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Direct joining of Aluminum Alloy and plastic sheets by friction lap Processing

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Abstract. It was difficult to join dissimilar materials such as metallic material and polymer. Conventional joining processes of these materials were mechanical fastening, using adhesion, thermal pressing, laser welding and so on. These processes had disadvantages such as expensive apparatus, restriction of dimension of products and lack of anti-weather resistance.
Friction Stir Welding (FSW), which was one of the solid state joinings, was available as a joining process for dissimilar metals. However, in case of joining metal and polymer, it was not available to use the tool for FSW. So we proposed Friction Lap Process to join a metallic material with a polymer and investigated mechanical and metallurgical properties of this dissimilar joint. Itwas described in this paper that joining mechanism is discussed with evaluation of microstructure at the interface between aluminum alloy and polymer. High density polyethylene was not able to be joined for as received aluminum alloy. Anodizing was effective to join these materials.

Introduction

Dissimilar welding between aluminum alloys and copper alloys or steels is recently under developing in several industrial applications. Especially this process is already applied for electric parts. By the way, this welding process is focused on transportation industries such as automotive manufacturing or aviation industry and electronics industry applying joining between light metal and thermoplastics for the purpose of weight reduction.

Mechanical joining, adhesive joining, injection molding, ultrasonic welding, high frequency induction heating, hot pressing and laser welding are already proposed and realized as dissimilar welding methods.

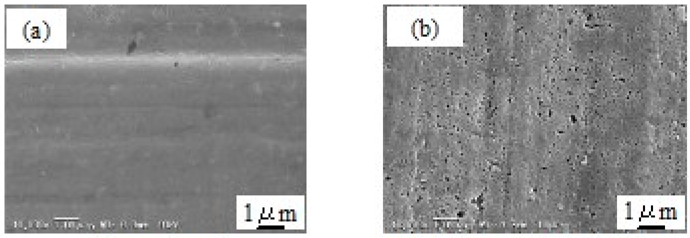
However, these processes have disadvantages for each process. For example, bolts or rivets are required for mechanical joining. Moreover, this process has other disadvantages such as inferiority of design variety or expensive consumables and increasing total weight, low air and water tightness. In case of adhesive joining, as organic solvent is applied for adhesive such as acrylic or epoxy resign, this adhesive is submitted to VOC regulation taking into account of human health because its vapor is harmful. Moreover, it takes long time in adhesive process to attain required joint strength and this strength is decreasing after long time service. These disadvantages are not acceptable in practical applications.

In this decade, friction stir welding (FSW), which is one of solid state joining, is available to joining process for dissimilar materials [1, 2]. One of the authors has investigated to dissimilar lap joint steel/Al alloy [3], steel/Mg alloy [4], steel/Ti [5], steel/Ni alloy [6], Al alloy/Mg alloy [7], and Al alloy/Ti [8]. Then he found the results of mechanical properties with satisfaction.

Based on these results, we have proposed a new joining process for dissimilar materials called Friction Lap Processing (FLP) as a joining process between metal and resign or polymer [9, 10]. Also we have estimated joining mechanism and join properties.

In recent years, we have evaluated the joining parameters and surface treatment conditions on the joint properties of dissimilar lap joints between Al alloy and PE or EAA with FLW process. We have then investigated the microstructure of interface between these two materials after welding and mechanism of welding.

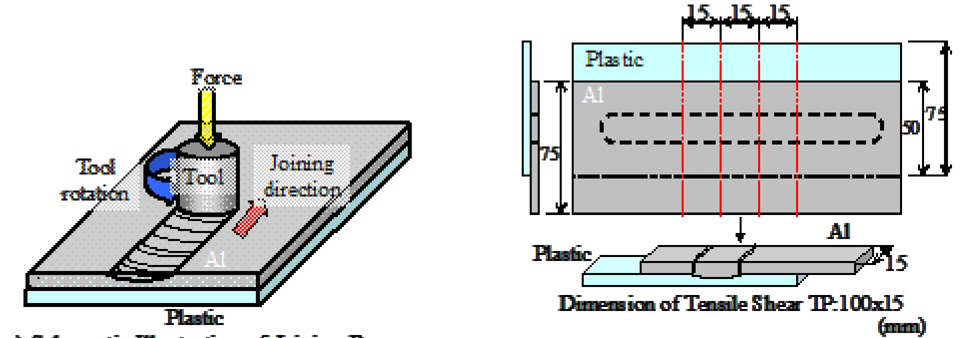
Experimental procedure



As received — Anodizing with Oxalic Acid

Fig.1 Surface Appearance of A2017P-T4

Materials used. A2017P-T4 is selected as Al alloy of high strength sheet material and dimensions of test material are 1.5mm thickness, 150mm length and 75mm width. Its' chemical Composition is Si: 0.55 Fe: 0.21 Cu: 4.13 Mn: 0.70 Mg: 0.56 Cr: 0.03 Zn: 0.06 Ti: 0.02 Al: Re (wt %) respectively. Anodizing with Oxalic acid (without sealing of anodic oxide coating) is applied on A2017 to estimate the effect on weld-ability to polyethylene. SEM observations of surface appearance of test pieces are shown in Fig.1.High density polyethylene (PE) and ethylene-acrylic acid copolymer (EAA) are used for lap joint withA2017P-T4. The latter material is superior in adhesive property. Dimensions of these materials are 150mm length, 75mm width and 1.7mm thickness. The structural formula of PE is polymer with C-H and the softening point is 369K.The melting point is 405K. Also EAA has the same structural formula as COOH and, softening point 355K and melting point 371K respectively.



a) Schematic Illustration of Joining Process — b) Sampling Position and Configuration of TP

Fig.2 Schematic Illustration of Joining Process and Configuration of Tensile Shear TP

Friction Stir Lap welding. Position controlled FSW equipment is used for joining. Schematic illustration of friction lap process (FLP) is shown in Fig.2a. A2017 is put on the resign and these are fixed on backing plate made of stainless steel. Probe less tool is applied for joining and its diameter is 15 mm. Tool is inclined 3 degree from normal position behind toward the welding direction. Plunge depth of tool is 0.5mm from the surface of test piece and tool rotating speed and traveling speed is 1000rpm and 400mm/min respectively.

Surface view and observation of microstructure at transverse section. The surface of A2017 and thermoplastics are observed after welding to estimate the melting area of thermoplastics. Microstructure at the transverse cross section is observed by optical scope and scanning electron microscope after welding. In addition, chemical analysis of the component at this section is made with EDX attached with SEM. Ultra microstructure is analyzed with transmission electron microscope at this section.

Tensile shear testing of welded joint. Tensile shear test is conducted to estimate the mechanical property of welded joint. Sampling position, configuration and dimensions of test specimen are shown in Fig.2b. Test specimens are cut to coupons with 15mm width normal to the welding direction and 3 coupons are tested for each welding parameters.

After sampling the test specimens, their widths are measured and their welded lengths are specified by their width.1.5mm spacer is set on the holding jigs to apply the normal load on specimen during tensile shear testing. Cross head speed is selected 5mm/min, and tensile stress is estimated as value of the maximum load divided by the welded width.

Observation of fractured surface after tensile shear testing. The fractured surface at the interface after tensile shear testing is observed with SEM, and for test pieces fractured at thermoplastics, peeling is applied to appear the interface between the resign and A2017, and then its interface is observed with SEM. Before observation, Au and Pd are coated on the fractured surface a using Spatter coater.

Temperature measurement at interface during welding. Temperature at interface during welding is measured by a thermocouple. K type thermocouple (1mm) is contacted on A2017 surface and fixed by inserting through a hole in the thermoplastic plate. Measuring positions are (a) the center area which tool passed (b) 5mm apart from the edge of the advancing side (c) 10mm apart from the edge of the advancing side, respectively. (a) and (b) are located within the tool passing area, and (c) is outside of tool passing area. (a) is located 120mm away from the origin of welding (b) is located 100 and (c) is located 80mm away from the origin of the welding, respectively.

Results

Surface appearance and cross section view of welded joints. Surface appearances and cross section views of each welded joint are shown in Fig.3. In case of using EAA, it can be welded in, both of surface conditions i.e. as anodizing and as received. Also the root surface has colored area where it is welded, correspond to tool diameter. This is considered that melted EAA is spread out in the gap between A2017 and solid EAA. At tool traveling path, A2017 is pushed against EAA because the tool is plunged into A2017. The colored area on the root surface corresponds to the tool traveling path.

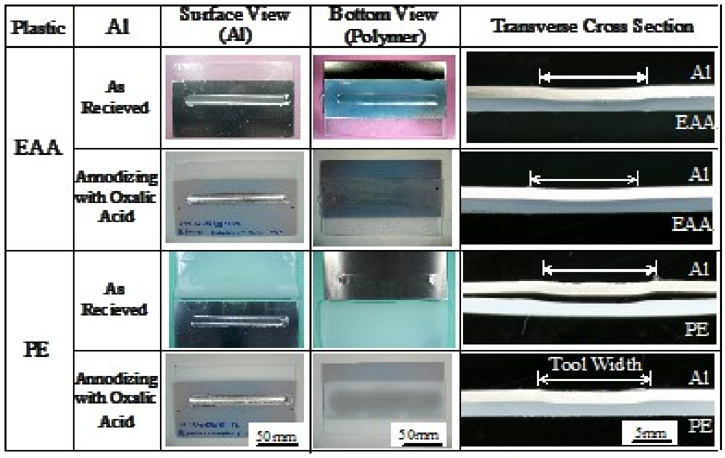


Fig.3 Surface, Bottom and Cross Sectional View after joining

In case of using PE, separation between A2017 and PE occurs immediately after welding for as received A2017, and only anodized A2017 is possible to weld. Surface appearance and the cross section view after welding are the same as those of using EAA for anodized A2017.

Results of tensile shear test. Results of tensile shear tests are shown in Fig.4. In case of using EAA, the joint strength is satisfied because maximum shear load reaches over 12N/mm of elastic limit of EAA in spite of exiting fracture at interface between A2017 and EAA.

On the other hand, in case of using PE, only anodized A2017 is able to join and its strength is the yield strength of base material of PE(39N/mm). Surface view before and after tensile shear testing of each test specimen is shown in Fig.5.

Observation at fractured surface for the combination of as received A2017 and EAA. The reason why fracture at the interface occurred in combination of as received A2017 and EAA is investigated by SEM observation and EDX analysis at the fracture surface on A2017. These results are shown in Fig.6. Also, the center of the area where tool the passed (position 1 in Fig.6) and 5mm apart from the edge of the advancing side (position 2 in Fig.6) on the fractured surface are observed by SEM. As shown in SEM image in Fig.6b, one can see many fine depressions due to extrusion exit on the surface of as received A2017. Carbon is distinctly detected in these depressions by EDX (Fig.6c). It is believed that melted EAA permeates into these depressions during joining and is torn during tensile shear testing, and then it existed on the as received A2017 after testing.

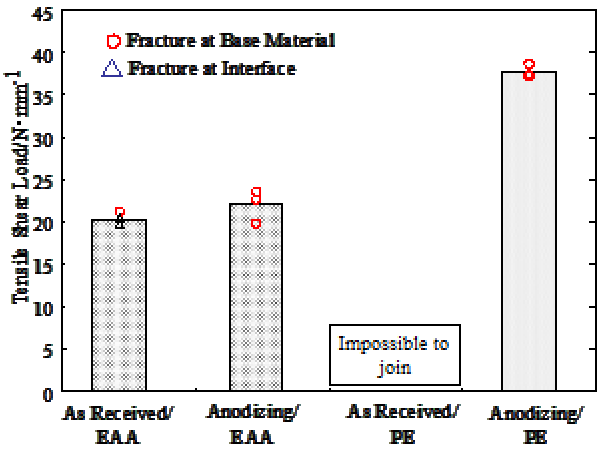


Fig.4 Effect of Surface Treatment for A2017 on Tensile Shear Load after Joining

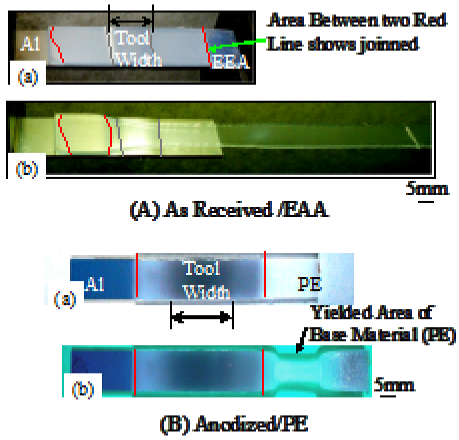


Fig.5 Surface View of Joint (a) Before (b) After Tensile Testing

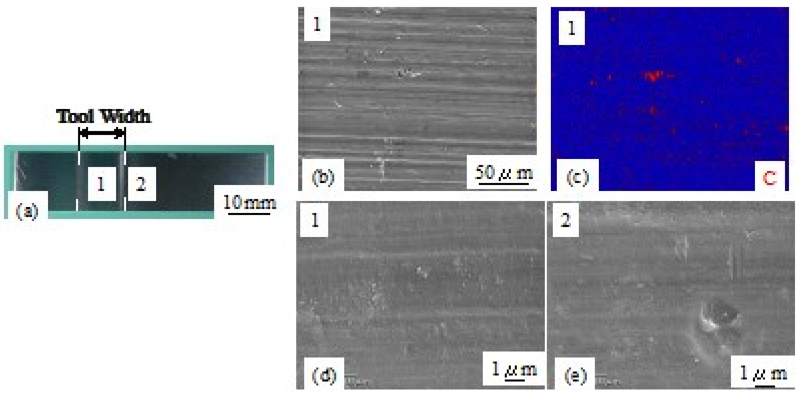


Fig.6 Appearance of Fractured Surface (a), SEM Image (b) and C mapping with EPMA (c) Higher Magnification Image by SEM (d) and (e) are at 1 and 2 respectively Combination of As received A2017 and EAA

Observation at fractured surface for the combination of anodized A2017 and PE. Fracture occurred at the base material of PE in case of tensile shear tests of welded joints using test pieces composed of anodized A2017 and PE. So PE had to be peeled from the joint to investigate the interface morphology. SEM observation and EDX analysis are conducted on the interface of A2017.The results are shown in Fig.7. Torn PE exists in depressions whose diameters are a few μm on the interface shown in Fig.7 (b). Though this retained PE is observed in the whole area joined, it is speckled and a few quantities based on EDX analysis (Fig.7(c)). Fig.7 (e) and (f) show higher magnification images of the rectangular depression shown in Fig.7 (d). Retained PE after tensile shear testing is observed in many depressions on the surface of A2017.

Temperature measurement at the interface. Maximum temperature is measured to be 543K at the 2 points inside the tool passing through area and 363K at the point outside the tool passing through area. As the melting points of EAA and PE are 405K and 371K, The temperature rise at the measuring points reaches over the melting points of these materials. It is considered that friction heat due to the rotating tool pressed onto A2017 conducts to the thermoplastic and heats up and melts it.

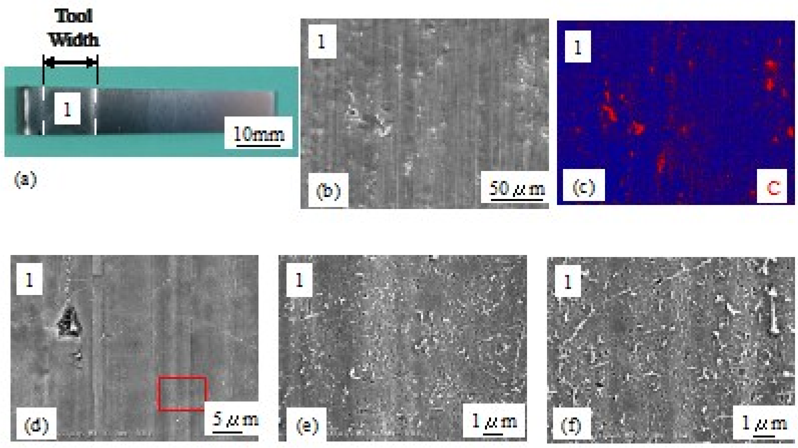


Fig.7 Appearance of Fractured Surface (a), SEM image (b) and C mapping with EPMA and Higher magnification of SEM Image at Position1(e)and (f) Combination of Anodizing with Oxalic Acid A2017 and PE

Discussion

Observation by higher magnification at the interface. The weld interface between as received A2017 and EAA is observed by TEM and measured by EDX. These results are shown in Fig.8. The weld interface is very smooth within the observed area, and it exists a dark region of under 10 nm thick. This layer is composed mainly of C, O and Al as shown by EDX in point 1 in Fig.8(c). No composition is detected at point 2, 3 and 4.

The weld interface between anodized A2017 and PE is shown in Fig.9. The dark region is suggesting that a reactive layer is not observed in this interface. However, differently contrasted region from the peripheral area exists in the depression in the anodized layer shown in Fig.9 (c). Observation in higher magnification (Fig.9 (d)) suggests that PE permeates into depressions of anodized layer.

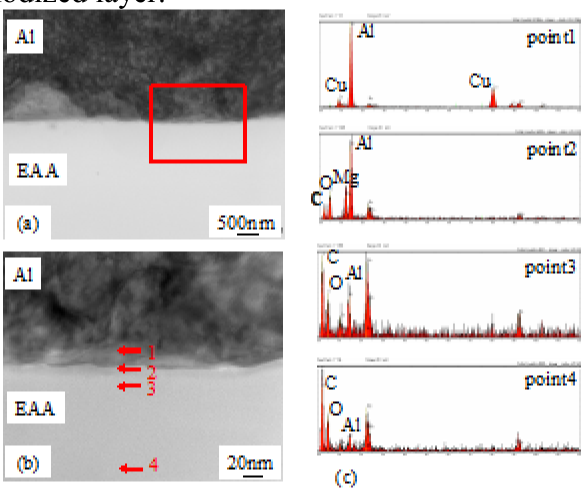


Fig.8 TEM Image and EDX Spectrum at interface :As Received A2017/EAA

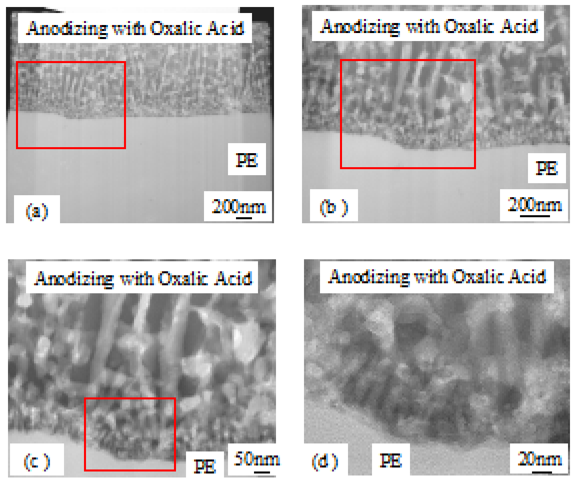


Fig.9 TEM Image at interface Anodizing with Oxalic Acid/PE

Consideration of the relation between molecular structure and polarity. In spite of surface treatment for Aluminum alloy, combination of EAA and Aluminum is able to be joined. On the other hand, combination of PE and aluminum is only able to be joined when used anodized aluminum. It is considered that this difference is due to the existence of polarity of the thermoplastics.

A part of the oxide layer on metal surface is decomposed by hydrolysis to form hydroxyl group. This group reacts to functional groups of thermoplastic and raises intermolecular force [11]. As EAA have COOH, when this polymer approaches aluminum, an intermolecular force arises between the natural oxide film on aluminum (Al2O3) and COOH. In addition, Coulomb's force between aluminum and oxygen, oxygen and hydrogen arises during welding, and then as received A2017 and EAA joined tightly.

Anodizing contributes to form stable oxide layer on A2017 and gives an anchor effect for which melted EAA permeates into depressions in anodized layer. On the contrary, as PE has no functional group, the intermolecular force is able to arise but the coulomb's force is not able to arise, so the combination of as received A2017 and PE is not able to join.

Summary

In this paper, it is recognized that Friction Lap Welding (FLW) makes it possible to join an aluminum alloy and some kind of polymer using friction energy in the atmosphere. It is concluded that:

1) High density polyethylene, which has no polarity, is not able to be joined for as received aluminum alloy. However, when it is coated with a porous film such as anodizing, it is able to be joined with sufficient strength. An anchor effect is contributed to this result.

2) EAA, which has polarity, is able to be joined with aluminum alloy in spite of anodizing (or not.)

3) In case of polymer with polarity, it is considered that intermolecular force and Coulomb's force arise between carbonyl group and oxide film on aluminum alloy and then they are joined with addition to an anchor effect.

Acknowledgements

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