Applicability of fine particle peening on surface modification of aluminum alloy

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ABSTRACT

The present study describes the hardening aluminum alloy modified by fine particle shot peening. The impact media were silica glass, zirconia, steel and fly-ash. Having 50 μm in diameter was accelerated with pressurized gas to collide against the target surface. Surface profile, element distribution and micro hardness were measured. As a result, optimizing of the peening condition such as treatment time and gas pressure required an increase in hardness and surface roughness increased with an increase in gas pressure when silica glass and zirconia were used. It was found that the smaller fly-ash particles resulted in crush of the cohesive particles was migrated into the surface and that an increase of the hardness was larger than what was obtained with silica glass and zirconia. In the case of fine steel particle peening, a significant increase of hardness caused by transfer of the steel to aluminum surface was found. Therefore, it was concluded that transfer and migration of the impact particles was effective to increase in hardness of the aluminum surface.

KEY WORDS

Fine particle peening, Hardening, Penetration, Transfer, Aluminum alloy, Fly-ash

INTRODUCTION

It is well recognized that generation of residual stress filed near the surface resulted from peening particles with high velocity improves hardness and fatigue strength of the structural components [1]. The dimple formed by particle collision also acts as an oil pocket and is expected to reduce friction resistance in lubricated condition with optimizing the geometry [2, 3].

The hardening obtained by peening is usually dominant with work hardening of the surface region and depends on the peening condition. Since the excess peening condition may result in erosive wear of the surface, an increase of hardness by peening is actually limited. On the other hand, it was confirmed that transfer of the soft impact particle effects on the surface hardness. Therefore, peening with hard particles anticipates a novel hardened process due to the transfer and/or penetration of the particle fragments [4].

The present study describes the peening effect with hard impact particles on the hardening of soft metal materials using the developed testing apparatus. Aluminum alloy and steel, zirconia, silica and fly ash were used for the target material as impact media, respectively. Hardness and element distributions were measured and the hardening mechanism was discussed.

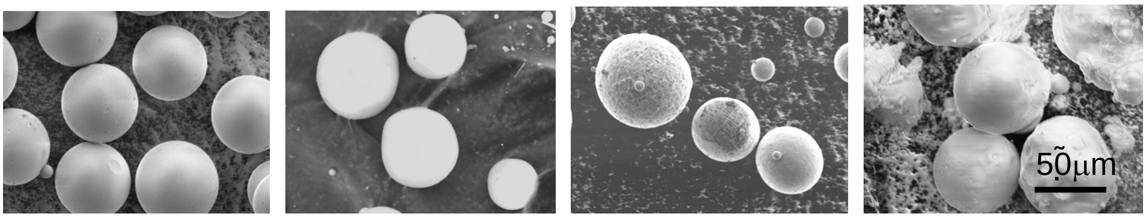
METHODS

Development of peening apparatus

In order to actualize the steady flow rate of smaller impact media less than 5 μm, the peening apparatus was developed. The basic system was a direct gas injection type and the impact media was storage into a steel vessel with rubber balls. The pressurized air was ejected into the vessel from the top and the rubber balls were moving and crushed to cohesive particles by turning flow. The particles are mixed with the air then ejected from a nozzle through a chimney settled on the vessel to the target surface. With optimizing the air pressure, height of the chimney and account of the ball, it was confirmed that the developed apparatus was possible to eject the smaller impact media without particle cohesion.

Materials

Materials of the impact media were silica (SiO_2), zirconia (ZrO_2), steel (Fe) and fly-ash (FA). Fly ash is one of industrial wastes from power plants using crushed coal as fuel and is consisted of alumina (Al_2O_3), silica and calcia (CaO). SEM images of the impact media are shown in Fig.1. The shape of the media was a sphere with 50 μm in diameter. Fine particles were found in FA because cohesion strength was too high to sieve. Table 1 showed mechanical properties of the media. The hardness of fly ash and density of steel were the highest among the four materials, respectively. The target material was aluminum alloy (A6063S) with a mirror finished surface (less than 0.02 μm Ra).



Silica glass Zirconia Steel Fly-ash

Fig. 1 SEM image of the impact media

Table 1 Mechanical property of impact media

Material	Density, g/cm^3	Young's modulus, GPa	Hardness HV
Silica glass	2.4	70	500
Zirconia	6.0	245	1200
Steel	7.8	200	700
Fly-ash	1.7	----	1000

Experiment

The impact media were mixed with pressurized air and were collided against the target surface. The distance and the angle between the nozzle and the surface were approximately 40 mm and 90°. After the peening treatment, surface profile and element distribution were analyzed with a stylus profile meter and SEM/EDX, respectively. Hardness was measured from the top of the surface with various indent loads of 3 and 10 mN, because the maximum shear stress due to the sphere impact is expected to occur at the specific depth. The corresponding depth was approximately 2 μm in 3 mN and 5 μm in 10 mN, respectively.

RESULTS

Influence of treatment time

The hardness as a function of treatment time with various conditions was shown in Figs.2. Peened with silica (Fig. 2a) and zirconia (Fig. 2b), hardness measured with 3 mN increased with an increase in treatment time but does not always increase in the gas pressure. The maximum hardness was 250 Hv, 2.5 times larger than the nominal surface, obtained at more than 0.5 MPa of gas pressure and 70 sec of the treatment time. The results of 10 mN showed that an increase of the hardness was relatively smaller. Therefore, the hardening region by silica glass peening restricted near the surface region. Similar tendency was found in the results with zirconia but the maximum hardness was 320Hv, larger than what was obtained with silica glass. In the result of the fly-ash peened surface (Fig. 2c), a larger increase of hardness, approximately 400 Hv was found and the hardened region expanded because the value measured at 10 mN also increased. The highest hardness, similar with that of hardened steel was confirmed in the result of the steel peened surface at the specific condition (Fig. 2d). However, the depth of the hardened layer was limited near the surface.

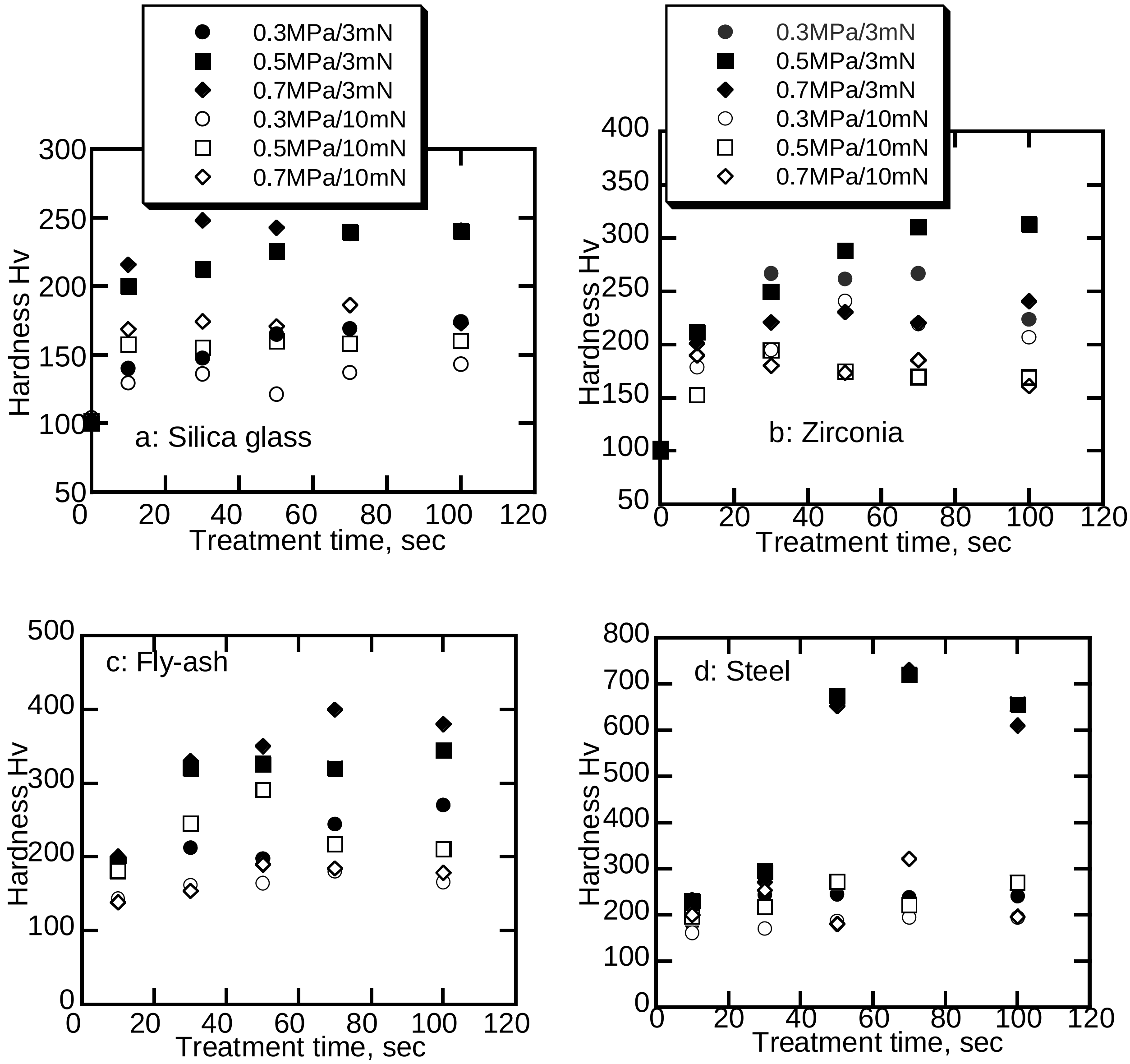


Fig. 2 hardness as a function of treatment time

Maximum hardness obtained in each condition was summarized in Fig.3. Linear relation between hardness and impact energy estimated from gas pressure and the media density except the results of fly-ash and steel. It was also found another relation on results peened with fly-ash and steel.

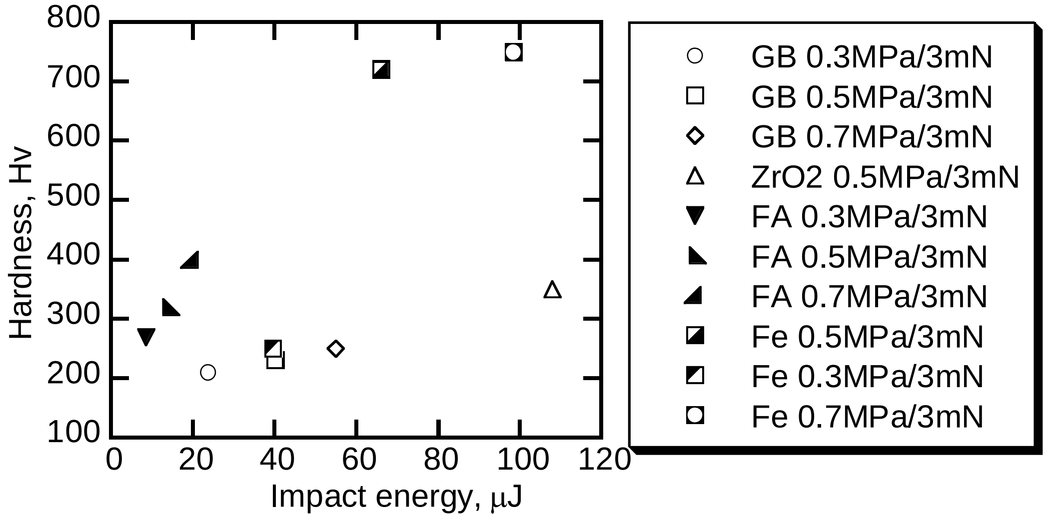


Fig. 3 Relationship between hardness and impact energy

Surface analysis

SEM images of the peened surface were shown in Fig.4 and Fig.5. Surface profile was different depending on the peening conditions and the impact media. Peened with silica glass (Fig. 4a) and zirconia (Fig. 4b) at lower gas pressure (0.3 MPa) and short treatment time (10 sec), formation of micro dimples with 10-20 μm in diameter were seen on the surface. At highest gas pressure (0.7 MPa) and longer treatment time (100 sec), the surface roughness increased. Considering the maximum hardness occurred at medium gas pressure (0.5 MPa), it was estimated that erosive wear loss of the hardened layer resulted in restriction of the increase of hardness.

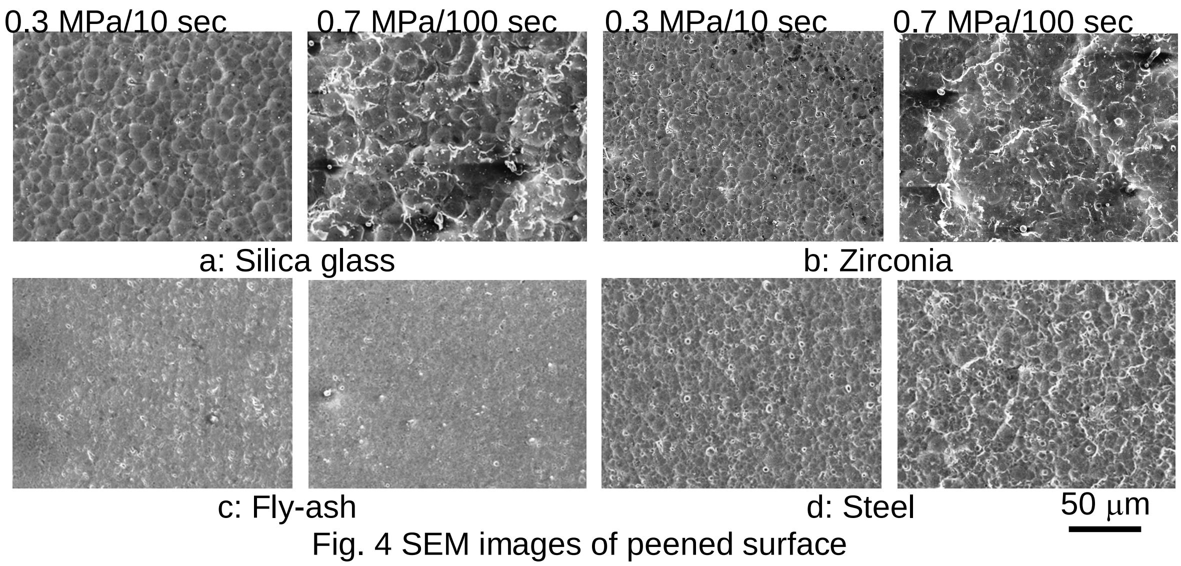


Fig. 4 SEM images of peened surface

In the result of peening with fly-ash (Fig. 4c) and steel (Fig. 4d), micro dimple formation was not clearly seen and the increase in the roughness with an increase in the gas pressure and treatment time.

From the SEM/EDX analysis, no element in contents of the media was found on the impact surface in the result of Silica glass and zirconia. On the other hand, treated with higher gas pressure, Si and Fe, were detected on the surface in case of the fly-ash and the steel (Fig. 5): The small fly-ash, particles shown in the enlarged image were migrated and migration and transfer of the steel fragment occurred on the surface. Consequently, the migration and the transfer resulted in a significant increase in hardness near the surface region of aluminum alloy and a decrease in the surface roughness.

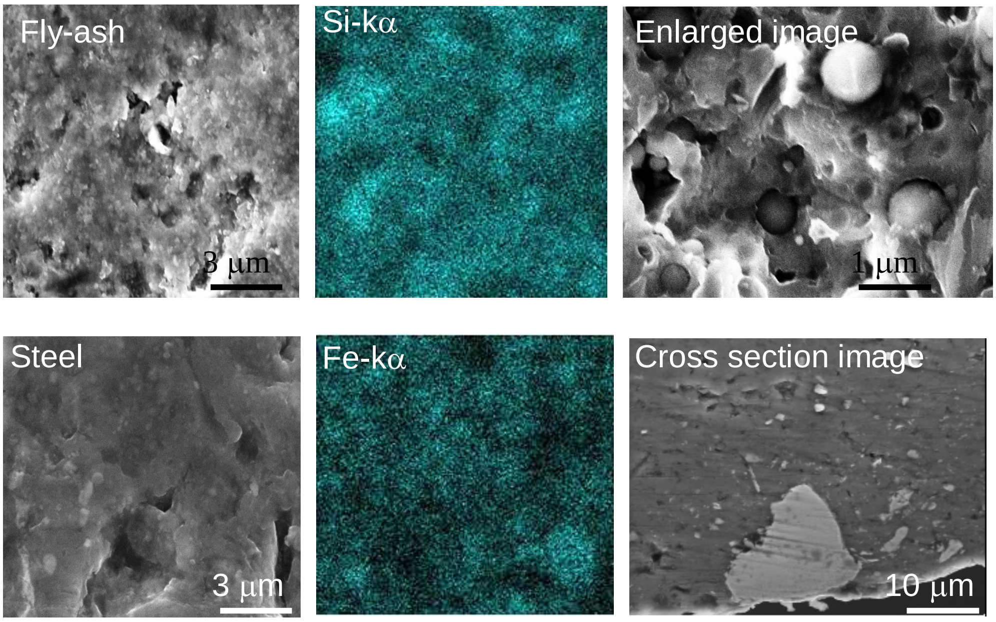


Fig. 5 SEM/EDX images of fly-ash and steel peened surface

Conclusion

In order to evaluate the hardening mechanism of fine particle shot peening, silica glass, zirconia, fly-ash and steel particles with the similar diameter were examined with various peening conditions. As result, it is confirmed that a significant increase of hardness is obtained by migration and transfer of the fragments of the impact particles.

References

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