SURFACE MODIFICATION OF CARBON STEEL BY SHOT LINING

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ABSTRACT

In the present study, a lining process for carbon steel using shot peening was investigated to improve the surface properties such as corrosion and oxidation resistances. In the shot lining, a foil set on a metal workpiece is pelted with many hard shots at a high velocity. The foil can be bonded to the surface of the workpiece due to plastic deformation induced by the collision of the shots. In the experiment, an air-type shot peenig machine with an electrical heater was employed. The shot speed and the coverage are controlled in the experiment. The effects of shot conditions and the heating temperature on the bondability were examined. To improve surface properties such as wear resistance and corrosion resistance, alloying of the lined foils was also attempted by heat treatment. The metal foil was successfully bonded to the surface of the substrate. It was found that surface properties of carbon steel could be improved by the shot lining process.

KEY WORDS

Lining, Surface modification, Carbon steel, Plastic deformation, Joinability

INTRODUCTION

The metal lining is available for the improvement of surface properties of the components. The plating or coating process is mostly used. However, the plated components are sometimes unacceptable for the use under severe conditions because of a thin plating layer. On the other hand, in thermal splaying a comparatively thick layer can be produced. In hard facing a relatively thick layer is deposited on the surface by the welding methods. However, the bond strength is often not high. It is desirable in industry to develop a process for lining components with a layer having appropriate thickness and strength.

The shot peening process is one of the surface treatments. In this process the peening effects are characterized by the fact that the surface layer undergoes large plastic deformation due to the collision of shots. Namely, overlapping dimples develop a uniform layer of residual compressive stress or work hardening. This effect can increase life-time of parts. In recent years, the joining processes by using shot peening have been studied to improve the surface properties. The dry coating techniques (Y. Kataoka, 2001) and cold splay (T. H. Van Steenkiste et al., 1999) are used. The metal particles and the substrate can be joined by the adhesion or embedding of particles at high speed. The authors have proposed a lining method by shot peening (Y. Harada et al., 1998). By means of peening with many shots, the foil was successfully joined over the surface of the substrate. This method, i.e., shot lining, is used for the lining of the dissimilar foils. We also examined the lining of the hard powders such as cemented carbide and ceramics by shot peening to improve the wear resistance of light metals (Y. Harada et al., 2002). In this method, the hard powders were successfully bonded over the surface.

In the present study, lining of carbon steel with metal foil by shot peening was carried out in order to improve the surface properties. The foil is bonded to the surface of the workpiece due to plastic deformation caused by the hit of shots. The joinability for lining of carbon steel with the pure aluminium foils was mainly examined. Also, alloying of the lined foil was attempted by heat treatment.

EXPERIMENTAL PROCEDURE

In shot peening a metal workpiece undergoes plastic deformation near the surface. Therefore, this plastic deformation is utilized for lining metal workpiece with dissimilar foil. As illustrated in Figure 1, when the dissimilar foil is set on the workpiece and then shot-peened, it can be bonded to the surface of the workpiece. The pressure and plastic deformation break up the oxide film and contamination at the interface between the dissimilar materials, and new and clean surfaces suitable for joining are generated. This method is useful in joining dissimilar metals because of the utilization of plastic deformation. The foil and the workpiece are heated in order to make the joining easy.

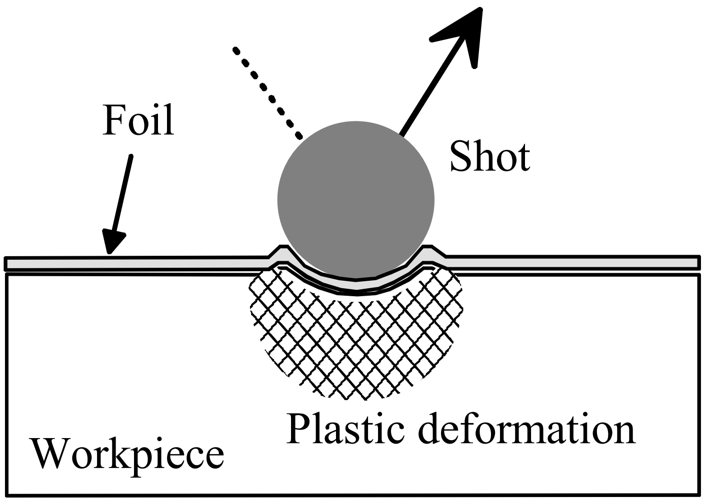


Figure 1 Schematic illustration of shot lining method

Table 1 Conditions of shot lining

Equipment	Air peening type
Shot material	High carbon cast steel, 700 HV
Shot size / d	0.6, 1.0, 1.4 mm
Air pressure / p	0.4, 0.6, 0.8 MPa
Coverage / C	100 %
Workpiece (S45C)	N: normalized at 850 ^{o}C for 3600 s, 210 HV QT: quenched from 850 ^{o}C and tempered at 600 ^{o}C for 3600 s, 270 HV
Foil	Pure aluminium, A1050 (t=0.02 – 0.06 mm)
Working temperature	RT – 300 ^{o}C

Shot peening was performed with an air-type machine using cast steel balls. The apparatus with a heating furnace was fabricated to examine the effect of the working temperature. The workpiece is set on the holder with the heater. The shot velocity and the coverage are controlled in the experiment. Air pressure is in the range from 0.4 to 0.8 MPa and coverage is 100 %. Coverage is defined as ratio of the dimpled surface to the total surface after shot peening. The coverage of 100 % is attained when the surface is just covered with the indentation.

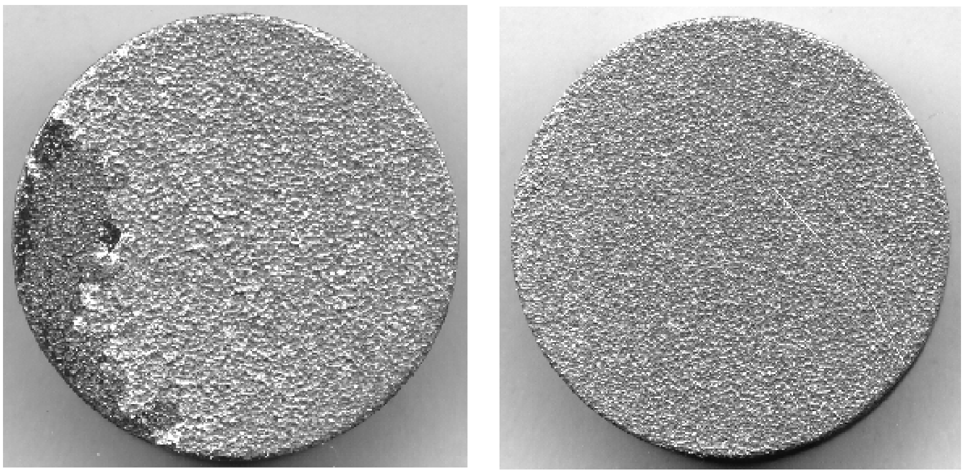
The foil was the commercial pure aluminum and the workpiece was the commercial carbon steel S45C normalized at 850^{o}C austenitizing temperature (workpiece N). Some of workpieces were tempered (workpiece QT). The dimensions of the workpieces are 25 mm in diameter, 10 mm in thickness. The surface of the workpieces was cleaned with emery papers prior to shot lining. The experiments were performed between room temperature and 300 ^{o}C in air. The conditions used for the shot peening experiment are summarized in Table 1.

RESULTS

Lining of pure Al foil

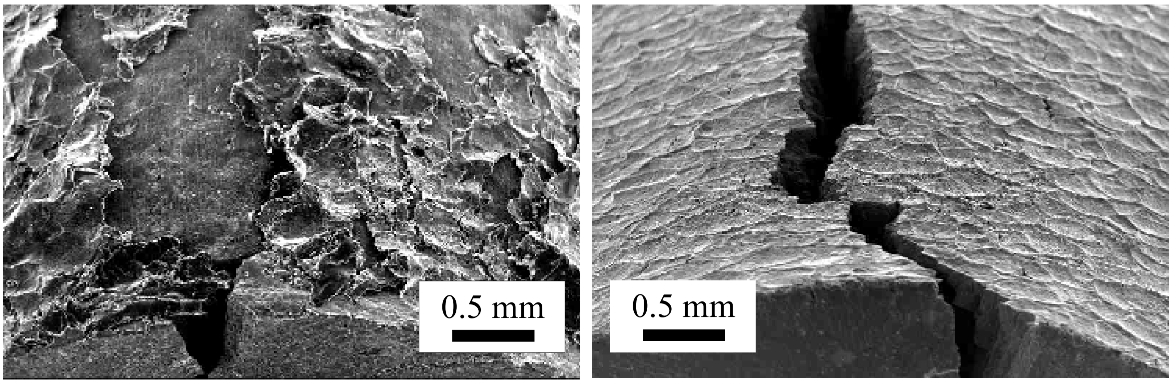
Shot lining of workpiece N with pure aluminium foil was carried out under several conditions. When the working temperature and air pressure are low, the joinability between the workpiece and pure aluminium foil is not high. As the working temperature and air pressure increase, the foil can be successfully lined to the surface of the workpiece. Especially, the increase of working temperature was effective for lining. However, when the ratio of the diameter of the shot to the thickness of the foil; d/t is small, the joinability is not high even if air pressure is high. The appearances of the lined workpieces at high pressure are shown in Figure 2.

To examine the joinability between the foil and the workpiece, the joint zone of the lined workpiece was observed by optical microscope. In the lined workpiece, the void was observed in the interface of the foil and the workpiece, although the lining of foil appeared to be the complete lining. Therefore, it is difficult to observe the voids by visual inspection, namely, to determine the degree of the joinability.



(a) Incomplete lining (b) Lining

Figure 2 Appearances of surface of the lined workpiececs:
(a) incomplete lining, 0.040mmt-Al, d=0.6 mm, p=0.8 MPa, RT;
(b) lining, 0.020 mmt - Al, d=1.0 mm, p=0.8 MPa, T=300 ^{o}C



(a) 100 % lining (b) Complete lining

Figure 3 SEM micrographs obtained for the lined workpiece N after bending: (a) d=1.0 mm, p=0.6 MPa, T=100 ^oC; (b) d=1.0 mm, p=0.6 MPa, T=300 ^oC

As noted above, the data from the appearances of the lined workpieces do not permit a determination as to whether or not the foil can be firmly joined to the workpiece without the voids. In addition, it is very difficult to measure the bond strength between the workpiece and thin foil. Therefore, the joinability for the lined workpiece is evaluated by bend test. In bend test, the lined workpiece was bent until cracks occurred. SEM photographs of the lined workpiece N after bending are shown in Figure 3. Air pressure was p=0.6 MPa. When the working temperature is low, the foil is torn by the bending (see Figure 3a). As the temperature increases, however, the exfoliation from the surface was not observed (see Figure 3b). It was found that the joinability for the workpieces lined at lower temperature was not good. In this study, the degree of lining is evaluated by bending the lined workpiece. Thus, the degree is classified into the following four categories:

(1) Complete lining: the foil is still joined to the surface after bending;
(2) Lining: the foil is tore after bending;
(3) Partial lining: the foil is partially joined to the surface after peening; and
(4) Failed: the foil hardly is joined to the surface after peening

To examine the joinability of pure aluminium foil, the critical lining limit was investigated. The variation of air pressure with the processing temperature in the combination of the workpiece N and pure aluminium foil of 0.020 mm in thickness is shown in Figure 4. The shots having d=0.6 mm were used for lining test. As air pressure increases, the joinability rises. Also the joinability is improved by increasing the processing temperature. Pure aluminium foil can be successfully joined to the workpiece at temperatures of the order of 200 ^oC and above.

To examine the effect of the shot size on the joinability, lining of the workpiece N with the aluminum foil was performed. The variation of air pressure with the processing temperature in the combination of the workpiece N and pure aluminium foil of 0.020 mm in thickness is shown in Figure 5. The average size of shots used was d=1.0 mm. The joinability of the foil was slightly improved (see Figure 4). The size of shots was changed. In the case of d=1.4 mm, however, joinability of the foil is nearly the same as that of the foil peened by shots with d=1.0 mm. The complete lining is shifted to low temperature.

To examine the effect of the thickness of the foil on the joinability, the lining of the workpiece N with the aluminum foil was carried out. In comparison with the lining of the thinner foil, the complete lining limit was higher.

The effect of hardness of the workpiece on the joinability was also examined. The variation of air pressure with the working temperature for the workpiece QT and aluminum foil of 0.020 mm in thickness is given in Figure 6. The shot size was d=1.0 mm. In comparison with the lining of the workpiece N with pure aluminium foil of 0.020 mm in thickness (see Figure 4), the joinability increases. The critical lining limit shifts to lower temperatures. Since hardness of the workpiece QT is higher than that of the workpiece N, the foil is easy to be deformed. Namely, the amount of plastic deformation of the foil is lager. In this case the slipping is caused at the interface between the foil and the workpiece. Large plastic deformation break up the oxide film at the surface of the foil, and new surfaces suitable for the joining are easy to be generated.

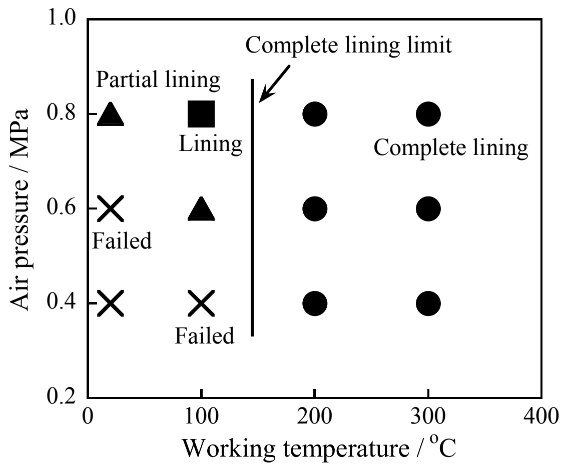


Figure 4 Relationship between air pressure and working temperature for the workpiece N and pure aluminum foil (t=0.020 mm, d=0.6 mm)

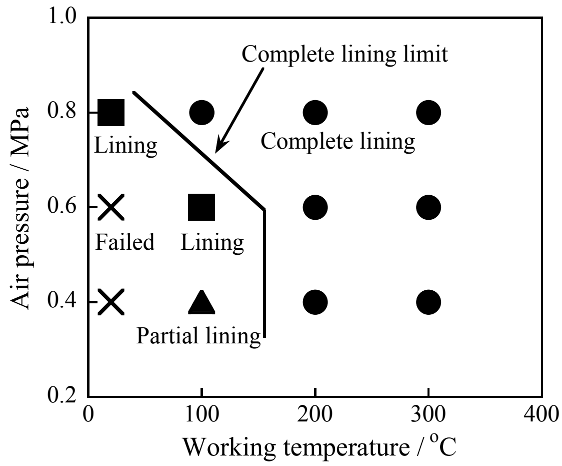


Figure 5 Relationship between air pressure and working temperature for the workpiece N and pure aluminum foil (t=0.020 mm, d=1.0 mm)

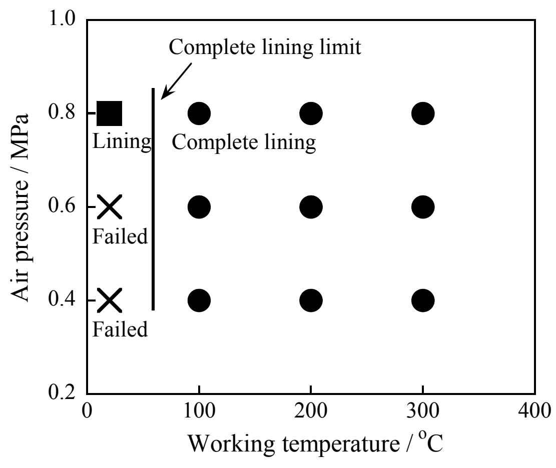


Figure 6 Relationship between air pressure and working temperature for the workpiece QT and pure aluminum foil (t=0.020 mm, d=1.0 mm)

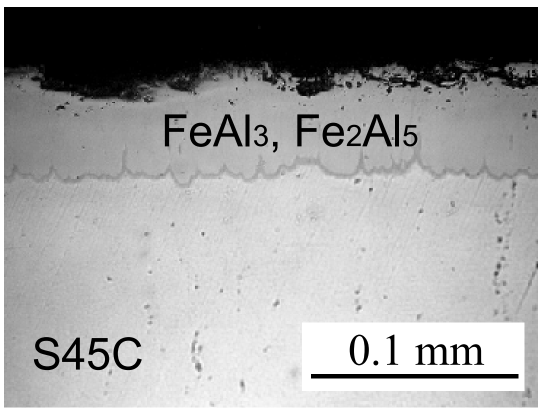


Figure 7 Cross-section observation for the lined workpiece N (Al foil: t=0.040 mm) annealed at 660 °C for 3.6 ks. Working conditions: d=1.0 mm, p=0.8 MPa, T=300 °C, C=100 %.

Alloying in surface layer by heat treatment

In shot lining, the collision of shot causes large plastic deformation of the surface. The surface layer of the lined workpiece is cold worked. Especially, the dislocation density in the foil increases with deformation. By making the heat treatment, alloying in the surface layer is relatively accelerated. For example, aluminium forms an intermetallic compound with iron. A study on the aluminizing treatments using aluminium foil on mild steel surface was carried out, and it revealed that the surface characteristics were remarkably improved (T. Sasaki and T. Yakou).

To improve the surface properties, the lined workpiece was heat treated. Lining of workpiece N with pure aluminium foil of 0.040 mm in thickness was carried out, and then the lined workpiece was annealed at 660 ^{o}C for 3.6 ks. The working conditions of shot lining were d=1.0 mm, p=0.8 MPa, T=300 ^{o}C, and C=100%. The microscopic photograph of the cross-section of the lined workpiece N is shown in Figure 7. The X-ray analysis proved that the surface layer contains $FeAl_3$ and Fe_2Al_5 (900 - 950 HV).

CONCLUSIONS

The lining of carbon steel with metal foils using shot peening was investigated to improve the surface properties such as corrosion and oxidation resistances. The effects of processing conditions on the joining between thin foil and the workpiece were examined. The dissimilar foils were successfully joined to the surface of the workpiece due to plastic deformation caused by the collision of the shots. Alloying of the surface of the lined workpiece was attempted using heat treatment. The surface of the lined workpiece became covered with hard layer of the intermetallic compounds. It was found that surface properties of carbon steel could be improved by the shot lining process.

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REFERENCES

Y. Harada, K. Mori and S. Maki, J. Mater. Proc. Technol., 80-81 (1998), 309-314.
Y. Harada, K. Mori and S. Maki, ibid., 125-126 (2002), 525-531.
Y. Kataoka, J. Surface Finishing Soc. of Japan., 52 (2001), 191-194.
T. Sasaki and T. Yakou, Tetsu-to-Hagane, 89 (2003), 1227-1232.
T. H. Van Steenkiste, J. R. Smith, R. E. Teets, et al., Surface and Coatings technology, 111 (1999), 62-71.