Bonding of Magnesium Alloy with Ceramics by Shot Peening

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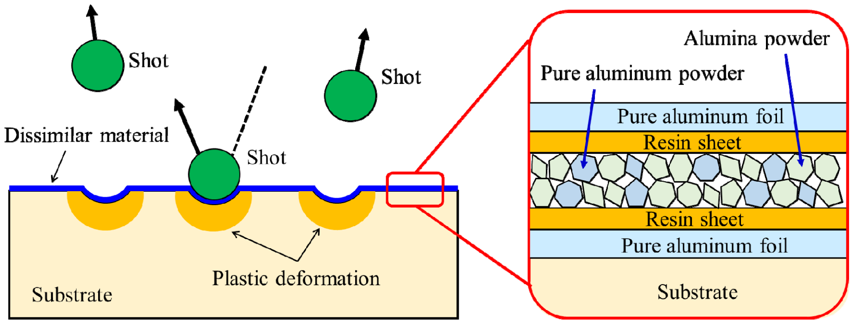
Abstract
Light metal materials such as aluminum and magnesium alloys are widely used in the field of transportation equipment where weight reduction of mechanical parts is required. However, it is known that wear resistance of light metals is lower than that of steel materials. Therefore, surface modification is being attempted by various coating techniques. In the present study, to improve the surface characteristics of corrosion resistance and wear resistance of light metals, surface modification was performed by bonding laminated sheet with ceramic powders and resin sheet to magnesium alloy using shot peening. The bondability of the laminated sheet was examined. Wear resistance was also evaluated. The laminated sheet could be bonded without peeling from the substrate. Bonding of hard powders was effective in improving wear resistance.

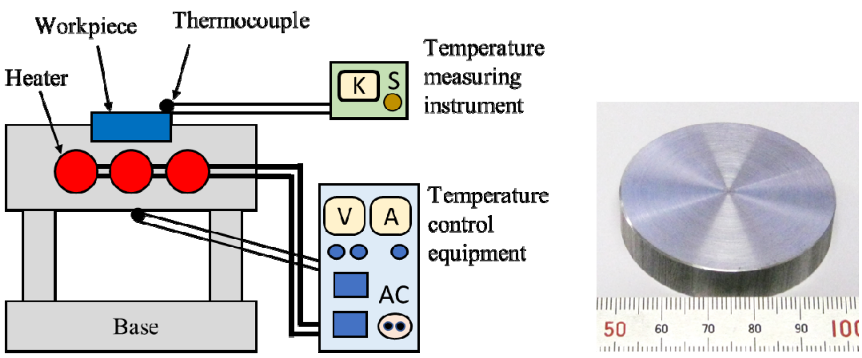
Keywords Bonding, magnesium alloy, ceramic, wear resistance, corrosion resistance.

Introduction
In recent years, light metals such as magnesium and aluminum alloys have been attracting attention in the field of transportation equipment such as aircraft and automobiles [1], [2]. Aluminum alloys have a high corrosion resistance and excellent recyclability. Magnesium alloys have a high specific strength, and are excellent in vibration absorption and dent resistance. However, corrosion resistance and wear resistance of light metals are lower than those of steel materials [3]. [4]. Therefore, many light metals are surface treated. The Yttrium-incorporated aluminizing of magnesium alloy for improved tribological and corrosion properties was carried out [5]. The properties of composite coatings electro co-deposited on magnesium alloy using triangular waveform pulse current were examined [6]. The effect of heat treatment on properties of Ni-P coatings deposited on magnesium alloy was investigated [7]. Coatings of functional materials have been used for magnesium alloys. Evaporation is performed by evaporating metals and oxides. The characterization and properties of hybrid coatings deposited onto magnesium alloys was examined [8]. Oxidation behavior of PVD processed magnesium alloy was carried out [9]. On the other hand, surface modification by plastic deformation of the surface has been performed for a long time. Typical techniques include burnishing and shot peening. It is known that surface hardness and fatigue strength increase in shot peening. It is widely used for automobile parts such as springs and gears, aircraft-related products such as jet engines and wings, and pressure vessels for chemical plants. Much research has been done to enhance the peening effect. The effect of warm shot peening treatments on surface properties and corrosion behavior of magnesium alloy was carried out [10]. The influence of shot peening on high cycle fatigue properties of the high-strength wrought magnesium alloy was examined [11]. The authors have been studying the bonding of dissimilar materials to metal surfaces by shot peening. Pure titanium foil and pure nickel foil were joined to improve corrosion resistance and wear resistance of the metal materials [12], [13]. In the present study, dissimilar materials were joined to magnesium alloy by shot peening. To improve corrosion resistance and wear resistance, attempts were made to join metal laminated sheets with resin or ceramic. The bondability of dissimilar materials was evaluated by bending test and microstructure observation.



(a) Bonding of dissimilar material (b) Composition of laminated sheet

Figure 1 Bonding method of laminated sheet by shot peening.



(a) Heating device (b) Workpiece AZ31

Figure 2 Equipment for bonding dissimilar material.

Table 1 Working conditions for bonding laminated sheet.

Equipment	Centrifugal peening machine
Shot material	High carbon cast steel, 450 HV
Shot diameter	1.0 mm
Impact speed	60 m/s
Heating temperature	573 K (300 °C)
Workpiece	Magnesium alloy AZ31, ϕ50x10mm
Hard powder	Almina Al_2O_3 (ceramic), 0.06-0.3 mm
Insert powder	Pure aluminum, 0.1 mm
Resin sheet	Thermoplastic polyimide, 0.025 mm
Insert foil	Pure aluminum, 0.02-0.04 mm
Surface finish	#120 (grain size 0.12 mm)
Atmosphere	In air, 298 K (25 °C)

Experimental Procedures

In shot peening, a metal workpiece undergoes plastic deformation near the surface due to the hit of a large number of shots at a high speed. Plastic deformation is utilized for bonding workpieces with dissimilar materials. A method of bonding dissimilar materials by shot peening is shown in Figure 1. Dissimilar material set on the substrate is hit with the shot. It is firmly bonded to the substrate (a). Dissimilar material is a laminated sheet composed of ceramic powders and the resin sheets (b). Ceramic was a hard alumina with a powder size of 0.06 to 0.3 mm. To examine the effect of powder size on bondability, powder size was divided into five groups. The average powder size of each group was 0.06, 0.12, 0.18, 0.25, 0.30 mm. The resin sheet was thermoplastic polyimide and had a thickness of 0.025 mm. Pure aluminum powders were mixed as an insert material because the bonding with the resin sheet was insufficient with only ceramic powders. The mixing ratio of ceramic particles to pure aluminum powder ranged from 10: 0 to 8: 2. Furthermore, pure aluminum foil was used as an insert material to improve the bondability with the substrate. Since the shot directly collides with the dissimilar material, plastic deformation of the substrate is small. Since the bondability of magnesium alloy is low, the use of pure aluminum foil is effective in improving the bondability [14].

A heating device for bonding dissimilar materials is shown in Figure 2. To promote plastic deformation of magnesium alloy, the dissimilar materials were joined in a warm state (a). The heating temperature was 573 K. The workpiece was a commercially available magnesium alloy AZ31 (b). An impeller type machine was used for shot peening. The shot material was made of cast steel with an average diameter of 1.0 mm. The peening speed was 60 m/s. The projection distance was approximately 270 mm. The surface of the workpiece was cleaned with emery papers prior to the shot peening. The dimensions of the materials used for the experiment are summarized in Table 1.

The structure of the cross section was observed by an optical microscopic observation near the surface where the laminated sheet was bonded. The bondability of dissimilar materials was tested by a three-point bending test. Wear resistance was evaluated by a wear test. The testing machine was the Suga type wear test machine (NUS-ISO3). On the surface after wear test, the depth from the surface was measured. It was a machine flat abrasion wear test using a rotating wheel. The force of 26.8 N was applied from the abrading wheel contact to the workpiece.

Experimental Results and Discussion

When the alumina powders were 100 %, the laminated sheet was peeled off regardless of the particle size. To improve the bondability, the pure aluminum powders were mixed as an insert material. Figure. 3 shows the bondability in the relationship between the mixing ratio of pure aluminum powder and the ceramic powder size. As the diameter of ceramic powder increased, the bondability improved. When the diameter of ceramic powder was 0.25 mm or less, however the bondability was not improve. Therefore, the mixing ratio of the pure aluminum powders was set to 20 %. As a result, the bondability of the laminated sheet was improved regardless of the diameter of ceramic powders.

Figure 4 shows the appearances of the shot-peened workpieces. When the powder size was small, the resin sheet was observed in the peeled workpiece. The peeled surface was broken with a layer of ceramic powder. Since the powder was hard, the laminated sheet was not easily deformed during the shot peening process.

In the workpiece showing good bondability, a cross section near the surface was observed by an optical microscope. Figure 5 shows an enlargement of the surface and a cross section near the surface. The mixing ratio of pure aluminum was 20 %, and the powder diameter of alumina was 0.18 mm. It was observed that no cracking or peeling occurred on the surface of the laminated sheet after shot peening (a). No voids were observed at the boundary between the laminate and the substrate in the cross section of the surface (b).

A three-point bending test was conducted to examine the bondability of the laminated sheet. The workpiece was bent until the substrate broke. Figure 6 shows the appearance of the workpiece and surface condition after bending test. The mixing ratio of pure aluminum was 20 %, and the powder diameter of alumina was 0.18 mm (a) and 0.3 mm (b). Although the laminate sheet broke with the substrate, no peeling was observed from the substrate. It was found that the bondability of the laminated sheet was good.

Wear test was performed on the workpieces showing good bondability. Figure 7 shows the appearances of the workpieces after wear test and its enlargement. The laminated sheet containing ceramic powders with a diameter of 0.18 mm were joined. The mixing ratio of the pure aluminum powders used as the insert material was 20 %. For comparison, the workpiece joined with laminated sheet without ceramic powders was also shown. In the workpiece without ceramic powder (a), metallic luster was observed in the worn area. In the case of the workpiece containing ceramic powders, however, the worn area was black (b). Ceramic powders were observed on the enlarged surface.

Wear test was performed on the workpieces covered with ceramic powders. Figure 8 shows the relationship between the powder size and the amount of wear. For comparison, the results of workpiece with shot peening, workpiece bonded with pure aluminum foil, and workpiece bonded with pure aluminum foil and resin sheet were also shown. In workpieces without ceramic powders, the wear depth ranged from 0.42 to 0.52 mm. For workpieces containing ceramic powders, the wear depth was approximately 0.3 mm. There was little effect of the size of ceramic powders on the depth of wear.

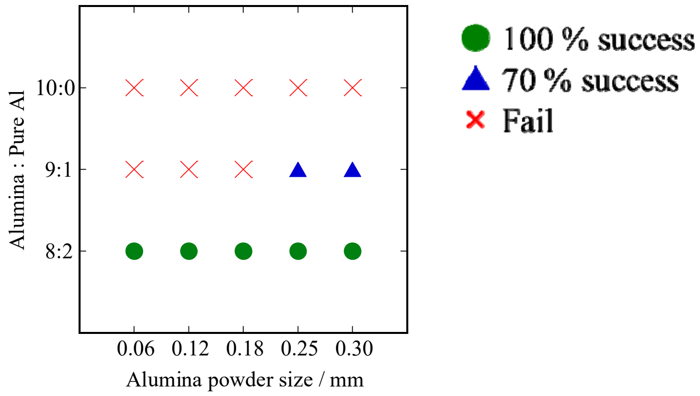
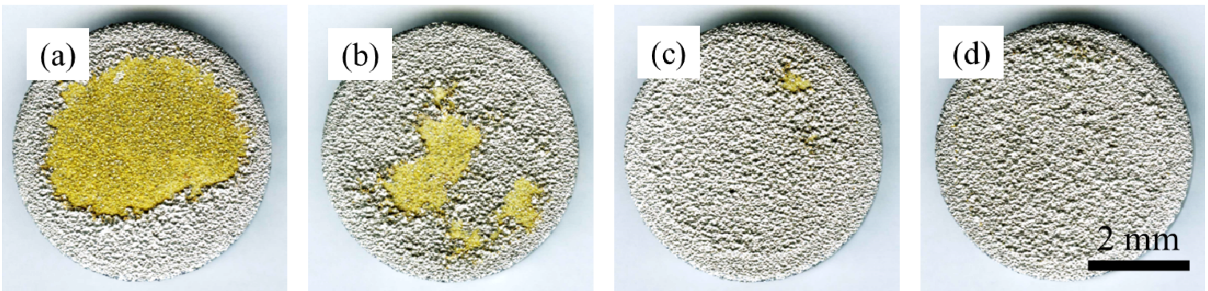
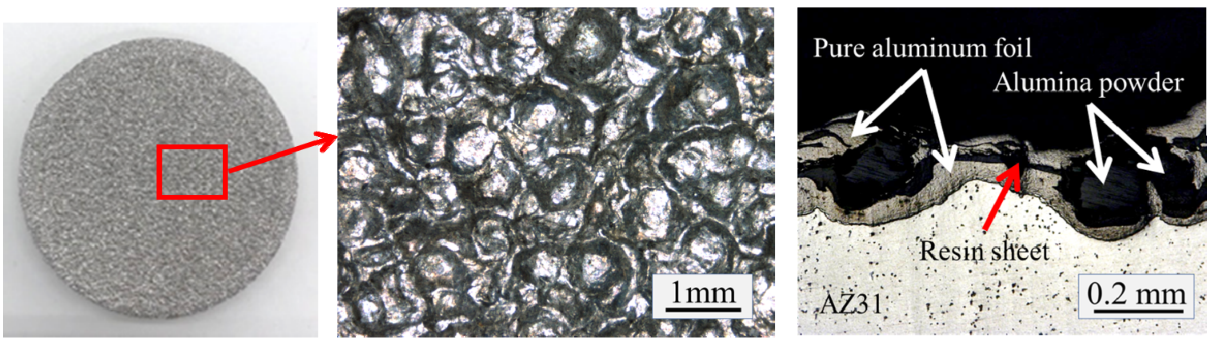


Figure 3 Bondability of laminated sheet.



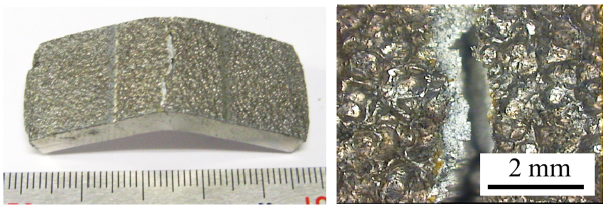
10 % Al powders, 0.12 mm | 10 % Al powders 0.18 mm | 10 % Al powders, 0.25 mm | 20 % Al powders 0.3 mm

Figure 4 Appearances of shot-peened workpieces.

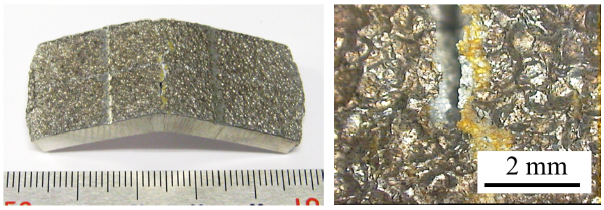


(a) Surface condition after shot peening (b) cross section near surface

Figure 5 Surface condition and cross-section near surface.



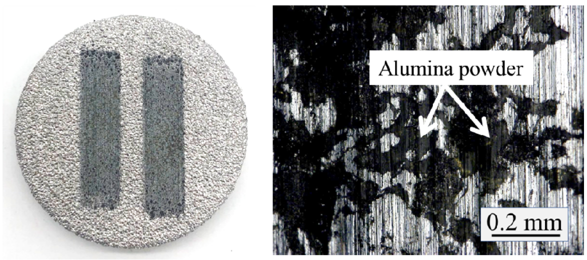
(a) 20% Al powders, 0.18 mm



(b) 20% Al powders, 0.3 mm

Figure 6 Appearances of workpieces after bend test.

(a) Laminated sheet without ceramic powders



(b) 20 % Al powders, 0.18 mm

Figure 7 Surface conditions of workpieces after wear test.

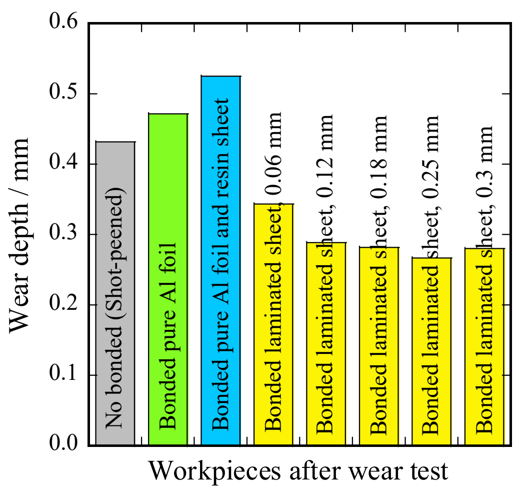


Figure 8 Relationship between powder size and wear depth.

Conclusions

The bonding method with the laminated sheet using shot peening was carried out. The laminated sheet with ceramic powders were successfully bonded to the surface of magnesium alloy by the hit of many shots. Pure aluminum powders used as the insert material to improve the bondability to the substrate. Bondability was evaluated by bending. Although the laminated sheet was fractured with the substrate, the laminated sheet peeled off from the substrate. The present method using shot peening was effective in wear resistance of the light metal products.

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