Effect of heat treatment on friction properties of functional graded materials fabricated by fine particle peening

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Abstract

This present study describes the effect of heat-treatment to the functional graded material fabricated by fine particle peening for improving tribological properties. The application of heat-treatment is to control properties of functional graded regions where the fine particles were migrated. Fine tungsten carbide particle used for the formation of the functional graded surfaces were coated with the steel beads and then were used to penetrate the alloy steel sample surface. The heat-treatment was carried out at various temperatures. The surface and the cross section after heat treatment were analyzed with SEM/EDX, and the hardness was measured by micro-indentation. The change of the micro structure and the increase in the hardness were found in the heat treated specimen.

Tribological properties of specimens were evaluated with the thrust type rolling contact experiment under lubricated condition. Hardened chromium alloy steel (SUJ2) was used as the rolling element. As a result, it was confirmed that the peened and heat treated specimen having higher hardness showed not only superior wear resistance but also lower traction coefficient than the mirror surface. Moreover, the damage of matching materials was reduced to the same level as the mirror surface.

Keywords Fine particle peening, Heat-treatment, Functional graded material, Tribology, Melting and penetration

Introduction

It is effective for the fatigue strength improvement of materials that they be hardened by plastic deformation and the impressions of the compressive residual stress on the surface and subsurface by high-speed projection of fine particles. [1] In addition, friction reduction and wear resistance improvement are expected because the texture which consists of micro-dimples formed by fine particle peening functions as the pockets for the lubricating oil and serve as abrasive powder. [2], [3]

The gradient composition layer is formed in the material surface region because the materials become composite by the migration or adhesion of the collision particle to the material surface depending on the peening condition. The fabrication of the material surface which has rigid and high hardness without the provided compressed residual stress by the controlling of the gradient composition layer, [4] and this is expected as new surface modification.

The surface modification layer fabricated by the composition of the migrated particles and modified material surface act like a film coating. Therefore it is concerned about the falling off of the particles which are migrated to by fine particle shot peening from material surface like a film coating. It is thought that the hard particles work as abrasive powder. In addition, because hard particles act, the wear resistance of material surface improves. But it is concerned about letting partner materials of the friction (e.g., a steel ball of the bearing) damage on the contrary. Therefore, it is necessary to control interface composition.

The present study describes the effect of heat-treatment to the functional graded material fabricated by fine particle peening with high-hardness particles of tungsten particle. Hardness and element distributions were measured, and frictional properties are discussed.

Methods

Fine particle peening

A low flow quantity of fine particle peening device shown in Fig.1 made by ITOH KIKOH was used for the fine particle peening processing. The characteristic of this device is that the fine particles which are easy to cohere and are easy to break up. The basic system was a direct gas injection type and double tube structure. The flow quantity and the acceleration of the particle were controlled by the gas pressure of the air. In addition cohered particles were individually crushed in a storage tank by a rubber ball being mixed in the tank.

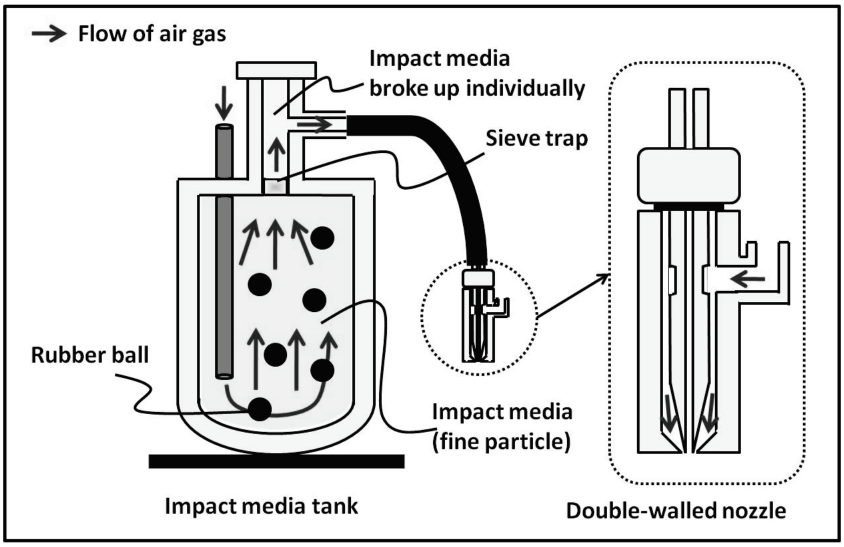


Fig. 1 Schematic of Low flow rate shot peening apparatus

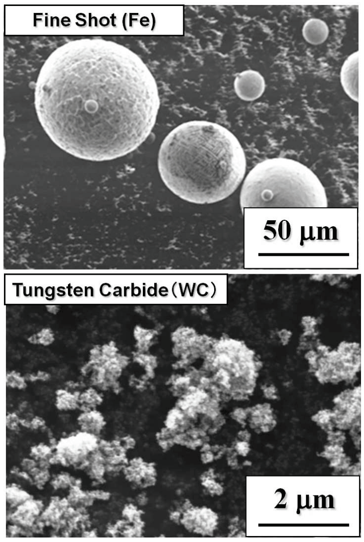
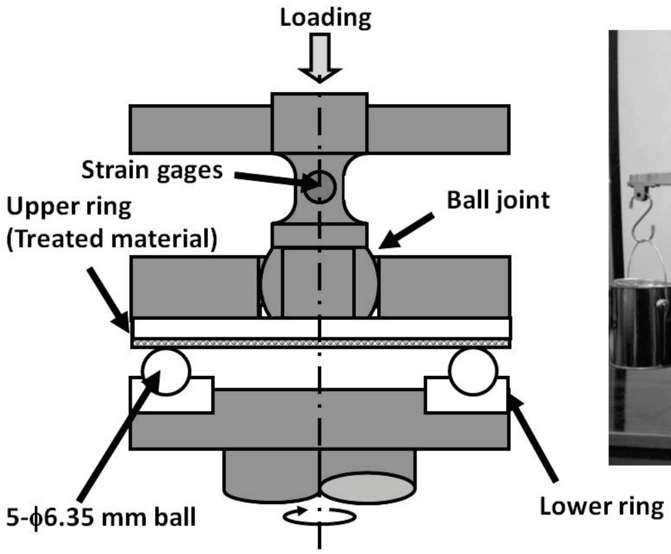


Fig. 2 Impact media

A spherical steel particle of 50 μm (SB) and angular fine particles of tungsten carbide (WC) shown in Fig.2 were used for impact media. These were mixed in a ratio of 5:1, and the particle mixture was projected onto the material's surface. High carbon chromium bearing steel was made with the dimensions of ϕ42mm X t3mm and was used for the test materials.

Experiment

The heat-treatment for the specimens was carried out by an electric muffle furnace in an oxidation atmosphere. The heat-treatment was performed on the peened surface at 300, 400, 500, and 600 degrees Celsius, in 60 and 120 minutes time periods. A pure carbon powder with particle size of 5μm was applied to control the oxidation of the specimens. The heat-treated material surface and surface region were observed by SEM/EDX, and the mechanical characteristics were evaluated by measuring the micro-Vickers hardness and surface roughness values. The frictional properties were evaluated by a thrust type rolling contact examination shown in Fig.3. The rolling contact examination was carried out under a lubricated environment by a condition that loaded was 450N. The friction distance was 325 m, the rate of rotation was 500 rpm (in other words, friction speed was 0.09m/s), and machine oil (40cst@40°) was supplied 30 micro-liter on the frictional surface. Five high carbon chromium bearing steel balls of ϕ6.3mm were arranged to the rolling element as matching material. Therefore, the contact pressure of the early appearance is 1.9GPa.



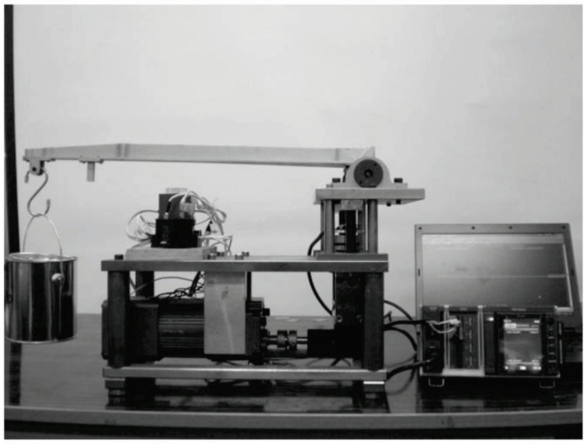


Fig. 3 Schematic of rolling contact apparatus

Results

Surface modification

SEM images of peened the surface by fine particle peening and the distribution of the tungsten element maps are shown in Fig.4. Fine particles of approximately 2μm were migrated in the specimen surface equally, and they showed the presence of tungsten element. In the case of the observation made from a cross section of a sample, the migration of the fine particles was seen in only the surface, and it showed a tungsten element. From these pictures, the WC particles were transferred to the material surface efficiently by the fine particle peening treatment following the mixed particles that coarse steel particle and fine tungsten particle were mixed, and it was confirmed that the crushing of the fine particles by the energy of projection did not occur because the migrated particles size did not change. In addition, it was confirmed that the WC fine particle did not penetrate the sample material only by this treatment.

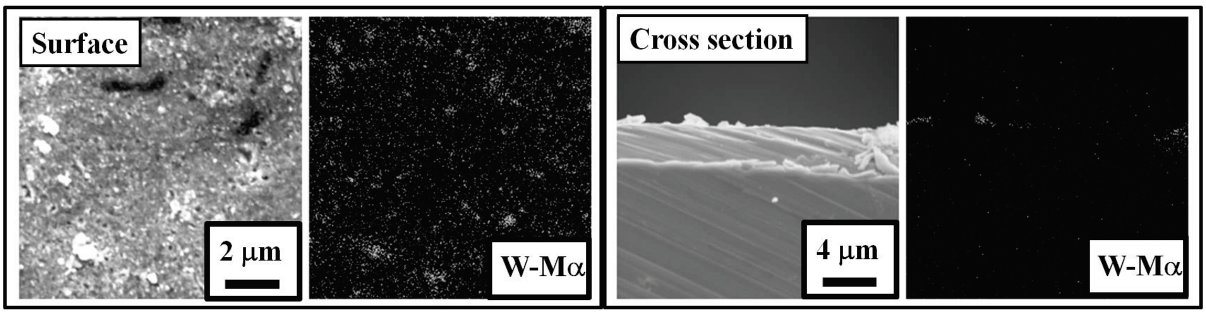


Fig. 4 SEM/EDX images from surface and cross section

Heat-treatment

The distribution of tungsten from surface and cross section are shown in Fig.5 and Fig.6, respectively. Even if migrated WC particles were heat-treated at 300 degrees C, a big difference was not found in comparison with particle size before the heat-treatment, and the penetration to the interior of the samples by the WC particles were not found equally, either. However, when treatment temperature was 400 degrees C, the diameter of WC particles reduced the tendency although there were few differences in comparison with before the heat-treatment. In addition, the distribution of tungsten was found in the depth of the specimen of approximately 1μm from surface. Moreover, when the treatment temperature became 600 degrees C, most of the WC particles did not remain behind on the material's surface, and only tungsten was distributed over the materials surface. In these results, it was confirmed that the migrated WC particles were melt and penetrated to the material inside by applying heat-treatment. The big difference was not found about in heat-treatment times.

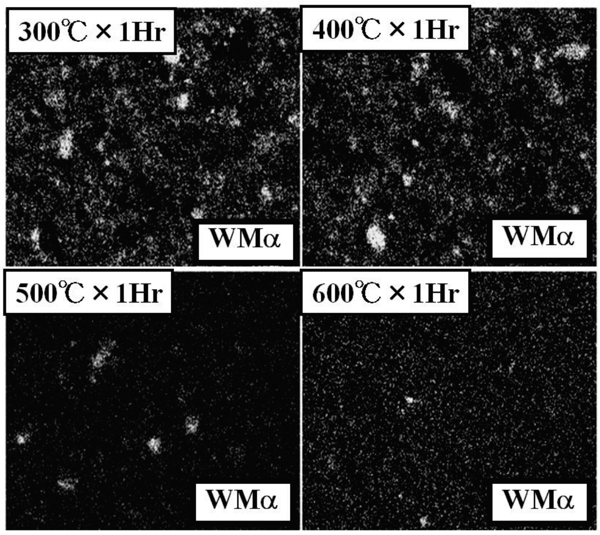


Fig. 5 W-Mα maps: observation from surface

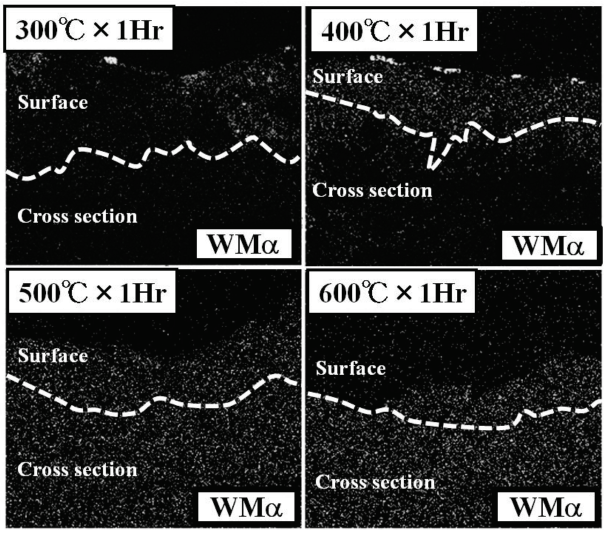


Fig. 6 W-Mα maps: observation from cross section

Mechanical properties

The result of surface hardness measured by micro-Vickers at 300 mN load after heat-treatment is shown in Fig.7. The surface hardness of the specimen before the heat-treatment increased approximately 100 HV in comparison with the machined surface of 300 HV by the hardening by shot peening effect plus the influence of the WC particle migration. Even if heat-treatment was applied to these specimens, the deterioration of the surface hardness had not occurred. Moreover, the surface hardness of heat-treated specimens at 400 degrees C was approximately 600 HV, and this was shown that the hardness increasing of 300 HV against the machining surface and 200 HV compared to the non-heat treated surface. In addition, the treatment temperature was more than 500 degrees C and a hardness increase was not found.

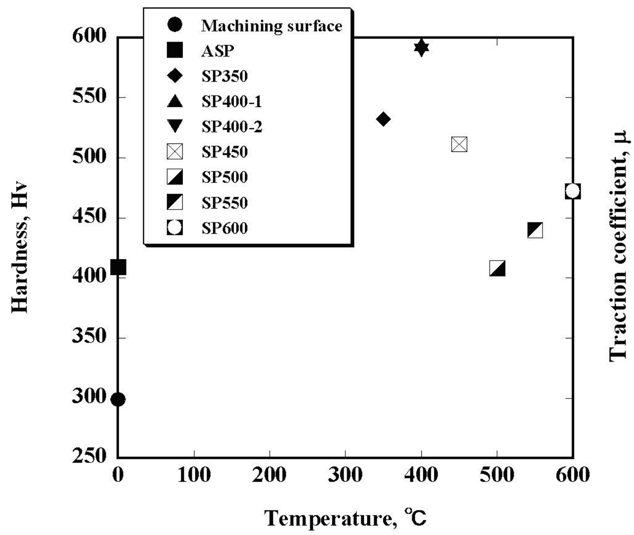


Fig. 7 Vickers hardness of heat treated surface as a function of heat treatment temperature

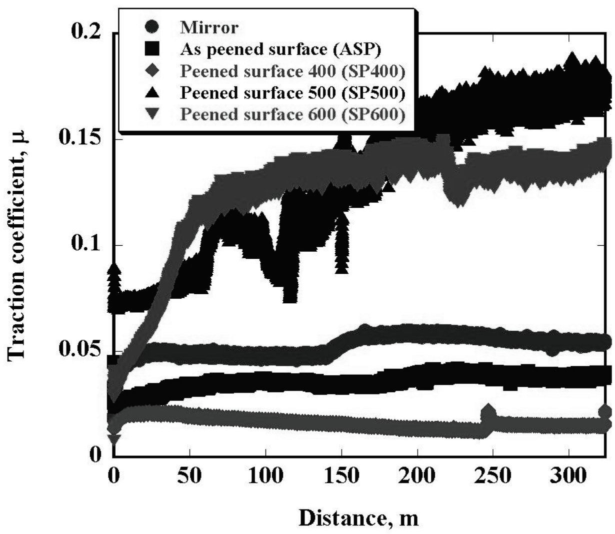


Fig. 8 Traction coefficient of various treated surface

Frictional properties

The result of traction coefficient is shown in Fig.8. The traction coefficient of the mirror surface that was prepared to 7 nm Ra by a lapping treatment beforehand was approximately 0.02 by during the early period of examination, but the traction coefficient increased to 0.06 at the maximum since friction distance exceeded 25 m. However, stable behavior of traction coefficient was shown during examination. The traction coefficient of a non-heat treated specimen (ASP) was approximately 0.04 at the maximum, this result was superior to the mirror surface over a long distance, and the behavior was stable after 100 m. The traction coefficient of the heat-treated surface at 400 degrees C (SP400) was the lowest, and although it increased once at the area of friction distance beyond 150 m, it was approximately 0.025 at the maximum, but the behavior was stable. The traction coefficients were shown higher than originally measured during the early period of their examination, then they continued to increase by the end of the examination.

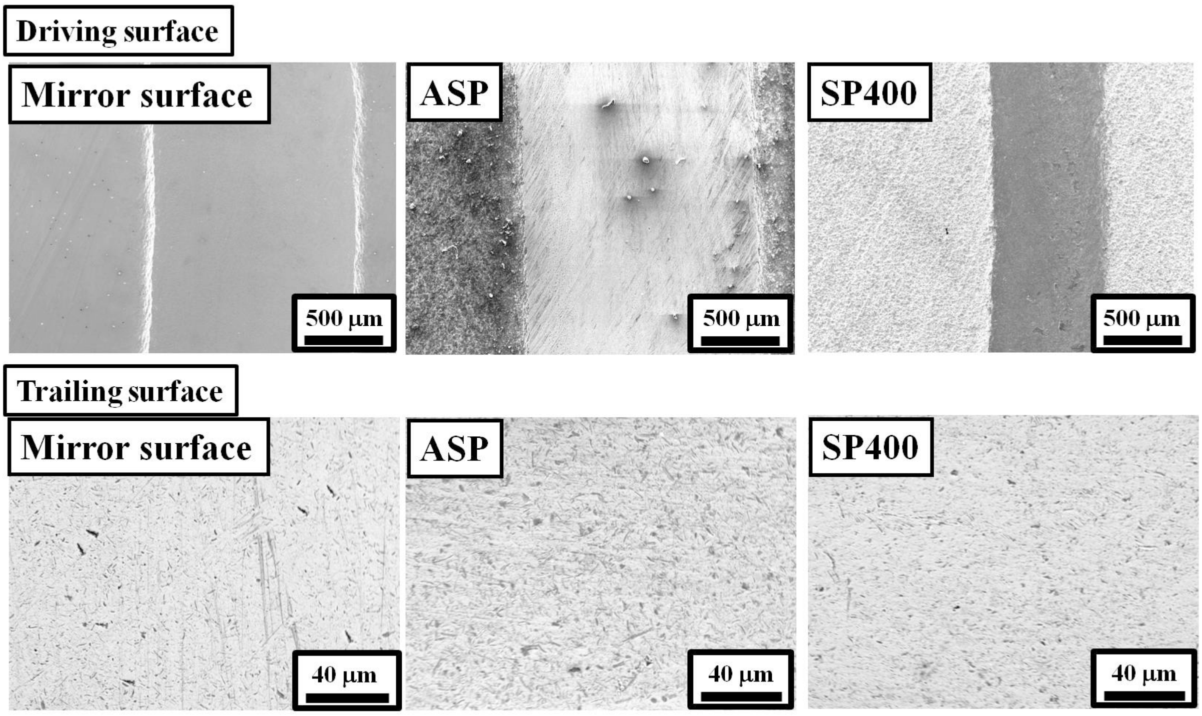


Fig. 9 Optical micrographs of driving surfaces and trailing surfaces

When the rolling contact surface was observed, it was confirmed that the wear track of 1.4 mm, 1.5 mm, and 0.7 mm was formed on the specimen surface that was a mirror finish, ASP(defined ASP), and SP400, respectively (Fig.9). It had confirmed that the difference of contrast was occurred at the end of wear track in the SP400 specimen and that the wear was the lowest in this study. It was hypothesized that the abrasion forms are different. Although the damage was formed on the surface of every contact materials, a lot of pits occurred in the rolling contact material for ASP in comparison with the others. On the other hand, big damage was not found on the surface of rolling contact specimens that were for heat-treated specimen in comparison with the rolling contact surface for ASP specimen, and it was equal with the rolling contact for the mirror surface.

Conclusions

The applicability of heat treatment to a micro shot peened surface with migrated tungsten carbide particles was examined to fabricate a functional graded surface. The tribological properties of the peened and heat treated surface was evaluated with a rolling contact experiment. Followings are the summary of obtained results.

[1] It is possible to migrate the fine tungsten carbide particles on the hardened alloy steel surface using the condition optimized peening system. Additional heat treatment at the specific temperature after the peening is effective for an increase in hardness.
[2] The migrated tungsten carbide seemed to solidify in the matrix of the alloy steel surface by the addition of heat-treatment.
[3] The anti wear properties of the peened and heat treated specimen was superior and the traction coefficient was lower than the mirror finished nominal surface.

References

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