by base metal was found less important with a increase of ceramics.

TiB_2 melted during laser cladding and then homogeneously precipitated as fine particles with an average particle size of 2μm in composite layers.

On the contrary, TiC hardly melted by laser irradiation and was dispersed in Al_3Ti matrix.

By laser cladding of Al_3Ti/ceramics composite layers on Al surface, wear property was remarkably improved especially on the high speed sliding conditions. Wear property was more improved with increasing the volume fraction of ceramics up to 30vol%. The particle size as well as volume fraction of dispersoid ceramics has an effect on wear property.

Introduction

Aluminum and its alloys are light materials and now going to be used in a wider field. But their low wear resistance prevents wider prevailing. To improve the wear property, application of surface modification has been examined. As a surface modification technique for Al alloys, alumite treatment[1] or spraying[2] is well known. But the surface modified layers have not been satisfactory in thickness or adherence to base metal. The authors have successfully formed intermetallic compound Al_3Ti layer on Al surface by laser cladding[3][4]. By the presence of hard intermetallic compound on Al surface, wear property was remarkably improved especially on the sliding condition at high speed. Moreover, Al_3Ti-ceramics(TiB_2, TiC) composite layer was formed by laser cladding to give higher wear property[5].

In this work, the composite layer containing various volume fraction of ceramics was formed. By changing the volume fraction of ceramics, changes in the laser irradiating condition to obtain sound surface layer or the wear property was examined.

Experimental procedure

Figure 1 shows the schematic view of laser cladding performed in this work. A 99.9% purity

Al plate with a thickness of 6mm was used as a base metal. The surface of Al was blasting treated to increase the laser beam absorption ratio. The powders used for laser cladding were pure Al, Ti and ceramics (TiB_2, TiC) with average particle sizes of 35, 45, 45 to 150 and 20 to 45μm, respectively. These powders were mixed to the desired compositions and adhered on the base metal with a thickness of 400μm by ethyl silicate binder(colcoat HAS-10).

Multi mode continuous CO_2 laser beam (Mitsubishi MEL 15S2, focus distance 137mm, maximum laser power 2.5kW) was irradiated on the sample. Laser beam was defocused for 10mm to obtain wide laser clad layer. In case of laser cladding on Al surface, voids are likely to be included in clad layer, so beam travelling was fixed to relatively low speed, 1.67mm/s so as to gain longer solidification time. To avoid oxidation of the samples or generation of plasma, Helium assist gas was flown in the parallel direction of laser beam at a flow rate of $1.7 \times 10^{-4} m^3/s$. To form wider clad layer, multi pass laser irradiation was performed without changing the laser condition. The overlapped distance was 1.5mm, which is about a half of laser clad layer.

The microstructure of laser clad layer was observed by scanning electron microscope(SEM). The synthesized phases during cladding were identified by energy dispersive X-ray(EDX), and X-ray diffraction analysis using Co Kα radiation.

The wear property was examined by Ohgoshi abrasion test using SUJ2 abraser. For abrasion test, load and sliding distance were fixed to 10N and 100m, respectively. Sliding speed was 2.37m/s and 4.36m/s. For the investigation of wear mechanism, wear surfaces of the clad layers were observed by SEM.

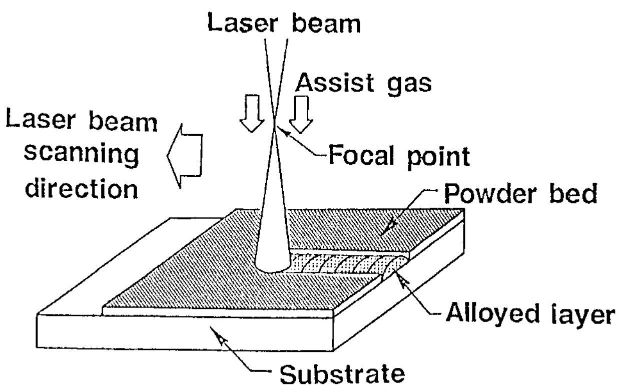

Figure 1. Schematic view of laser cladding

Results and discussion

Formation of laser clad layer

Table 1 shows the formability of laser clad layer when each type of powder mixtures was used as cladding materials. When mixture of only Al and Ti powders was used as cladding material, sound surface layer was able to be obtained in wide laser conditions. But by adding ceramics powder,it needed higher laser power to obtain clad layer.

Figure 2 shows the area variation of melted substrate as a function of laser power in case of Al_3Ti or Al_3Ti-TiC cladding. Melted area increased with increasing the laser power and was larger in case of Al_3Ti cladding than in case of Al_3Ti/TiC cladding. This is because, by adding ceramics with larger specific heat or latent heat, more of the heat input by laser was consumed to heat or melt powder bed and then smaller heat was transferred to base metal.

Table 1. Formability of laser clad layer

Powder	Laser Power (kW)			
	1.0	1.5	2.0	2.5
Al_3Ti	○	○	○	○
10vol%TiC	×	△	○	○
20vol%TiC	—	△	○	○
30vol%TiC	—	×	△	○
40vol%TiC	—	×	△	○
10vol%TiB_2	△	○	○	○
20vol%TiB_2	—	△	○	○
30vol%TiB_2	—	×	△	○
40vol%TiB_2	—	×	×	×

○: Good △: Irregular ×: No clad layer

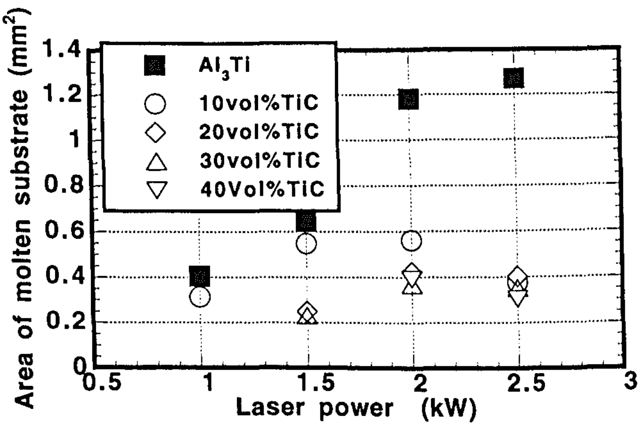

Figure 2. Area variation of molten substrate as a function of laser power

Figure 3 shows the microstructures of the obtained laser clad layers. The thickness of obtained layer is about 200μm. As the melting of base metal and the dilution by the melted base metal are suppressed by the precise control of laser power, clad layers are consisted of only Al_3Ti or Al_3Ti/ceramics free from Al.

Figure 3(c) shows the microstructure of Al_3Ti/TiB_2 clad layer. Fine particles with an average size of 2μm is homogeneously dispersed in Al_3Ti matrix. By EDX and EPMA analyses, this particles are confirmed to be TiB_2. As the starting powder was 50μm in diameter, TiB_2 was considered to melt during laser irradiation and then precipitate in Al_3Ti matrix. Melting point of TiB_2 is about 3000K to which temperature clad layer is not heated by laser irradiation but there are some reports that TiB_2 melts even around 950K in the presence of Al[6].

Figure 3(d) shows the microstructure of Al_3Ti/TiC clad layer. Particles about 30μm in diameter were dispersed in Al_3Ti matrix. These particles were confirmed to be TiC and the morphology was hardly changed in comparison with that of starting powders. In conclusion, TiC did not melt during laser cladding and remained as starting powders. Partially fine Ti_2AlC particles were observed around TiC particles near the surface.

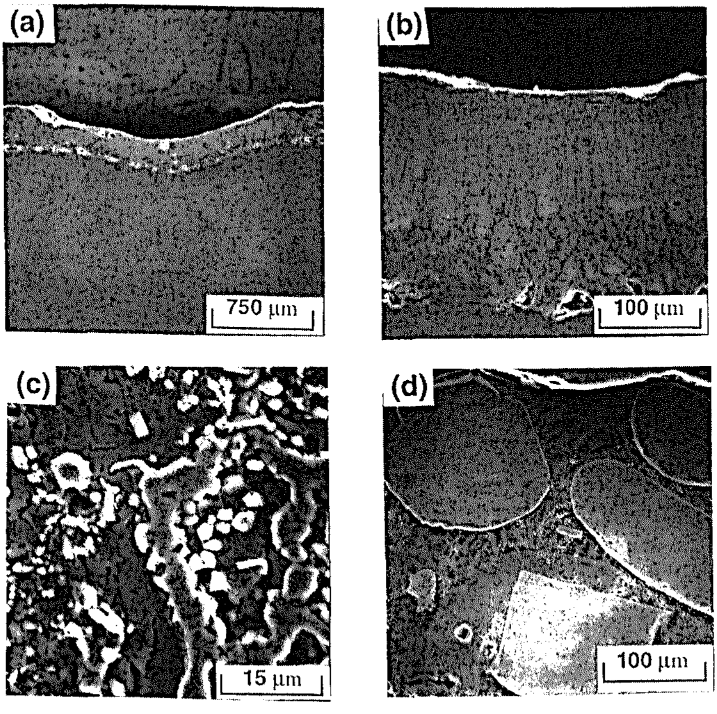

Figure 3. Microstructure of laser clad layer. (a)general view (b)$TiAl_3$ layer (c)$TiAl_3$/TiB2 layer (d)$TiAl_3/TiC$ layer.

Formation of multi pass clad layers

Figure 4 shows the general view of multi pass Al_3Ti clad layer. By irradiating laser beam 3 times, sound clad layer with a width of 5mm was obtained.

Figure 5 shows the microstructure in the overlapped area of the milti pass clad layer. As shown in Figure 5(a), in the case of laser cladding of Al_3Ti, clad layer was diluted by base metal Al and a sound multi pass clad layer in the present laser condition, which is a suitable condition in the case of single bead cladding. For this result, two reasons can be considered. First reason is the difference in laser absorption ratio between powder bed and previously alloyed layer. Namely, powder bed is consisted of pure Al and Ti, but overlapped area is previously alloyed to Al_3Ti by the first laser irradiation. Laser absorption ratio of intermetallic compounds is generally known to be much larger than that of pure metals. The second reason is the increase of heat conductivity. Previously alloyed layer is dense in comparison with the porous powder bed which is only adhered by binder. In conclusion, larger heat was input to clad layer by laser and was easily conducted to base metal resulting in the over melting of the base metal in the overlapped area. However, as shown in Figure 5(b) and (c), composite layer was soundly clad even in the overlapped area without dilution of base metal. This result can be understood from Figure 2 suggesting that less control of heat input is necessary to suppress the melting of base metal. Dispersed state of each ceramics was hardly changed in comparison with that of single bead clad layer.

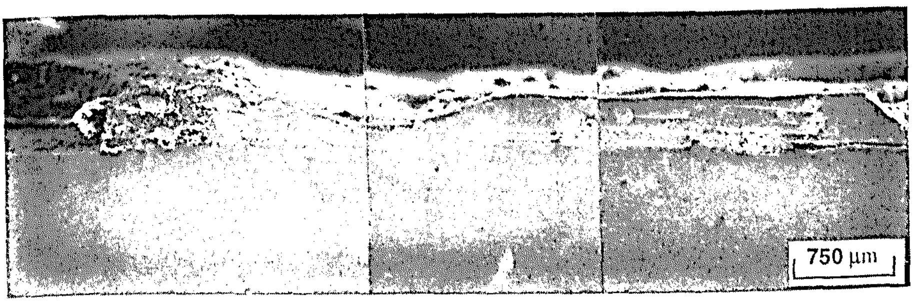

Figure 4. General view of multi pass clad layer

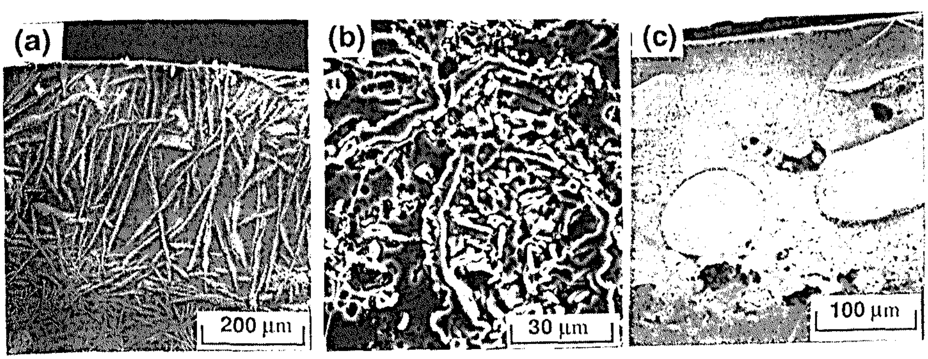

Figure 5. Microstructure of multi pass clad (a)Al_3Ti (b)Al_3Ti/TiB_2 and (c)Al_3Ti/TiC layer

Wear property of laser clad layers

Figure 6 shows the changes in wear resistance of laser clad layers as a function of volume fraction of ceramics. From this figure, it is confirmed that Al is improved in the wear property by laser cladding. Moreover, in comparison with Al_3Ti clad layer, Al_3Ti/ceramics clad layer shows superior wear property. This is due to the existence of ceramics with larger hardness and higher melting temperature. With increasing the volume fraction of ceramics up to 30vol%, clad layer revealed superior wear property. But when the volume fraction of ceramics exceeded 30at%, wear property hardly changed. In comparison with Al_3Ti/TiB_2 clad layer, Al_3Ti/TiC clad layer had a better wear property. There are no significant differences between TiC and TiB_2 in the melting temperature or the hardness, which affects the wear property, between TiC and TiB_2. To investigate this difference in wear property, the wear surface was observed.

Figure 7 shows the wear surfaces of Al_3Ti, Al_3Ti/TiC and Al_3Ti/TiB_2 clad layers. Matrix Al_3Ti of composite clad layer exhibited similar wear surface to Al_3Ti clad layer. It is noticed that there were no special wear surfaces in fine TiB_2 particle although wear trace could be obviously observed on the coarse TiC particle. In the previous paper, it was confirmed that not sound Al_3Ti clad layer diluted by Al was much inferior in wear property to sound Al_3Ti clad layer because of the existence of soft Al. As well, TiB_2 particle is fine, so the effect of matrix can not be neglected. In fact, when Al_3Ti/TiC clad layer with a TiC particle size of 2μm were prepared and wear tested, the wear property was almost the same as that of Al_3Ti/TiB_2 clad layer. It is concluded that the particle size as well as volume fraction of dispersoid has an effect on the wear property.

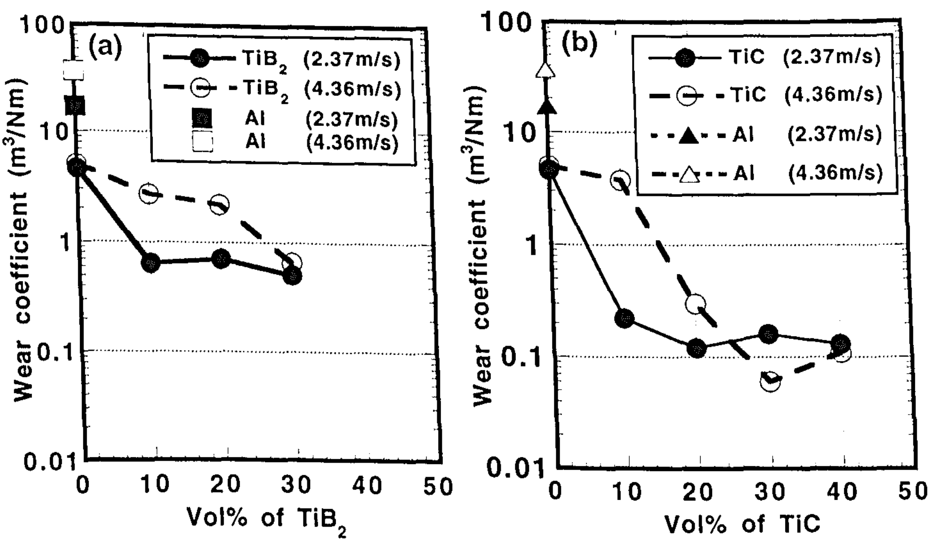

Figure 6. Wear property of (a)Al_3Ti/TiB_2 and (b)Al_3Ti/TiC clad layer.

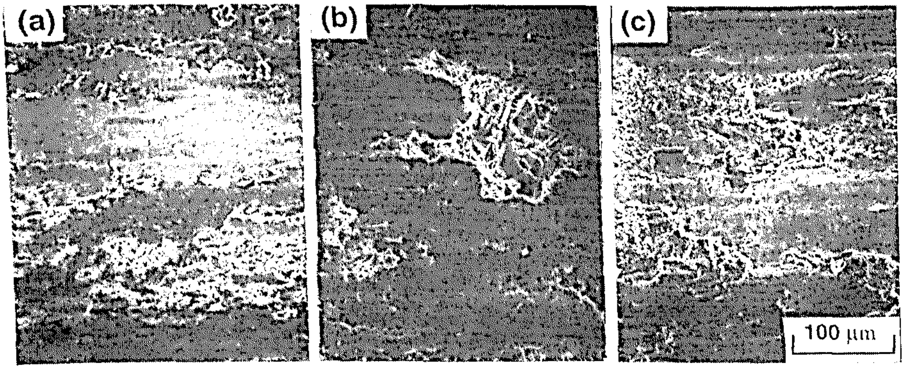

Figure 7. Wear surface of (a)Al_3Ti, (b)Al_3Ti/TiB_2 and (c)Al_3Ti/TiC clad layer

Conclusion

Al_3Ti-ceramic composite layers were elaborated on Aluminum surface by laser cladding. Obtained results are as follows.

(1) With increasing the volume fraction of ceramics in the clad layer, it needs higher heat input to obtain sound surface layer.

(2) TiB_2 melts during laser cladding and then homogeneously precipitates to fine particles with an average size of 2μm.

(3) TiC hardly melts by laser irradiation and is dispersed in Al_3Ti matrix.

(4) By the application of multi pass laser cladding, composite clad layer with a width of 5mm is obtained.

(5) By addition of ceramics to Al_3Ti for surface layer, wear property is improved in comparison with Al_3Ti clad layer as well as Al base metal.

(6) Particle size as well as volume fraction of the dispersoid ceramics has an effect on the wear property of clad layers.

Acknowledgement

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LASER SURFACING OF ALUMINUM CAST ALLOYS WITH CERAMIC PARTICLES

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Abstract

In spite of high strength and low density of aluminum alloys, their use is sometimes limited because of low surface hardness and wear resistance. In this investigation it is attempted to improve the surface properties of aluminum cast alloys by a combination of laser remelting and in-situ alloying with ceramic particles to produce a surface layer of metal-matrix composite with very good bonding to the bulk material.

AlSi 17 alloy is treated in a two step process. Firstly, a narrow cut is sawed into the surface and filled with ceramic powder. Secondly remelting takes place using a high-power CO_2-Laser. In some samples additional alloying of nickel leads to further strengthening of the matrix.

The remelting process can be subdivided into three stages: rapid heating of the material, partial melting and mixing and rapid solidification. Each stage contributes to the resulting microstructure.

In addition to the description of the microstructures the mechanical and tribological properties of the new layers are investigated by hardness measurement and different tests on grooving wear, sliding wear and cavitation erosion.

Introduction

Strength and hardness of Al-alloys with comparable microstructure is only one third of that of steels [1]. This is due to the lower energy of bonding, elastic moduli and consequently the lower value for theoretical limits for plastic shear and fracture of crystals of aluminum. It excludes Al-base alloys from applications for which a very high absolute strength or hardness is required. This is the case for example in tribological systems in which abrasion plays a role, in ball bearings or gear wheels.

Laserremelting is one possible way to improve surface properties of aluminum alloys. Thereby different types of resolidificated microstructures are possible, these may become crystallin, quasicrystallin [2] or amorphous structures [3]. Experiments proved, that all these structures can occur after laserremelting of different aluminum-alloys.

The current investigation is dealing with laserfusion of hard ceramic particles into surface layers of aluminum cast alloys with the aim to improve surface properties (i.e. hardness,