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Lining of Metal Surface with Hard-Metal Foil using Shot Peening

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1 Introduction

Light metals such as the aluminum and magnesium alloys are widely used for automotive components and electronic consumer products nowadays. Both alloys have a high ratio of strength to the weight and the low densities. Magnesium alloys have a good recyclable potential[1], but the application is still limited. Light metals, because they are not nearly as wear resistance as steel in ambient and high temperatures, are not commonly used in applications where wear resistance and strength are important. Therefore, there is strong demand to improve surface treatments that could guarantee the wear resistance of the parts in aggressive environments. For the improvement, the lining processes with hard metals such as steel and nickel are useful.

The surface treatments are usually used to improve the surface properties such as wear resistance and corrosion resistance. Plating, PVD and CVD are generally employed as the lining processes. The wear resistance of aluminum alloys was improved by dispersing the silicon-carbide particle to the surface [2] and by mixing PVD with ion implantation [3]. These lining processes, however, are inadequate for the use under severe conditions because of thin plating layers. Although a thick layer is formed by the thermal splaying process [4], the loss of thermal splaying material becomes large [5]. For the purpose of improving the surface properties, the bonding processes in metal forming are very effective. If hard materials are bonded to the surface of light metals, the surface wear resistance will be improved. Two metals are bonded by applying large pressure and plastic deformation in rolling and extrusion processes [6]. The pressure and plastic deformation break up the oxide film and contaminants at the interface between the two metals, and new and clean surfaces suitable for the bonding are generated. In these processes, however, the bonding becomes difficult in the case of a large difference between flow stresses of two metals, because the deformation is concentrated at the metal with a small flow stress.

The authors have proposed a lining process of metals with thin foils using shot peening [7]. In this method, the foil is bonded to the surface of the workpiece bringing about large plastic deformation and the pressure generated by the hit of many shots are utilized for the bonding. The lining process using shot peening is suitable for the bonding of thin and dissimilar foils required for the improvement of surface properties. By means of peening with many shots, the aluminum foil was successfully bonded over the surface of the carbon steel workpiece.

In the present study, a method for lining light metals with hard materials using shot peening is proposed. The hard materials are bonded to the surface of light metal workpieces by the collision of many shots. The effects of shot speed and the processing temperature on the bondability were examined. To evaluate the wear resistance for the bonded surface of workpiece, wear test was also examined.

2 Experimental Procedures

2.1 Method of Lining

In the shot peening process, a metal workpiece undergoes plastic deformation near the surface due to the hit of many shots at a high speed. This plastic deformation is utilized for lining metal workpieces with dissimilar foils as shown in Figure 1. Since plastic deformation caused by the shot peening is concentrated near the surface, the present method is suitable for the lining with the thin foil. In addition, this method is useful in bonding dissimilar metals because of the utilization of plastic deformation. The foil and workpiece are heated in order to make the bonding easy.

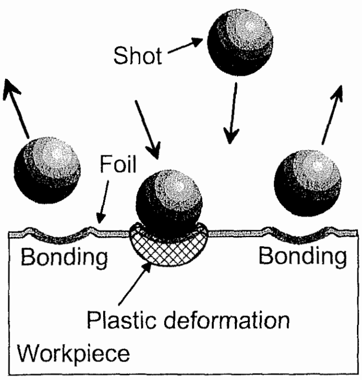


Figure 1: Lining method using shot peening.

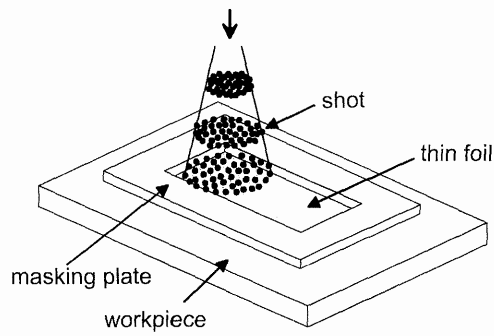


Figure 2: Lining of workpiece with thin foil using masking plate

2.2 Lining Using Masking Plate

Since the shots collide on the limited parts, shot peening is one of the partial processing, and thus this process is applicable for the partial lining. However, it is not easy to control the range of the collision of shots for the desired one. The range is limited by the masking plate as shown in Figure 2. The foil is slightly larger than the masking plate, and is fixed for the collision by the plate. The margin of the foil for the fixation is about 5mm, and the foil covered with the masking plate is removed by tearing after the shot peening. To improve the bondability, a pure aluminum foil was used as insert metal, because pure aluminum has high bondability.

To examine the shot lining, a centrifugal shot peening machine was employed in the experiment. To make the bonding easy, the metal foil and workpiece were heated in air. The shots used for the experiment are made of the high carbon cast steel (HV500), and the masking plate was made of the heat-treated tool steel. The conditions used for the experiment are summarized in Table 1, where t is the thickness of the foil and insert metal. The experiment was performed between room temperature and 400 °C in air.

2.3 Materials used for Experiment

The workpieces were aluminum alloys (A2017, A5052, A6061, A7075) and magnesium alloys (AZ31B, AZ91D), and the foils were commercially pure nickel, commercially pure titanium and stainless steel SUS304. The surface of the workpiece was cleaned with emery papers prior to the shot lining. The dimensions of the workpieces and foils used for the experiment are summarized in Table 1.

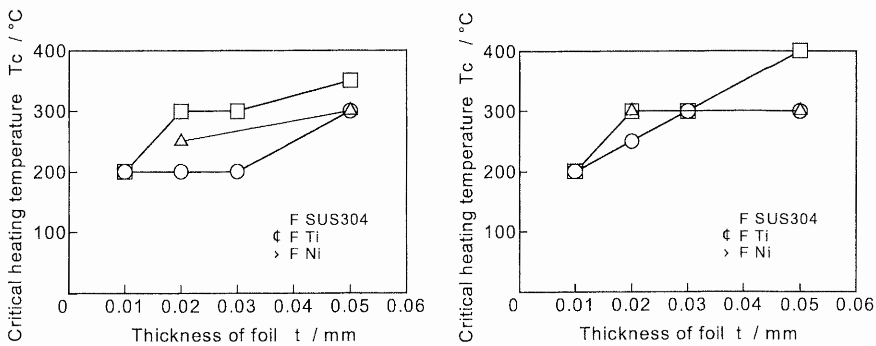
Table 1: Working conditions used for shot peening experiment.

Equipment	Centrifugal peening
Shot material	High carbon cast steel
Shot diameter d / mm	1.0
Impact speed v / m/s	40, 80
Coverage %	100
Heating temp. T / °C	20 – 400
Workpiece	A2017, A5052, A6061, A7075, AZ91D, AZ31B
Foil (t = 0.01 – 0.1 mm)	Nickel, Titanium, Stainless steel 304
Insert metal (t = 0.015 – 0.020 mm)	A1050
Surface finish (Emery paper)	# 120 (Ra = 3.3 μm)
Atmosphere	Air

3 Lining with Hard Materials

3.1 Critical Heating Temperature

The critical heating temperature for the bondability of foils was investigated. The variations of the critical heating temperature with the thickness of foil are given in **Figure 3**. The workpieces are aluminum alloys (a)A2017 and (b)A5052. Since pure nickel has a high oxidation resistance, the critical heating temperature of nickel foil is lower than that of the other foils. The critical heating temperature increases with the thickness of sheet. On the other hand, the lining for aluminum alloy A5052 was performed in order to examine the effect of the material of the workpiece on the critical heating temperature (Figure 3(b)). In comparison with the lining of the aluminum alloy A2017 workpiece with the metal foils shown in Figure 3(a), the critical heating temperature is higher. Since the magnesium content of the aluminium alloy A5052 is larger than that of the aluminium alloy A2017, the bondability of A5052 workpiece is smaller. In addition, the metal foils were successfully bonded to the aluminum alloys A6061 and A7075 workpieces. In the present study, the lining experiment was performed for the determined heating temperature.



(a) A2017(Al-Cu) workpiece

(b) A5052(Al-Mg) workpiece

Figure 3: Relationship between thickness of foil and critical heating temperature for aluminum alloys

3.2 Lining Surface

The lining of the aluminum alloy A2017 workpiece with the pure titanium foil using a rectangular masking plate at 300C was performed. The surface of the lined workpiece is given in **Figure 4**. The surface of the workpiece is uniformly hit with many shots. The exfoliation of the foil from the surface of the workpiece was not observed. The surface of the magnesium alloy AZ91D workpiece is given in **Figure 5**. Although the magnesium alloy has low bondability, the metal foils are successfully bonded to the magnesium alloy workpiece by increasing the processing temperature and using the pure aluminum insert. The lined shape is nearly the same as the masking shape. In addition, the lined shapes for the pure titanium and the stainless steel SUS304 foils are nearly the same.

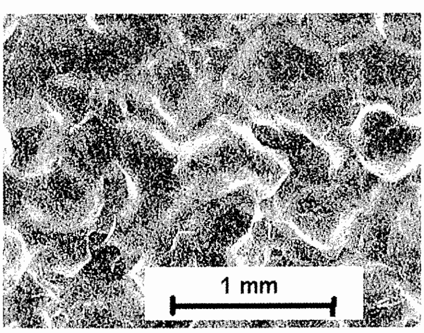


Figure 4: SEM photogaph of surface of bonded workpiece at 300 C for A2017 workpiece and titanium foil (t=0.05mm)

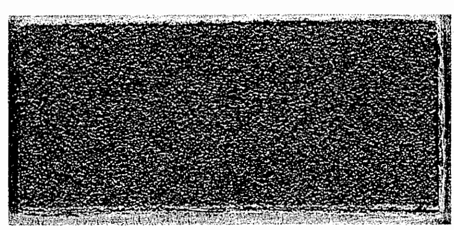
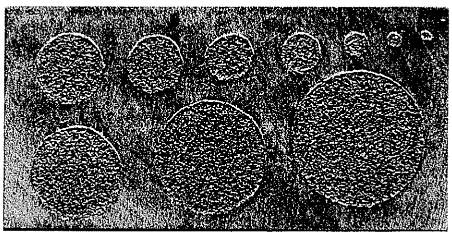


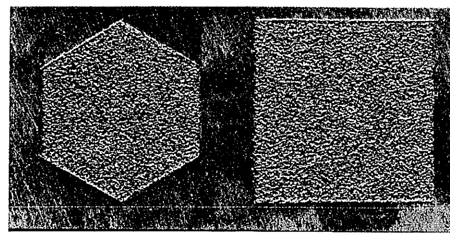
Figure 5: Surface of bonded workpiece at 300 C for AZ91D workpiece and nickel foil

3.3 Partial Lined Surface

To examine the accuracy of the lined shapes for the masking shapes, the partial lining using some masking plates was also carried out. The surfaces of the partially lined workpices using the various masking plates are shown in **Figure 6**. It is clearly that the lined shape is nearly the same as the masking shape.



(a) Circles (A6061 workpiece, nickel foil)



(b) Polygons (A5052 workpiece, titanium foil)

Figure 6: Surface of bonded workpieces for aluminum alloy workpieces and hard foils

3.4 Bond Strength

The microscopic photograph of the cross-section at 300 °C is shown in **Figure 7**. The bonding near the interface between the workpiece and foil is good.

Since the foil is very thin, it is difficult to measure the bond strength between the workpiece and foil. To evaluate the bond strength between the workpiece and foil at the boundary, the lined workpiece was bent until cracks occur. The SEM photograph of the bonded surface at boundary after bending is given in **Figure 8**. The workpiece is A2017, and the foil is SUS304. Although the foil tore, the exfoliation from the surface was not observed. The bonding of the foil was sufficient.

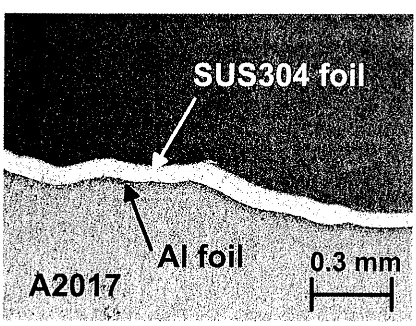


Figure 7: Microscopic photograph of cross-section for A2017 workpiece and SUS304 foil (t=0.05mm)

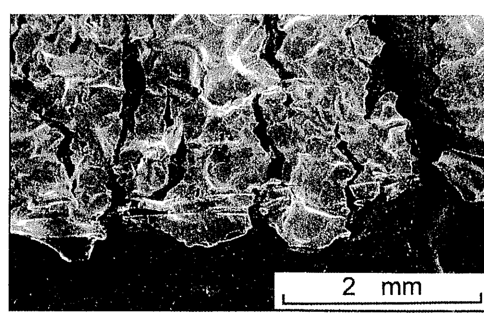


Figure 8: SEM photograph of surface of bonded A2017 workpiece after bending

4 Lining of Hard Powders

4.1 Method of Lining Using Hard Powders

The hard foils such as stainless steel, titanium and nickel were successfully bonded to the surfaces of the aluminum and magnesium alloys in Section 3.2. However, it is very difficult to bond in case of lining between light metals and hard materials such as ceramic and cemented carbide. Since many shots directly collide with the hard materials, plastic deformation in light metals is very small. In the present study, by using the powder of hard material, the lining of hard materials to light metals is tried. The hard powders are bonded to the surface of light metal workpieces by the collision of many shots.

The hard powders set on the workpiece are impacted with many shots in the experiment. However, on the smooth surface, the powders are moved by the impact of shots in the shot peening. Since it is not easy to fix the hard powders on the surface of workpiece in the shot peening, the lining process of workpiece with sandwich foil shown in **Figure 9** was tried. In the experiment, the powders are sandwiched in between two aluminum foils by a press. The foil used for the sandwich is a pure aluminum foil of 0.015 mm in thickness. The impact speed of shot and the processing temperature are 80 m/s and 300 °C, respectively.

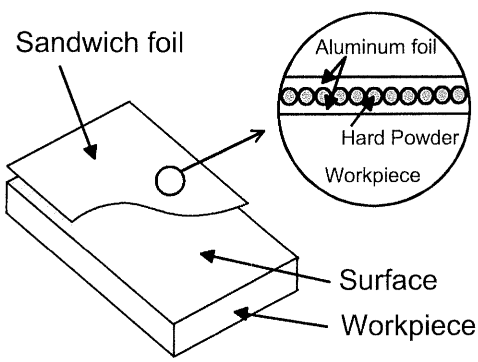
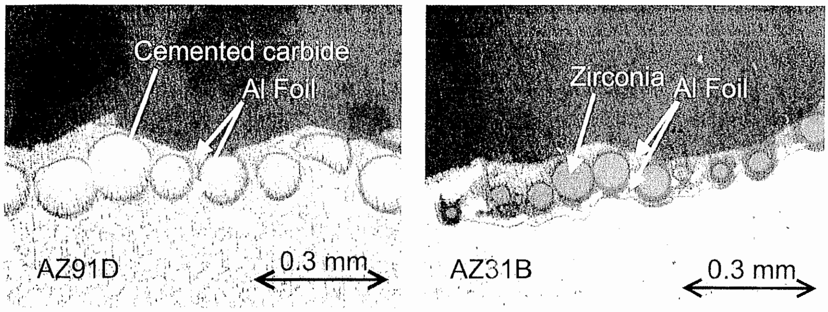


Figure 9: Schematic illustration of shot lining of workpiece with hard powders using sandwich foil

4.2 Lining with Hard Powders

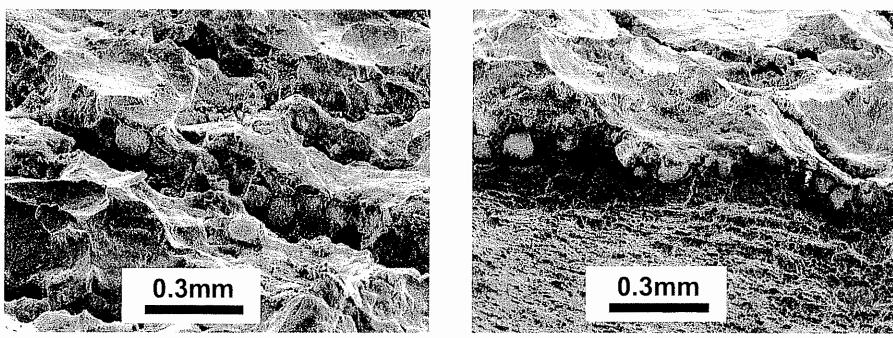
The microscopic photographs of cross section for the magnesium alloys and hard powders are shown in **Figure 10**. Although the magnesium alloys have low bondability, the hard powders are successfully bonded to the magnesium alloy workpieces using sandwich foil. In addition, the bondability for the aluminum alloys and hard powders is nearly the same.

The bonding for the workpieces and powders is sufficient in Figure 10. However, it is very difficult to measure the bond strength between the workpiece and powders. Thus, the bonded workpiece was bent until cracks occur. The SEM photograph of the bonded surface after bending is given in **Figure 11**. The workpieces are aluminum alloys A2017, and the powders are cemented carbide and zirconia. Although cracks were generated on the surface, the separation from the surface was not observed. The bonding of the powders was sufficient.



(a) Cemented carbide (b) Zirconia

Figure 10: Microscopic photographs of cross-section for magnesium workpieces and hard powders

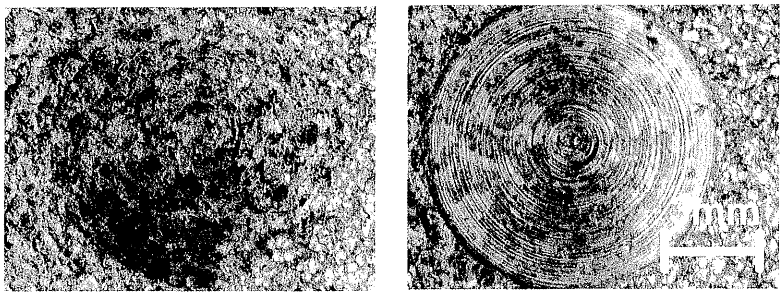


(a) Cemented carbide (b) Zirconia

Figure 11: SEM photographs of surface of bonded workpieces after bending

4.3 Wear Resistance

To evaluate the wear resistance for the bonded surface, wear test was examined. A cylindrical grinding wheel is removing a layer of material under a certain load. The workpiece is held in place with a chuck. The size of abrasive grain is about 0.2 mm. The experiment was performed in a wet atmosphere in order to prevent the friction heat. The equipment used for wear test imposes a load of 2 kg on a 10 mm diameter wheel. The surfaces of the bonded AZ31B workpieces after the wear test are given in **Figure 12**. The surface of the workpiece with the chromium powder becomes a flat by the grinding. In the case of the lining with the cemented carbide powders, the wear is smaller. Namely, the bonded surface has a fairly good resistance to wear. In addition, the wear test for the bonded aluminum alloy workpieces was also performed. The wear resistance for the bonded workpieces is nearly the same as the magnesium alloy workpieces. Since the hardness number on cemented carbide and alumina is higher, the wear on the surface is small. It is clearly that the lining with hard powders is effective in the wear.



(a) Cemented carbide (b) Chromium

Figure 12: Surfaces of bonded AZ31B workpieces after grinding

5 Conclusions

A lining method with hard metals using shot peening was carried out. The hard metals were successfully bonded to the surface of the metal workpieces by the hit of many shots. The accuracy of the lined shapes was sufficient. The bond strength of the lined workpiece was sufficiently confirmed by a bending test. The lining with sandwich foil was also tried. The hard powders were successfully bonded to the surface of the metal workpieces. The wear resistance of the lined workpiece was confirmed to be sufficient by wear test of lined workpieces. It was found that the present method using shot peening is effective in wear resistance of the metal products.

6 Acknowledgement

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7 References

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