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Laser Joining of Different Materials between Aluminum and Plastic Using Insert Materials

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Laser joining for different materials between A1050P aluminum alloy sheet of 1mm thickness and polypropylene plate of 2mm thickness using a newly developed insert sheet was studied. The diode laser-irradiation to the polypropylene side was carried out in air. The effects of an anodizing onto the aluminum specimens on the joining properties were examined. It was not possible to join the A1050P aluminum sheet to polypropylene plate directly under the various laser-irradiation conditions. However, the use of insert sheet held between the aluminum sheet and the polypropylene plate made it possible to join the A1050P aluminum sheet to polypropylene plate by laser-irradiation. The joining strength increased with the increase in the input energy by laser-irradiation, and the anodizing for A1050P aluminum sheet improved the joining strength. It was found that the chemical state of aluminum surface strongly affected the joining strength.

Keywords: *Laser joining, Different material, Insert material, Diode laser, Aluminum-Plastics, Elastomer*

1. Introduction

Recently, aluminum alloys are increasingly being used to the improve fuel consumption of vehicles by reducing their weight along with their excellent workability and corrosion resistance [1]. Plastics materials are also increasingly being used to the reduction in the weight and cost because of their light weight and excellent formability. So, importance of the plastic joining technology increases.

The new joining technology between plastics of the equal type by using the property in which laser beam penetrates the plastic is noticed, thus this technology has mainly been used practically in the automobile industry [2]. On the other hand, adhesive and mechanical fastening are generally used for the joining of different materials such as between the plastics and the metals. These processes, however, have the disadvantage such as generation of the volatile organic compound and high cost. We reported that laser joining for different materials between metal and plastics was possible by using a newly developed insert sheet, and then the polarity of these insert sheets affected the joining strength [3, 4].

In this study, for the purpose of reducing the weight, possibility of the laser joining for different materials between A1050P aluminum alloy plate and polypropylene sheet using a newly developed insert sheet was examined. In addition, effects of the various surface treatments on the joining ability were examined.

2. Experimental Procedure

2.1 Experimental materials

The A1050P aluminum sheet (here-after, described "A1050P") ($50\times25\times1^{t}$mm), the chemical compositions of which is shown in Table 1, and the polypropylene plate (here-after, described "PP") ($50\times25\times2^{t}$mm) were used as joining materials. Surface treatments shown in Table 2 were conducted for A1050P, and then effects of the various surface treatments on the joining strength were examined.

After the surface treatment, SEM observation and the three-dimensional surface shape measurement were conducted on each treated surface. The styrene block copolymer (SBC) thermoplastic elastomer sheet whose polarity was given by carboxyl group was used as insert materials. 1 mass% of the laser absorption pigment was added into these insert materials in order to improve the absorption of the laser beam.

2.2 Laser joining and its analysis

A diode laser with 1kW in maximum output (Laser Line Co.,Ltd, LDF600-1000) was used for this study. Laser joining was carried out according to the scheme shown in Fig.1. Experimental conditions of laser joining are shown in Table 3.

After the laser joining, cross-sectional observation at the joining area was undertaken, and joining strength was measured by the shearing test. Observation and element mapping analysis of the peeling plane were carried out by FE-EPMA in order to reveal the peeling mode.

Table 1 Chemical composition of A1050P aluminum alloy.(mass%)

Alloy	Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti	Others total	Al
A1050P	0.24	0.37	0.02	0	0	0	0	0.03	0.01	bal.

Table 2 Surface treatment.

Alkaline cleaning	Pickling	Anodizing
(Na_2CO_3($20kg/m^3$)+Na_2SiO_3($10kg/m^3$)) (Room temperature-60s)	Alkaline cleaning ↓ Pickling(1HF+$3HNO_3$) (298K-10s)	Pickling ↓ Anodizing Sulfuric acid:15v/v% Bath temperature:294±1K Current density:$130A/m^2$

Table 3 Experimental conditions of laser joining.

Wavelength	Focusing distance	Spot diameter	Defocusing distance	Exposure mode	Exposure angle	Laser power(W)	Joining speed
800nm	100mm	600 m	12mm	CW	80°	100, 150, 200	5 mm/s

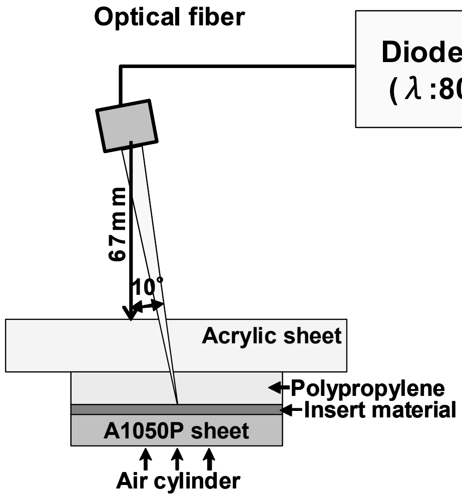

Fig.1 Schematic drawing of experimental set-up of laser joining.

3. Experimental Results and discussion

3.1 Surface states with various surface treatments

Figure 2 shows FE-SEM micrographs of the various treated surfaces formed on A1050P substrate. Surface morophologies of alkali cleaning and pickling were extremely smoothed, however, the tool mark formed by the rolling in the manufacturing, was observed. So, the effect on the surface morophplogy by thses treatments is scarcely distinguished. Anodized surface morophlogy became much smoother than those of the former.

Figure 3 shows the three-dimensional surface shape and surface roughness (Ra) of the treated surfaces measured using a non-contact scanning white light interferometer. On each specimen, it is possible to confirm the tool mark observed in Fig.2. Surface roughness (Ra) of anodic oxidation coating in the thickness of 10 m was the lowest, and Ra after the pickling is 0.302 m, so, this surface was the roughest.

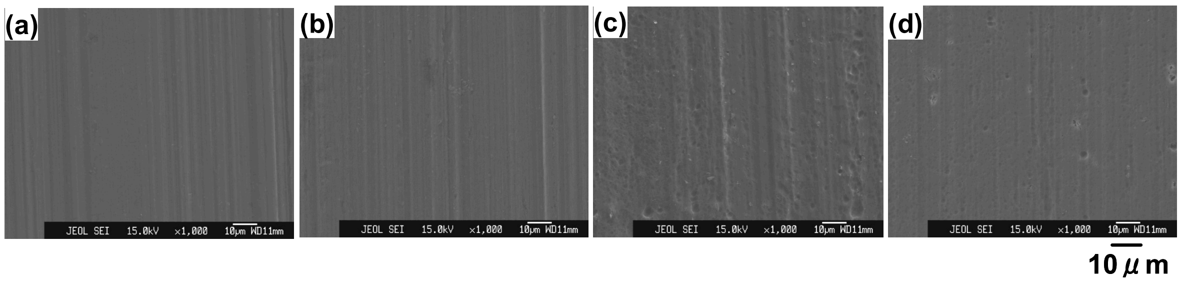

Fig.2 Secondary electron images of specimens showing various treated surfaces on A1050P aluminum plate. (a) Alkali cleaning (b) Pickling (c) Anodizing; 5 m (d) Anodizing; 10 m

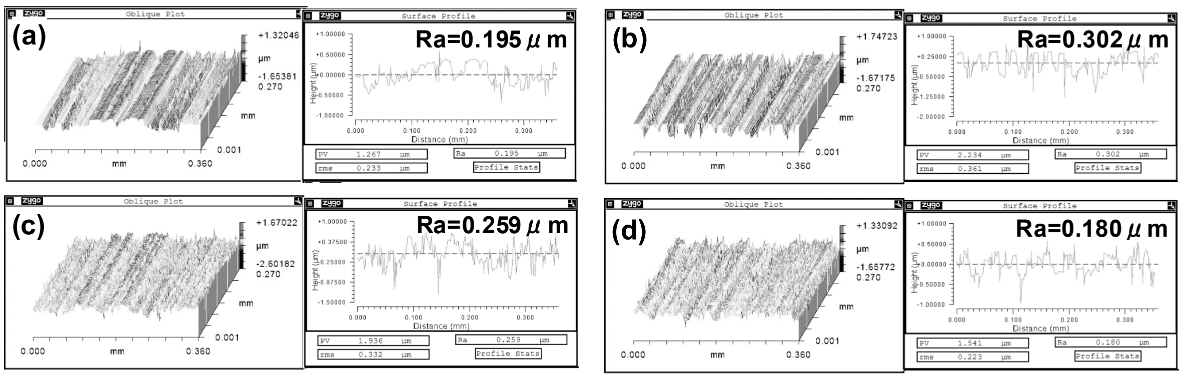

Fig.3 Surface morphology of specimens showing various treated surfaces on A1050P aluminum plate. (a) Alkali cleaning (b) Pickling (c) Anodizing; 5 m (d) Anodizing; 10 m

3.2 Effect of insert materials on joining between A1050P and PP

It was not possible to join bewteen the A1050P and PP under the laser joining conditions shown in Table 3 irrespective of whether each surface treatment was undertaken on A1050P substrate, as the insert materials was not used for the laser joining shown in Fig.1. At that time, the change in apperance at laser irraddiated area of A1050P and PP was not any observed. These results indcate that the temperatuer at laser irradiated area was under 443K whose value was melting point of a PP. Suppression of this temperature rise is attributable to excellent thermal conductivity of an aluminum.

Subsequently, as laser joining was tried under the condition of laser output of 500W, PP was melted and decomposed (Fig.4). However, it was not possible to join between the A1050P and PP under this condition in which the thermal damage generated. Then the change in apperance such as melting and discoloration on A1050P at laser irradiated area was not any observed. Thus far diffrent materials between the metal and the plasitics wihtout polarity such as a PP can not be directly joined

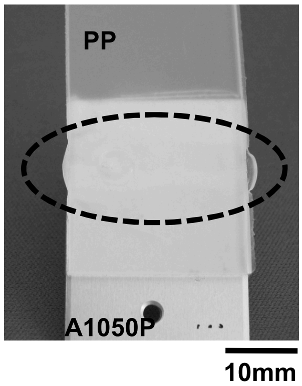

Fig.4 Appearance of laser joining area without insert material at laser output of 500W.

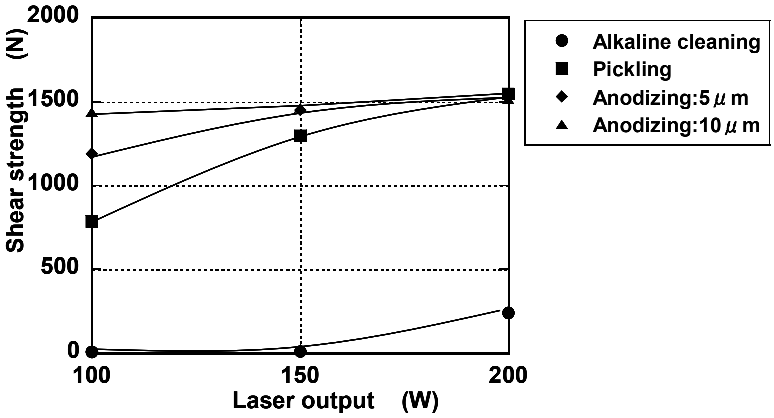

Fig.5 Laser power dependence of shear strength of joint parts using insert materials with various surface treatments.

by laser, and this agerrs with foregoing results.

In the case of the insert materials were used for this laser joining, it was possible to join between the A1050P and PP under the laser joining conditions shown in table 3.

Figure 5 shows the relationships between the laser power and shear strength of joint parts using insert materials with various surface treatments. It was found that the shear strength depended on the laser output and type of surface treatment. On the specimen with alkaline cleaning, it was impossible to join under laser output of 150W, but shear strength at laser output of 200W was 250N, and the slight adhesion cloud be obtained. As a result of observing the peeling plane with laser irradiated at 200W, all of the insert materials adhered to the PP side. Since the carbon which originated from the insert materials was not detected by the FE-EPMA analysis, the peeling had been generated in the interface of A1050P and the insert materials.

In the case of the specimen with pickling, shear strength at laser output of 100W was 780N, and then shear strength increased with the increase in the laser output. Finally, shear strength at laser output of 200W attained 1500N, and the appearance after this shearing test was shown in Fig.6. The white part in width of 10mm is the joining area. Although the diameter of the laser beam at joining interface is 3 mm, the joining area spreads up to about three times. Therefore, the adhesion with plastic deformation of the PP can be obtained. In this way, the extension of joining area for the beam diameter is an advantage of this process [5, 6].

In addition, shear strength of anodized specimen surpassed the specimen with pickling under laser output of 150W. At laser output of 200W, shear strength, as well as the pickling, was 1500N with plastic deformation of the PP.

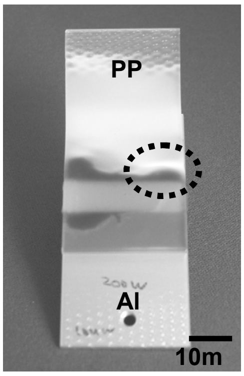

Fig.6 Appearance of laser joining specimen after the shearing test.
(Pickling treatment, Laser output; 200W)

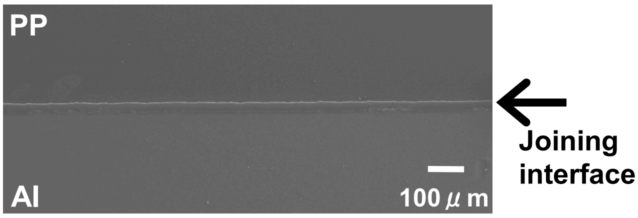

Fig.7 Cross sectional SEI of laser joining specimen. (Pickling treatment, Laser output; 200W)

In this way, it was found that joining ability changed by each surface treatment. These results suggest that the chemical state of aluminum surface is very effective to joining between the A1050P and the insert materials.

Figure 7 shows the cross sectional secondary electron image of laser joining specimen with pickling treatment at laser output of 200W using insert materials. Cross sectional observation revealed that the excellent joint were formed between A1050P and PP through the insert materials. This joint without the defects such as the void and space as well as the extension of joining area would result in excellent adhesion with plastic deformation of the PP shown in Fig.6.

3.3 Characteristics of joining at interface

The above-mentioned investigation clarified that the joining between A1050P and PP by using the insert materials consisting of the styrene block copolymer (SBC) thermoplastic elastomer was most effective. At that time, it was important to characterizie the bonding mechanism at interface on the adhesion. As a result of observing the peeling plane after the shearing test, it was found that the part of insert materials adhered to the aluminum surface. This result suggests the formation of chemical bond between the A1050P and insert materials. Figure 8 shows the secondary electron images and X-ray maps with carbon obtained by FE-EPMA analysis for the surface of A1050P after the shearing test. Carbon exists at the laser irradiated area in addition to the part in which the insert materials adhered. These results indicate that insert materials were fractured.

In this way, it was not possible to observe the adhesion of the carbon on aluminum surface by visual examination, however, EPMA analysis revealed the formation of chemical bond between the A1050P and insert insert materials. In general, as with adhesion model of the metal-resin, van der Waals bond, induced dipole interaction, and interaction of the acid-base reaction, and hydrogen bond are well known [7]. Since the change of chemical state of aluminum surface by surface treatment such as alkaline cleaning, pickling, and anodizing significantly affects the reactivity to the insert materials in this investigation, Acid-base interaction is suspected to be responsible for the adhesion model between the A1050P and insert materials. On the other hand, the results of obtaining the strong adhesion with plastic deformation of the PP suggest that hydrogen bond occurs between the carboxyl group in insert materials and the oxide film or hydroxide formed on the aluminum surface. At present, the details of this bonding mechanism between the A1050P and insert materials are not clear. Further details on the bonding mechanism will be reported in the near future.

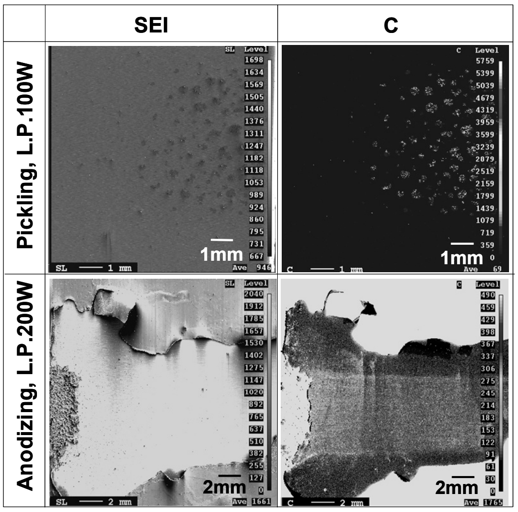

Fig.8 Secondary electron images and X-ray maps with Carbon obtained by FE-EPMA analysis for the surface of A1050P after the shearing test.

4. Summary

For the purpose of reducing the weight, this study examined the possibility of the laser joining for different materials between the A1050P aluminum alloy plate and polypropylene plate using a newly developed insert sheet. The use of insert materials held between the A1050P sheet and PP sheet made it possible to join the A1050P plate to PP sheet with plastic deformation of the PP sheet by laser-irradiation. This process would be expected as new technology in which the application of the aluminum expands. It was found that the chemical state of aluminum surface with various surface treatments such as alkali cleaning, pickling, and anodizing strongly affected the joining strength.

Acknowledgments

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