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Author(s)	Hino, Makoto; Mitooka, Yutaka; Katayama, Saiji
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Joining mechanism between aluminum and polypropylene resin using insert materials by laser irradiation[†]

HINO Makoto^{*}, MITOOKA Yutaka^{*} and KATAYAMA Saiji^{**}

KEY WORDS: (Laser joining) (Different material) (Insert material) (Diode laser) (Aluminum) (Plastics) (Elastomer)

1. Introduction

Metals and plastics have been widely used in industrial application such as automobiles, aircraft and electronic devices [1]. Joining a metal and a plastic is necessary and important from a manufacturing viewpoint. Such joining is generally performed using adhesive bonds or mechanical tools, such as bolts and rivets. These joining processes have problems in terms of environmental restriction on the emission of volatile organic compounds, the difficulties of mass production, and high production costs. Therefore, another process strongly needs to be developed for joining a metal and a plastic.

In this study, on laser joining between a 1050P aluminum sheet and a polypropylene resin sheet with a newly developed insert sheet, the effects of the 1050P aluminum sheet having its surface shape and chemical state changed due to a surface treatment such as alkaline dipping or acid dipping on the joining properties were examined in order to clarify the joining mechanism.

2. Experimental

A 1050P aluminum sheet (1050P) (50×25×1^tmm) and a polypropylene sheet (PP) (50×25×2^tmm) were used as the joining materials. Chemical treatments shown in **Table 1** were done for a mirror surface by buffing in order to clarify the effect of the chemical state of the 1050P surface on the joining strength. After the chemical treatment, surface shape measurement and XPS analysis were conducted on each treated surface in order to examine the chemical state.

The styrene block copolymer (SBC) thermoplastic elastomer fabricated into a sheet 50 μm in thickness was used as the insert material, and polarity was given by a carboxyl group or an amine group for these insert materials in order to improve the joining ability with 1050P.

The insert sheet was placed between the joining materials, as illustrated schematically in **Fig.1**, and laser joining was conducted under the condition shown in **Table 2**.

After laser irradiation, joining strength was measured by the shearing test.

3. Results and Discussion

Table 3 shows the surface roughness (Ra) and the surface area (I Surf Area) of the specimens with chemical

Table 1 Chemical treatments for 1050P aluminum substrate after mirror buffing.

Alkaline dipping	Acid dipping	Second alkaline dipping
(Na ₂ CO ₃ (20kg/m ³)+ Na ₂ SiO ₃ (10kg/m ³) (325K-30s)	Alkaline dipping	Acid dipping
Washing	Washing	Washing
	Nitric acid (60%)	Alkaline dipping
	Washing	Washing

Table 2 Experimental conditions of laser joining.

Wavelength	808nm
Focusing distance	100mm
Spot diameter	600 μm
Defocusing distance	12mm
Exposure mode	CW
Exposure angle	80° for the joining material
Laser power	200 W
Joining Speed	5 mm/s

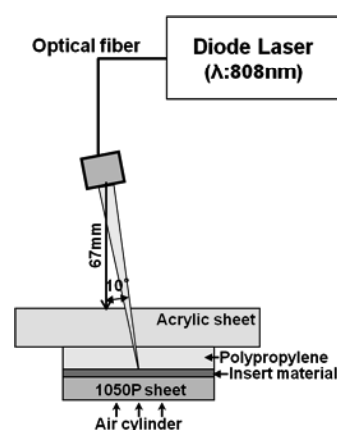


Fig. 1 Schematic drawing of experimental set-up of laser joining.

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^{*} Industrial Technology Research Institute of Okayama Prefecture, Okayama, Japan

^{**} JWRI, Osaka University, Osaka, Japan

treatment shown in Table 1 for the 1050P with mirror buffing. The surface roughness increased with each chemical treatment, and the surface then became rougher, however, there was no significant difference in the surface roughness and the surface area with each chemical treatment. Therefore, an aluminum surface is etched in the first alkali treatment, but that surface is hardly etched in the next chemical treatment such as the acid treatment or the second alkali treatment. Thus, in spite of the same alkali treatment for the buffing or acid treatment, the etching effect is remarkably different. This result demonstrates that the state of the oxide film which is formed after the buffing or acid treatment is different.

Table 4 shows the shear strength of the specimen after each chemical treatment. The shear strength with the first alkali treatment was improved in comparison with that of the buffing of a surface that was not treated. The shear strength with the next acid treatment then improved further than that with the first alkali treatment. However, the shear strength with the second alkali treatment was lowered further than that of the buffed specimen. In spite of the fact that there was little difference in the surface shape with each chemical treatment based on the results shown in Table 3, the shear strength after each chemical treatment was different. These results indicate that the chemical state of the surface aside from the surface shape seems to affect the joining strength in this process.

Figure 2 shows the XPS Al 3p_{1/2} narrow spectra at the surface with buffing and for each treated surface. The peaks of the metal and the oxidation state were present for all specimens, the proportion of the peak of the metal state and oxide state changing with each treatment. This result suggests that the chemical state at the outermost surface varies with each chemical treatment.

In this study, the reactivity between the metal and the insert material allows improvement by giving the insert material polarity with a carboxyl group. Because the change in the chemical state of the aluminum surface by chemical treatment such as alkali or acid significantly affects the reactivity with the insert materials, acid-base interaction [2] is suspected to be responsible for the adhesion model between the 1050P and the insert materials. Degeneration of the insert material was produced by the -NH₂ group which was the basic functional group in contrast with the -COOH group, and similar laser welding was then carried out; the shear strength was measured in order to clarify the acid-base interaction. The results of shear strength are shown in **Fig. 3**. In comparison with the shear strength of the insert materials denatured by a -COOH group or an -NH₂ group, because the shear strength after acid treatment is the highest though the absolute value is different, the shear strength due to each treatment tended to be similar. This result indicates that another joining mechanism exists in addition to the acid-base interaction.

In general, the adhesive bonds for metals having organic functional groups such as an OH radical, an -NH₂ group, a -COOH group in the molecule are firmly fixed on the metal surface by means of the interaction force based on the hydrogen bond between the hydroxyl groups on metal surface and the organic functional groups [2]. The results

showing a similar tendency of the shear strength between the -NH₂ group and the -COOH group as shown in Fig.3 demonstrate that the hydrogen bond should be generated between the hydroxyl groups on the aluminum surface and the -NH₂ group or -COOH group of the given insert materials. By the way, it was not possible to join 1050P and PP, because no reaction was generated between aluminum and the insert materials on using the insert materials without a denaturant. These results strongly support the above-mentioned hydrogen bond between the 1050P and the PP.

Table 3 Surface roughness (Ra) and surface area (I Surf area) for various chemical treatments of mirror buffed

	No treatment	Alkaline dipping	Acid dipping	Second alkaline dipping
Surface roughness, Ra(μm)	0.063	0.219	0.214	0.207
Surface area (mm ²)	0.016	1.548	1.540	1.540

Table 4 Shear strength with various chemical treatments of 1050P aluminum substrate.

	No treatment	Alkaline dipping	Acid dipping	Second alkaline dipping
Shear strength (N)	936.7	1023.0	1122.3	847.7

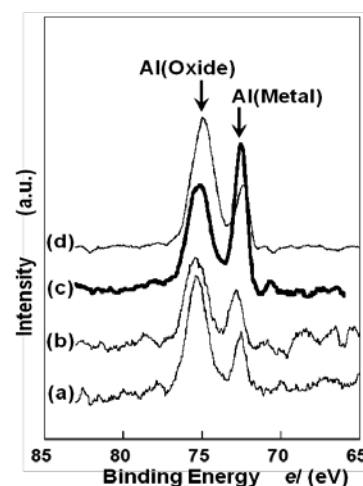


Fig. 2 XPS Al3p_{1/2} narrow spectra of aluminum substrates after various chemical treatments.

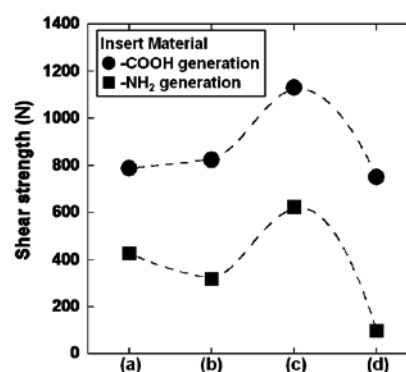


Fig. 3 Shear strength with various chemical treatments of 1050P aluminum substrate.

(a) No treatment, (b) Alkaline dipping, (c) Acid dipping, (d) Second alkaline dipping

4. Conclusions

The conclusions of this study are summarized as follows. The joining strength changed with a chemical treatment such as acid or alkaline dipping of the aluminum surface, and this tendency was similar for the insert materials denatured by a -COOH group or an -NH₂ group. Therefore, a hydrogen bond is a controlling factor in the joining of aluminum and the insert materials compared to the acid-base interaction. At that time, the state of the hydroxyl

group at the outermost surface depended on the oxidation state which seemed to affect the hydrogen bond, and the shear strength then changed.

References

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