Joining of Corrosion-resistant Metal Foil to Magnesium Alloy by Shot Peening

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The joining of magnesium alloys with dissimilar metal foils was investigated to improve the surface properties. In the experimental method, the metal foils were pure titanium, pure copper, pure nickel, pure iron and stainless steel. Shot peening was performed on a centrifugal shot peening machine. The shot media was cast steel with an average diameter of 1.0 mm. The peening velocity and peening time were 60 m/s and 10 s, respectively. After joining, no voids or cracks were observed at the joining interface. In bending test, the metal foil did not peel off even when the substrate was broken. In addition, the bondability of dissimilar metal foils was improved by heat treatment at 450 °C. Wear resistance was also improved by the joining of stainless steel foil. This method was effective for surface modification of magnesium alloys.

Keywords: *shot peening, surface modification, bondability, magnesium alloy, corrosion resistance, pure titanium*

1. Introduction

Magnesium is a lightweight material among practical metals and has a lower density than other metals. In addition, the alloy has several attractive properties such as high strength-to-weight ratio, good machinability, good electromagnetic shielding properties, and recyclability. Therefore, it is widely used in various industries such as automotive, aerospace, and electronics. In particular, weight reduction is considered to reduce the environmental impact of vehicles in the transportation sector. However, most magnesium alloys require improved corrosion and wear resistance [1, 2]. For example, it is known that magnesium alloys are susceptible to corrosion when in contact with other metals in a wet environment. Hence, to improve the surface properties of magnesium alloys, surface modification is applied to form thin films [3, 4]. Various treatments such as chemical conversion, vapor deposition, and plating are used to form thin films on the surface. In the case of the physical vapor deposition (PVD) process, it is a thin film deposition process in which the coating grows on the substrate atom by atom. Hard coatings are typically applied as a protective covering for engineering components. On the other hand, shot peening (SP) process is known as a surface treatment technology. The main purpose of this technology is to improve the strength and fatigue of mechanical parts [5, 6]. In SP, the material surface is plastically deformed by small steel balls. The authors have attempted to use this plastic deformation to join dissimilar materials [7, 8]. In SP, the workpiece surface is hit repeatedly with a large number of cast steel. This action causes plastic deformation of surface. The steel balls collide with a thin sheet of dissimilar material placed on the surface of the material, and the sheet is bonded to the material. By means of peening with many shots, the aluminum foil was successfully bonded over the surface of the carbon steel workpiece [9]. This joining method is known as shot lining (SL). In the present study, the joining of magnesium alloys to dissimilar metal foils by SP was investigated to improve surface properties. Joining and wear resistance of dissimilar metal foils were evaluated, and the effect of heat treatment after SP was investigated.

2. Experimental procedure

2.1 Materials

Several types of magnesium alloys were commercially available extruded round bars. The alloy types were AZ31, AZ61, AZ80, AZX611. These grades are JIS (Japanese Industrial Standards) standard. The substrate was cut into a diameter of 50 mm and a thickness of 10 mm. Dissimilar metal foils were pure titanium (Ti), pure copper (Cu), pure nickel (Ni), pure iron (Fe), stainless steel SUS304 and SUS316L. The range of the foil thickness was from 0.02 to 0.04 mm. Pure aluminum (Al) foil which range from 0.02 to 0.08 mm was used as the insert materials, to enhance the bondablity.

2.2 Shot lining

The shot lining process was performed on a centrifugal shot peening machine incorporating a prototype heating device. The substrate and metal foils were heated at 300 °C and 350 °C. This is because the deformation resistance of the metal material is reduced by heating, and the bondability of different materials is improved. The shots had an average diameter of 1.0 mm and were made of cast steel. Their hardness was approximately 450 HV. The peening speed and peening time were 60 m/s and 10 s, respectively. **Figure 1** shows the illustration of heating device for SL. SL was performed in two steps. First, pure Al foil was bonded to the surface of the substrate by SP (first process). Subsequently, the dissimilar metal materials were joined by SP (second process). Pure Al foil used in the first process was a thickness 0.02 mm, and the working temperature was 300 °C.

2.3 Bondability

The surface and cross section of the joined workpiece after SL were observed using an optical microscope. Cross section elemental mapping analysis by SEM-EDX (Energy Dispersive X-ray spectroscopy) was also examined. The joinability was evaluated by a three-point bending test. Bending workpieces were cut into 20 mm width and 5 mm thickness. The joined surface of dissimilar materials was bent outward. It was bent until the substrate broke.

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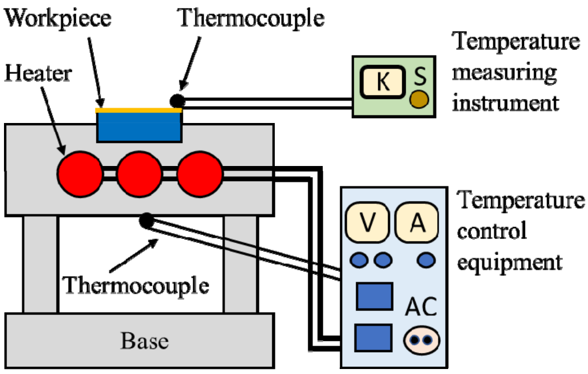


Figure 1 Heating device for shot lining.

3. Results and discussions

3.1 Bondability of metal foil

When joining the corrosion-resistant metal foil to the magnesium alloys, it was possible to join the metal foil by SL processing in the second process. Joining was possible at processing temperatures of 300 °C and 350 °C for 0.02 mm thick Ti and Fe foils and 0.04 mm thick Cu, Ni, SUS304 and SUS316L foils. Joining of Ti foil with a thickness of 0.04 mm was possible at a processing temperature of 350 °C. It was found that the metal foil can obtain sufficient plastic deformation at a processing temperature of 350 °C. For all the alloys used, metal foil joining was possible at a processing temperature of 350°C. Surface observation did not show any metal foil scattering or erosion due to shot impact. **Figure 2** shows the surface conditions of Ti foil with a thickness of 0.02 mm joined to AZ31. In the cross-sectional observation, each metal foil with a thickness of 0.02 mm was bonded to the base material without breaking with a shot diameter of 1.0 mm.

3.2 SEM observation

In the magnesium alloy AZ31, 0.02 mm thick Ti foil was bonded at 300 and 350 °C, and elemental analysis was performed by EPMA on the cross section near the surface. **Figure 3** shows the SEM image near the Ti foil bonding surface and the mapping images of Ti, Al, and Mg. Distribution of both elements was confirmed between the substrate and Al foil. The Mg-Al alloy layer was formed. The thickness of the alloy layer was approximately 7 µm at a processing temperature of 300 °C and approximately 12 µm at a processing temperature of 350 °C. As the processing temperature increased, the thickness of the alloy layer also increased. In addition, the alloy layer was formed with two layers with different concentrations. A qualitative analysis was performed for each layer. The atomic ratio of Mg and Al in the Al foil side layer was approximately 2:3, and the atomic ratio of the Mg substrate side layer was approximately 17:12. Therefore, the respective layers were found to be intermetallic compounds of Mg and Al, Al_3Mg_2 and $Mg_{17}Al_{12}$.

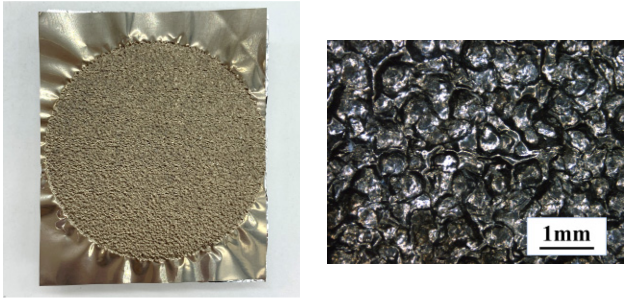
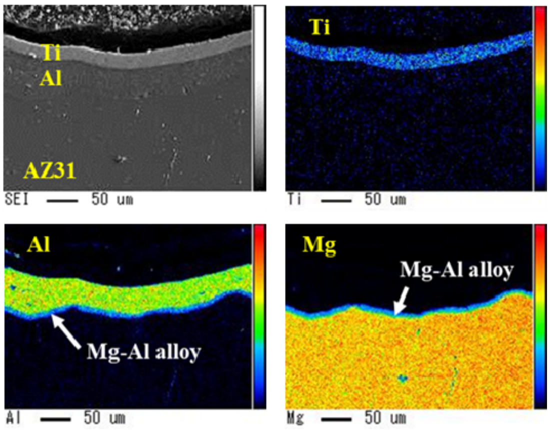
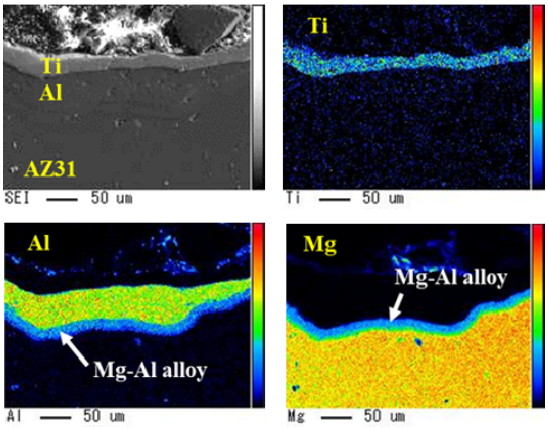


Figure 2 Surface conditions after SL



(a) working temperature, 300 °C



(b) working temperature, 350 °C

Figure 3 Cross sections near the surface of Ti foil bonded to AZ31 alloy.

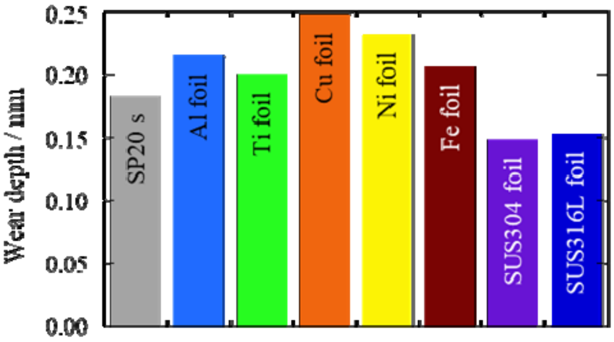
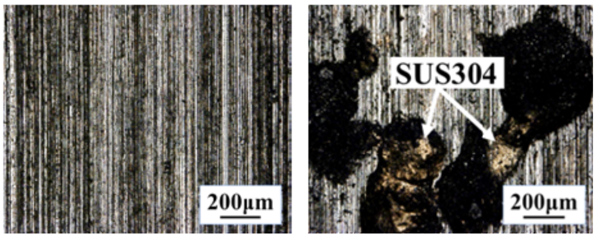


Figure 4 Wear depth of workpieces in which various metal foils were bonded to AZ31 alloy



(a) only shot peened (b) joining of SUS304 foil

Figure 5 Surfaces of AZ31 alloy after wear test

3.3 Bending test

A three-point bending test was performed to examine the bondability. In the workpieces of Ti foil, Ni foil, Fe foil, SUS304 foil, and SUS316L foil joined at a processing temperature of 300 ºC, each metal foil did not delaminate significantly even when the substrate was fractured. In the workpieces bonded at a working temperature of 350 ºC, however, the metal foil near the fracture part detached more than in the case of the workpieces joined at a working temperature of 300 ºC.

Bending test was performed on the workpiece of Ti foil with a thickness of 0.04 mm bonded to flame-retardant AZX611 at a processing temperature of 350 °C. Pure Ti foil was slightly peeled off near the fracture surface. Therefore, to improve bondability, heat treatment was applied after bonding pure Ti foil, and bending test was performed. When heat-treated at 400 ºC and 425 ºC, pure Ti foil delaminated significantly. When heat-treated at 450 ºC and 500 ºC, however, delamination of Ti foil did not occur.

3.4 Wear resistance

To investigate the wear resistance of the bonded workpieces, wear test was carried out by Suga type abrasion tester. **Figure 4** shows the wear depth after the wear test of workpieces joined with SP, Al foil with a thickness of 0.02 mm, and metal foil with a thickness of 0.02 mm to the base material AZ31. When SUS304 foil and SUS316L foil were joined, the wear depth was small. Therefore, it was found that the bonding of stainless steel foil was effective for wear resistance. Moreover, when SUS304 foil with a thickness of 0.04 mm was bonded, the wear depth was further reduced.

Figure 5 shows the wear surface after the wear test with only SP treatment on the substrate AZ31 (a) and with SUS304 foil with a thickness of 0.02 mm (b). There were only wear marks on the worn surface of the SP-only workpiece (a). However, some SP traces and residual SUS304 foil were observed on the worn surface of the workpiece (b) to which the SUS304 foil was bonded.

3.5 Corrosion resistance

Corrosion tests were performed to investigate the corrosion resistance of the bonded workpieces. Corrosion was observed before and after workpieces of untreated material, shot-peened only, joined with 0.02 mm thick aluminum foil, and joined with 0.02 mm thick metal foil. No corrosion was observed on the surface when the corrosion-resistant metal foil was bonded. Therefore, it was found that the SL treatment improves corrosion resistance.

4. Conclusions

Surface modification of magnesium alloy was performed using particle collisions such as SP. Joining of magnesium alloys with dissimilar metal foils were investigated. The metal foils were possible to join by increasing the processing temperature from 300 ºC to 350 ºC. As the thickness of the dissimilar metal foil increased, they could be joined by increasing the thickness of the inserting Al foil. Wear resistance was also improved by the joining of stainless steel foil. This SL method was effective for surface modification of magnesium alloys.

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