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SURFACE TREATMENT OF ALIMINUM ALLOY WITH LASER IRRADITION TO INCREASE WEAR RESISITANCE

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Abstract. Laser irradiating process with Nd-YAG laser is investigated in order to improve the adhesion and wear resistance of low pressure plasma sprayed layer on the surface of aluminum extruded shape using the atomized powder of Al-50mass%Fe, Al-15mass%Fe-17mass%Si and Al-50mass%Si. The effect of pulse energy of laser beam on the microstructure, micro hardness and wearing rate of these laser irradiated layers are evaluated. Laser irradiated layers have appeared more smooth surface and better adhesion than as sprayed layer. Depth profile of micro hardness where laser irradiated is respectively kept constant. In the microstructure of laser irradiated layer of Al-50mass %Fe, fine needle-like Al_3Fe and massive Al_2Fe are dispersed. Micro hardness increases with decrease of the pulse energy of laser beam However, the wearing rate of laser irradiated layer increases due to the initiation of cracking. In the microstructure of laser irradiated layer of Al-15mass%Fe-17mass%Si, ultra fine needle-like and massive (Al, Fe, Si) ternary crystals are aggregated. In the microstructure of laser irradiated layer of Al-50mass%Si, ultra fine hyper-eutectic structure is observed. Micro hardness of these layers are HV250-350, HV150-200, respectively and wearing rate of these layer are 1/7 or less than anodized surface.

1. Introduction

Aluminum extrusion shape has widely been applied for sliding parts of industrial equipment in these decades. These parts are anodized to protect wearing. However, this anodized layer is very thin such as a few ten μm, so wearing performance of the layer is insufficient under heavy sliding load. By the way, many trials for improving wear resistance of light metals have been practiced in these decades. Thin metal which is different from base metal can be joined by shot lining and improved surface characteristics of aluminum [1, 2]. N_2 ion implanting improves surface hardness and wear resistance of aluminum[3,4] and plasma transferred arc surfacing(PTA) process is applied to improve the surface hardness of aluminum alloy with several ceramic powder such as Al_2O_3.[5,6]. These processes have many advantages and disadvantages such as process cost and heat affect under considering industrial use. On the other hand, high power pulse energy irradiation can modify metal surface [7, 8, 9] and its process can be expected to increase the hardened layer with spray coating and then to improve the wear resistance of aluminum alloys.

This paper is described on the wear resistance of laser irradiated surface of A6063 alloy after low pressure plasma spraying using hard particles compared with anodized surface and cast Al-Si hard alloy.

2. Experimental Procedure

2.1 Materials

A6063 (Al-Mg-Si alloy) is used for base material under T5 heat treatment and its dimension is 50mmx60mmx6mmt. 3 types of atomized particles such as AL-50mass%Fe (herein after called AL-50Fe, its average diameter is 81 μm), Al-15mass%Fe-17mass%Si (same as Al-15Fe-17Si, 78μm) and Al-50mass%Si (same as Al-50Si, 79μm) are used for spray coating materials before laser irradiation.

2.2 Plasma Spraying

Low pressure plasma spraying is applied before Nd-YAG laser irradiation. 0.027Pa Ar gas is used for spraying and powder feed rate is 22.6 to 32.9g/min. Carrier gas is also used Ar (feed rate 48little/min.). Plasma output power is 33kw (600A, 55V) and distance from nozzle tip to base metal is 250mm. 100 to 200 μm alloyed layer is formed after laser irradiation.

2.3 Laser irradiation

Fig.1 shows schematic illustration of laser alloying process. Nd-YAG laser is used and its pulse energy is varied from 10 to 30J. Sprayed aluminum alloy is placed on a firebrick in the chamber which is filled of 0.29MPa Ar atmosphere to protect the alloyed layer from oxidation. Laser beam is defocused on the base metal and its diameter is 2mmφ on the base metal. Beam frequency is 7Hz and pulse width and traveling speed are 1.5ms and 100mm/min. respectively. Rapping ratio is 0.88 for traveling direction and is 0.5 for transverse to its direction. The area of laser irradiated is 1500mm^2(30mmx50mm).

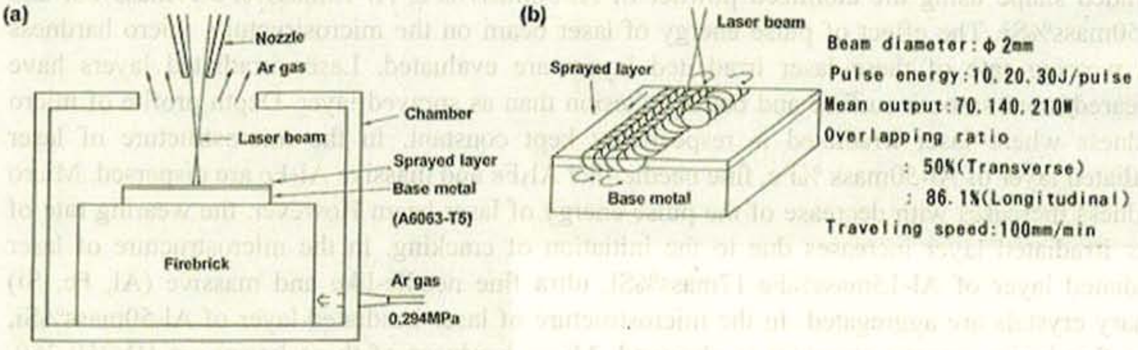

Fig. 1 Schematic illustration of laser alloying process; (a) Apparatus, (b) Procedure of laser alloying.

2.4 Estimation for modified surface layer

Laser irradiation forms alloyed layer on the surface of aluminum base metal due to interaction between sprayed surface and aluminum. Cross section of this layer is observed by optical micrograph and Fe and Si in this alloyed layer are quantitatively analyzed by EPMA and XPS. X-ray diffraction is also applied to confirm the morphologies of intermetalic compound in this layer using Cu-Kα. Depth profile of hardness in this layer is tested with micro Vickers hardness tester(Load:0.245N) and wearing rate is estimated with Ring on Disk test equipment using SKD61(Hv 464) ring. Applied load is 98N and testing rate is 0.5m/s at dry condition.

3. Results and Discussion

3.1 Cross section view of sprayed layer

Fig. 2 Cross section view of sprayed layers.

Fig.2 shows cross section view after spraying 3 types of powders onto aluminum. It is observed many blow holes and cracks in each sprayed surface and also insufficient adhesion between sprayed layer and base metal. Some debris is exfoliated from these sprayed layers.

3.2 Effect of pulse energy on formation of alloyed layer

Fig.3 shows surface appearance of laser irradiated layers after spraying. Each alloyed surface is getting dark with increasing laser pulse energy. This is due to evaporation of Mg in the aluminum base metal and easily wiped out by cloth. These surfaces become tarnished after wiping and surface roughness Ra is less than 4μm. Tarnished surface without Mg is observed at E=10J/p for Al-50Si though it cannot be alloyed at E-10J/p for Al-50Fe. This is why in case of materials including Fe, laser beam energy is absorbed in the plasma plume which induced above the material immediately after laser irradiation.

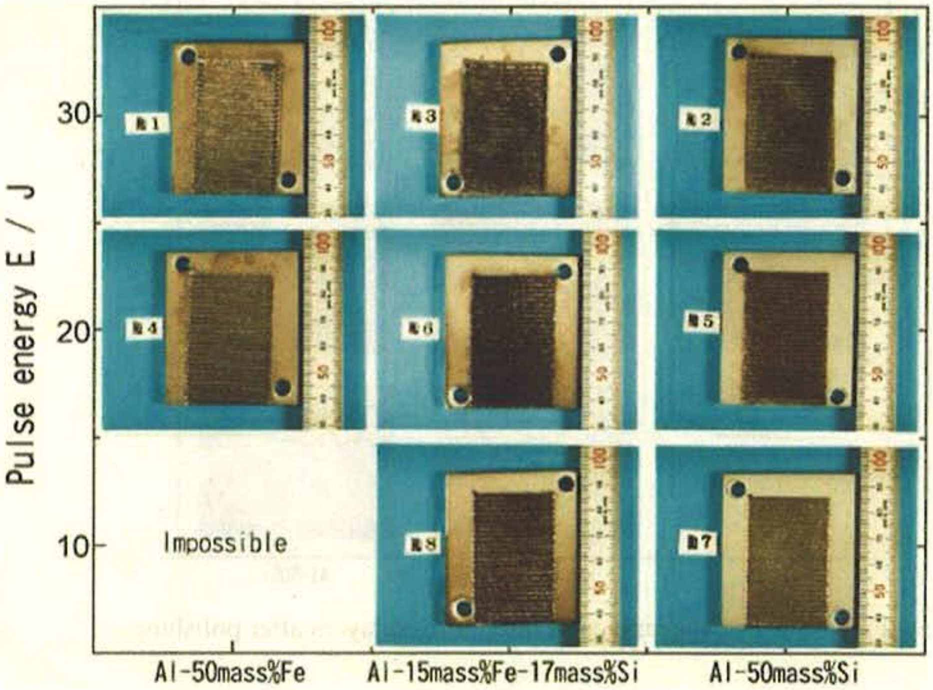

Fig. 3 Surface appearance of alloyed layer.

Fig.4 shows etched surface after polished with emery paper. Rippled trace which shows laser pulse is observed. This trace means repetition of melt and solidification at each pulse. Alloyed surface including Fe shows crack. In case of Al-50Fe, wide width of crack is widely spread at E=30J/p and it is aggregated at E=20J/p. Width of crack decreases with decreasing pulse energy. In case of Al-15Fe-17Si, quantity of crack is less than in comparison with the case of Al-50Fe and width of crack is independent of pulse energy. In case of Al-50Si, no crack is observed on the alloyed surface. Fig.5 shows microstructures at cross section of alloyed layer. Each photograph shows improvement of adhesion of sprayed layer to base metal.

In case of Al-50Fe, dilution by aluminum appears white region and fine Al-Fe intermetalic compound disperse another region where appears dark region under white region at E=30J/p. These intermetalic compounds is aggregated at E=20J/p and this region appears more dark than at E=30J/p. In case of Al-15Fe-17Si, it is appeared small difference of microstructure among 3 pulse energies. All of crack is arrested at the interface between alloyed layer and base metal. In case of Al-50Si, No crack is observed at cross section of alloyed layer and Si is diffused to grain boundaries of base metal. Fig.6 shows X-ray diffraction pattern of each alloyed layer. In case of AL-50Fe, slightly broad peak such as $Al_{76}Fe_{24}$, $Al_{13}Fe_4$ and Al_2Fe is observed in as sprayed layer. This is why amorphous or meta-stable intermetalic compound is formed by spraying. Sharp peak is appeared after laser irradiation and Fe rich AlFe peak is appeared with decreasing pulse energy. These compounds are also confirmed by quantitative analysis by EPMA and XPS. In case of Al-15Fe-17Si, (Al, Fe, Si) ternary compound is considered by diffraction pattern at as sprayed condition. After laser irradiation, dilution from aluminum base metal contributes to formation of sharp peak of aluminum and on the contrary, peak of ternary compound is decreased or disappeared. In case of Al-50Si, sharp peak of Si and Al is appeared at as sprayed condition and the former is decreased after laser irradiation due to dilution by aluminum. However, dilution is decreasing with decreasing laser pulse energy and at E=10J/p, alloyed layer includes 33.8mass%Si. It is also appeared that peak of Al (111) decreasing and peak of Al (200) increasing with decreasing pulse energy.

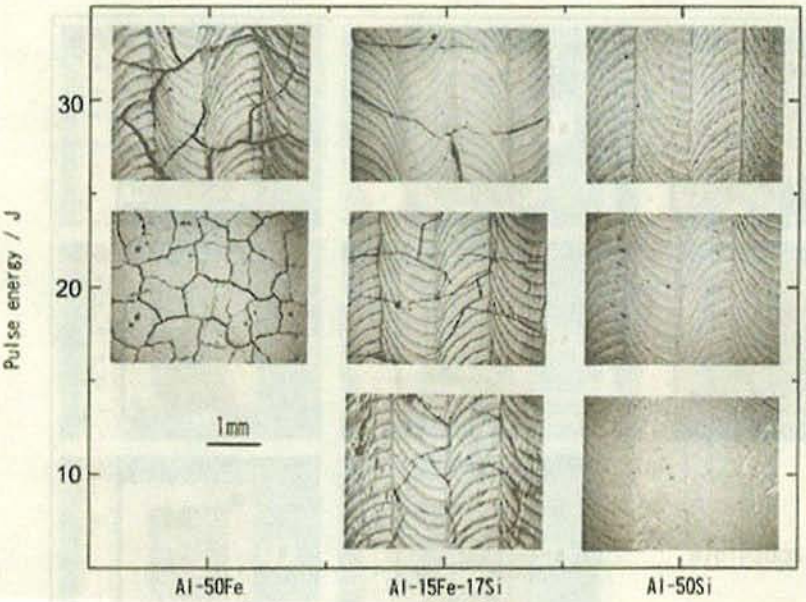

Fig. 4 Surface appearance of laser alloyed layers after polishing.

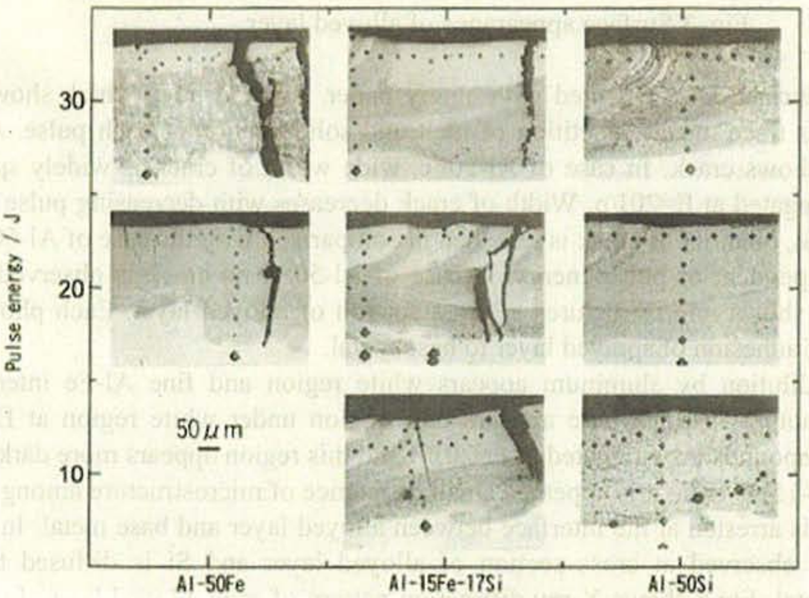

Fig. 5 Optical macrograph of cross section of laser alloyed layers.

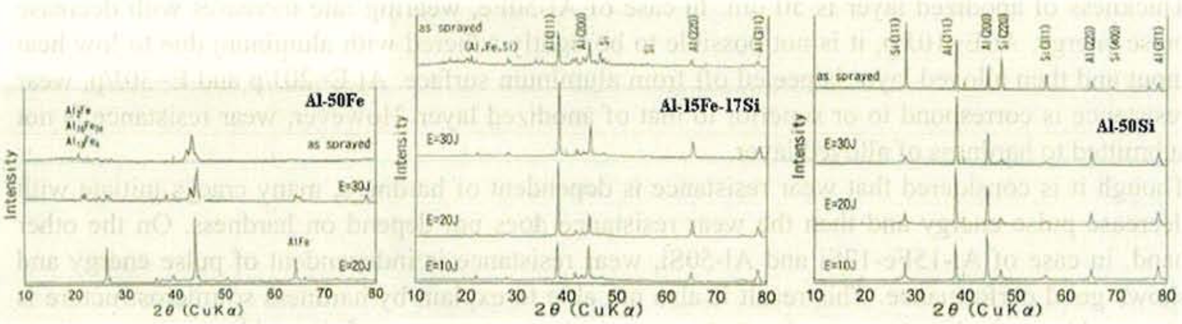

Fig. 6 X-ray diffraction pattern from the surface of laser alloyed layers.

3.3 Depth profile of hardness and wear resistance of alloyed layer

Fig.7 shows depth profile of Vickers hardness in alloyed layer. In case of Al-50Fe, though thickness of sprayed layer is 100μm and its hardness is Hv800, laser irradiation makes alloyed layer widen and reduce the hardness due to dilution by aluminum. Thickness of alloyed layer increased to 250μm and hardness of them are Hv500 at E=20J/p and Hv300 to 400 at E=30J/p. In case of Al-15Fe-17Si, though thickness of sprayed layer is 150μm and its hardness is Hv500, the former increased to 200 to 250μm and the latter decreased to Hv250 to Hv350 due to dilution by aluminum. In this case, laser pulse energy less affects on the hardness profile in the alloyed layer than that in case of E=30J/p. In case of AL-50Si, similar effect of laser irradiation is observed. Among these conditions, thickness of laser irradiated alloyed layer shows 200 to 250μm and hardness of them is decreased with decrease of Fe content and increase of Si content.

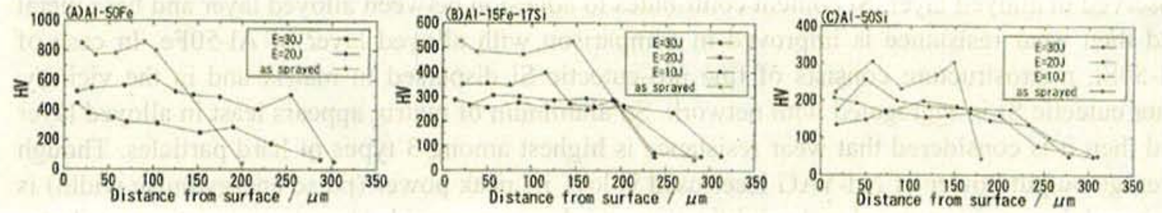

Fig. 7 Depth profile of micro hardness on cross section of laser alloyed layers

Ring on disk wear test is conducted to estimate the wear resistance of alloyed layer. Fig.8 shows its result. Surface of alloyed layer is polished with emery paper before wear testing. Anodized aluminum and Al-25Si cast aluminum alloy are also wearing tested in comparison with alloyed layer. Anodizing is conducted using 273k sulfate solution and immersed aluminum for 7200seconds in it. Current density is 1.5A/cm^2.

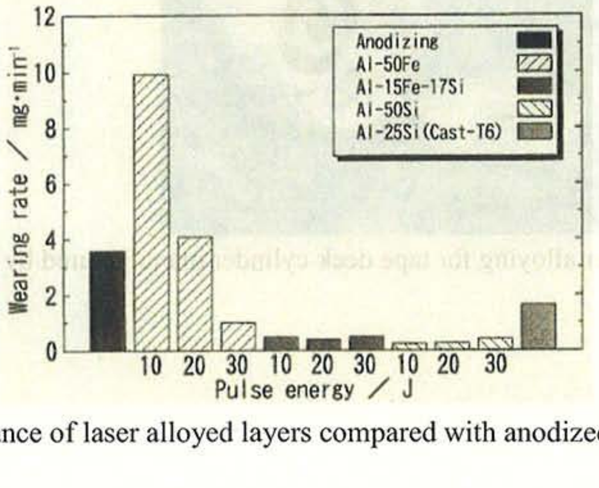

Fig. 8 Wear resistance of laser alloyed layers compared with anodized surface and cast alloy.

Thickness of anodized layer is 50 μm. In case of Al-50Fe, wearing rate increases with decrease pulse energy. At E=10J/p, it is not possible to be tightly adhered with aluminum due to low heat input and then alloyed layer is peeled off from aluminum surface. At E=20J/p and E=30J/p, wear resistance is correspond to or superior to that of anodized layer. However, wear resistance is not submitted to hardness of alloyed layer.

Though it is considered that wear resistance is dependent of hardness, many cracks initiate with decrease pulse energy and then the wear resistance does not depend on hardness. On the other hand, in case of Al-15Fe-17Si and Al-50Si, wear resistance is independent of pulse energy and shows good performance. This result is also not able to explain by hardness so microstructure is observed by optical microscope. Fig.9 shows typical microstructure of alloyed layer.

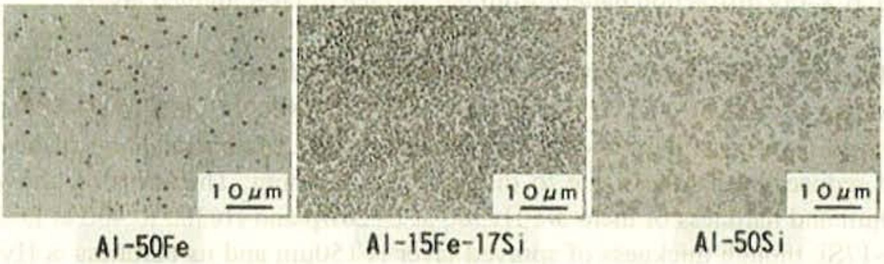

Fig. 9 Optical micrographs on cross section of laser alloyed layers.

In case of Al-50Fe, microstructure consists of aggregated needle like ALFe and hardest but wear resistance is poor because of crack existence. In case of Al-15Fe-17Si, microstructure consists of ternary massive compound and fine needle like crystalline. In this case, though crack also observed in alloyed layer, Si content contributes to adhesion between alloyed layer and base metal and then wear resistance is improved in comparison with alloyed layer of Al-50Fe. In case of Al-50Si, microstructure consists of fine pro-eutectic Si dispersed in matrix and in the vicinity, finer eutectic Si is aggregated with network. So aluminum of matrix appears least in alloyed layer and then it is considered that wear resistance is highest among 3 types of hard particles. Though average output power of Nd-YAG laser used is low, its peak power (pulse energy/pulse width) is high and then melting speed and solidification speed are very rapid. This characteristic contributes to refinement of microstructure and improvement of solidification line of Fe and Si. In addition, Nd-YAG laser contributes to low temperature rise of base material and in this work, temperature of aluminum base metal rises up to 373k. So this process is available to thin base material. Fig.10 shows application of this process to thin aluminum tape deck cylinder.

Fig. 10 Application of laser alloying for tape deck cylinder manufactured by aluminum alloy.

4. Summary

In order to improve wear resistance of aluminum alloy, atomized particles such as AL-50Fe, Al-15Fe-17Si and Al-50Si are sprayed onto A6063 alloy before Nd-YAG laser irradiation. Laser irradiation contributes to forming alloyed layer which increases wear resistance. When Al-50Si particle is sprayed to form alloyed layer, the highest wear resistance is shown in ring on disk testing. This resistance is dependent on microstructure after irradiation of pulse beam laser.

References

[1] HARADA Yasuhiro "Improvement of Surface Layer Characteristics by Shot Lining" Int. Journal. Ser A. Solid Mech. Mater Eng Vol.48 NO.4; p269-274

[2] HARADA Y, MORI K et all "Partial lining of metals with thin foils using shot peening" Metal Form 2000 p343-348

[3] MANOVA D, MAENDL S, et all "Evolution of surface morphology during ion nitriding of aluminum" Surface Coat Technology Vol. 180/181 p118-121

[4] FALKENSTEIN Z, et all "Surface modification of aluminum and chromium by ion implantation of nitrogen with a high current density ion implanter and plasma-source ion implantation" J. Mater. Res. Vol.14 No.11, p4351-4357

[5] DEUIS R L, SUBRAMANIAN C, "Aluminum composite coatings produced by plasma transferred arc surfacing technique" Material Science Technology Vol.13 NO.6 p511-522

[6] BOLDUC M, et all "Plasma Process to Harden the Surface of Aluminum and Alloys" SAE Tech Pap Ser. SAE-2003-01-2921, p5

[7] WALTER K C, "Nitrogen plasma source ion implantation of aluminum" J Vac. Sci. Technol. B Vol.12 NO.2 p945-950

[8] BILLER W, et all "Modification of steel and aluminum by pulsed energetic ion beam" Surf Coat. Technol. Vol.116/119 p537-542