# Applicability of Surface Flow Process for Modification of Tribological Properties of Titanium

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## Abstract

The present study proposed a novel surface modification process based on surface plastic deformation, surface flow process, to improve tribological properties of pure titanium (Ti) surfaces. The developed process is consisted from a micro shot peening and a roller burnishing: The former and the latter processes is applied to fabricate to micro dimples and to penetrate molybdenum disulfide ($MoS_2$) fine powders into the dimple. During the burnishing process, the surface was truncated and the penetrated $MoS_2$ into the dimple was densified simultaneously. As results, the treated surface was relatively flat and was consisted from micro dimples filled with dense $MoS_2$. Tribological properties of the treated surface were evaluated with a ring on disc type testing apparatus using a hardened steel ring as a mated specimen in lubricated condition. Results showed that the tribological properties of the treated surface is significantly improved including restriction of seizure occurrence.

**Keywords:** surface design, surface texture, solid lubricant penetration, surface plastic flow, shot peening, roller burnishing, tribology, titanium

## 1 Introduction

Titanium and its related alloy are one of the candidate materials for mechanical elements required superior specific stiffness and strength such as aerospace components [1]. In addition, the anti-oxidation properties are excellent, the titanium has been used as conventional mechanical elements, such as bolts, nuts, valves subjected to sliding motion [2]. On the other hand, the lower thermal conductivity and the higher reaction activity are occasionally resulted in inferior tribological properties including seizure occurrence [3].

Coating is frequently used as the surface modification for reduction and stabilization of friction resistance of the titanium [4]. Nitride and carbide coatings have sufficient adhesion strength between the interfaces and is effective means to improve the tribological properties of the titanium. However, the coating process required controlled environment and the specimen geometry was restricted. Although the coating process of solid lubricant such as graphite [5] and molybdenum disulfide ($MoS_2$) [6] are also attempted, the adhesion strength is insufficient and the wear loss of the coating is frequently resulted in seizure occurrence of the titanium. Therefore, a novel surface modification is required for the titanium interface.

The present study proposed a surface modification technique based on surface plastic flow processes for improvement of tribological properties of titanium surfaces. The modified surface consisted from truncated titanium region and micro sized dimples filled with dense molybdenum disulfide ($MoS_2$) powder. The tribological properties was evaluated with a ring on disc type testing apparatus using a hardened steel as a mated material. Mechanisms of the low and stable friction resistance of the modified surface was discussed.

## 2 Experimental

### 2.1 Surface modification

A commercial grade pure titanium was used for the specimen. A disc shape, ϕ42×ϕ20×t9 mm was fabricated with turning. The mating specimen was a hardened steel containing 0.45 wt. % carbon (S45C, JIS), having a ring geometry of ϕ40×ϕ30×h15mm and a Vickers hardness of 700 Hv.

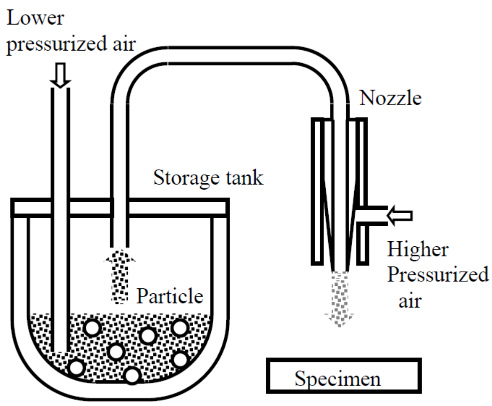



**Fig. 1 Schematic of peening apparatus**

The proposed technique was consisted from a micro shot peening and a roller burnishing processes: The former and the latter is to fabricate micro dimples and the truncate. During the truncation, molybdenum disulfide powder ($MoS_2$, 2μm in size) was penetrated and densified simultaneously. A schematic of the micro shot peening apparatus was shown in **Fig. 1**. Glass beads having 50 μm in size used as impact media was stored into the storage tank. Pulsed pressurized air was introduced to the inner tube of the double walled structure nuzzle through the tank. Further acceleration of the glass beads was obtained with mixing with higher pressure air at the tip of the nozzle. Therefore, the flow rate and the impact velocity were possible to control individually with adjusting air pressure. The micro shot peening condition was listed in **Table 1**.

**Table 1 Micro shot peening condition**

| Outer tube gas pressure | Inner tube gas pressure | Nozzle distance |
|---|---|---|
| 0.6 MPa | 0.3 MPa | 100 mm |

A roller burnishing was carried out after the shot peening. An overview of the roller burnishing process was shown in **Fig. 2**. The roller materials was fine grained cemented carbide (WC-Co) and the geometry was 37mm of a diameter and 4.5 mm of a tip radius. The roller was mounted to the tool post of a conventional lathe through the holder installed loading system and the contact load was applied with a pre-loaded coil spring. The roller burnishing condition was listed in **Table 2**.

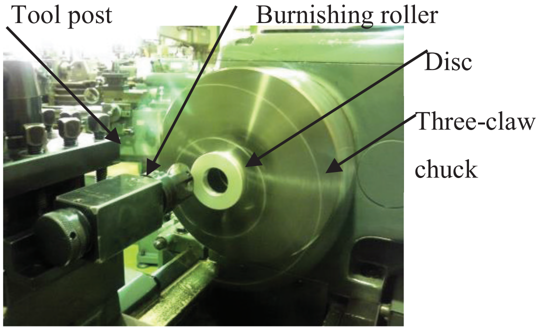



**Fig. 2 Overview of burnishing process**

**Table 2 Roller burnishing condition**

| Contact load | Disc rotation speed | Feed rate of roller |
|---|---|---|
| 25 N | 550 rpm | 0.44 mm/rev. |

An optical micro image and a surface profile of discs treated with various condition were shown in **Fig. 3**. Periodical grooves having 2-4 μm of depth and 44 μm in pitch, corresponding the feed rate of the cutting condition was found on the nominal surface. Truncated micro dimples resulted in plastic deformation, having 10-20 μm in diameter and 2-4 μm in depth, was formed on the shot peened-burnished (SP+B) surface.

Application of $MoS_2$ onto the disc was carried out after the shot peening with different methods, painting and penetrating. In the former process, suspended $MoS_2$ powder into ethanol was painted to the shot peened-burnished surface. The ethanol was evaporated then the $MoS_2$ film was left on the surface. Although the $MoS_2$ film covered with the disc, the surface profile showed that the micro dimples was still remained.

In the penetration process, the ethanol with $MoS_2$ was painted to the shot peened surface then the burnishing was applied. The cross sectional profile of the $MoS_2$ penetrated surface is relatively flat.

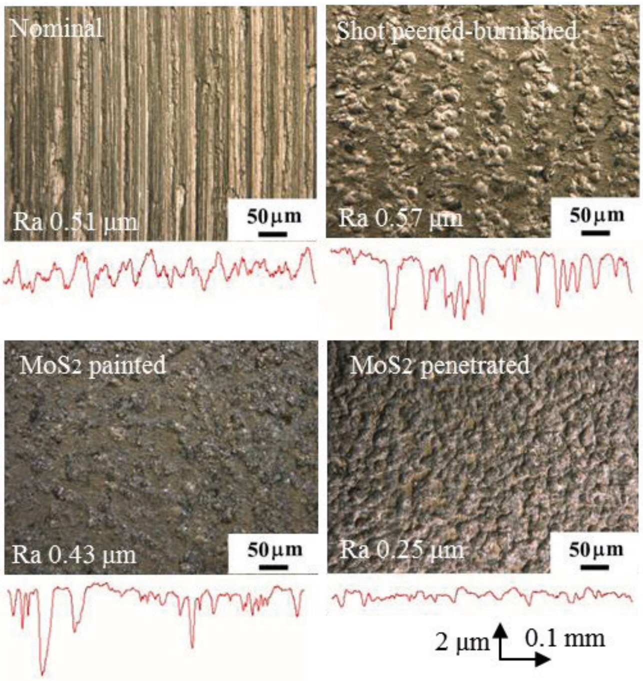
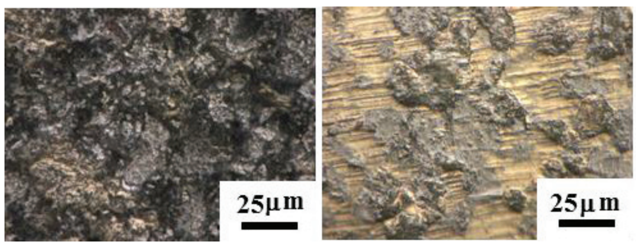



**Fig. 3 Optical micro image and surface profile of titanium disc surface treated with various conditions**

Expanded image of the $MoS_2$ applied surfaces were shown in **Fig. 4**. The micro dimples filled with the $MoS_2$ was found on the penetrated surface. A micro indentation testing at a load of 0.1 N was connected to evaluate the $MoS_2$ density. As results, it was found that the density was high enough to form the Vickers impression.




$MoS_2$ painted $MoS_2$ penetrated

**Fig. 4 Expanded images of $MoS_2$ applied and penetrated surface**

**2.2 Apparatus for tribological properties**

Tribological properties were evaluated with a ring on disc type testing apparatus, shown in **Fig. 5**. The disc specimen was mounted to a stationary shaft with a friction torque measurement device. The ring specimen was fixed to a drive shaft located upper part of the apparatus.

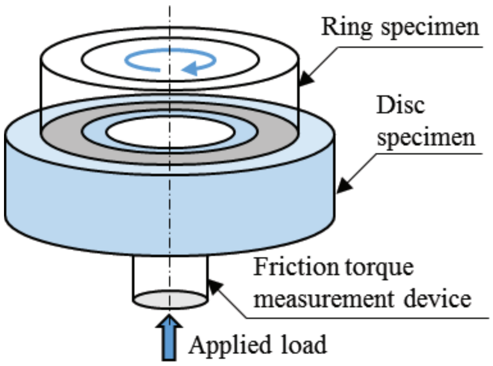



**Fig. 5 Schematic of testing apparatus**

The testing condition was listed in **Table 3**. The lubricant oil was supplied just before the experiment and did not replenish. After the oil supply, the contact load was applied with a dead weight then the disc specimen was driven with a DC motor. The friction torque was measured with a device installed below the disc specimen. The experiment was carried out in a laboratory air. The settled sliding distance was 2000 m and the experiment was interrupted when the rapid increase of the friction torque was detected. The experiment was carried out 3 times for each treated surfaces.

**Table 3 Testing condition**

| Applied load | Sliding speed | Sliding distance | Lubricant oil, PAO |
|---|---|---|---|
| 10 N | 1.0 m/s | 2000 m | 5cst@40℃ |

## 3 Results and Discussion

### 3.1 Friction coefficient

The friction coefficient calculated from the measured friction torque as a function of sliding distance was shown in **Figs. 6** for the nominal and the shot peened-burnished and **7** for the $MoS_2$ applied discs, respectively.

The friction coefficient of the nominal surface was ranged from 0.3 to 0.5 and the seizure occurred at less than 15 m of the sliding distance. The sliding distance up to the seizure of the shot peened-burnished (SP+B) surface was longer than that of the nominal surface. However, the friction coefficient ranged from 0.15 to 0.5 and the effect of the surface texture on the decrease of the friction coefficient was small.

The friction coefficient of the $MoS_2$ painted specimen ranged from 0.2 to 0.5 and similar to those of the nominal and the shot peened-burnished discs. On the other hand, the sliding distance up to the seizure seemed to be longer. The friction coefficient of the $MoS_2$ penetrated disc was approximately 0.12 to 0.15 and stable during the experiment without seizure. Therefore, it was found that the friction properties was different depending on the $MoS_2$ applying processes and that the significant improvement of the friction properties was obtained with the $MoS_2$ penetrated disc.

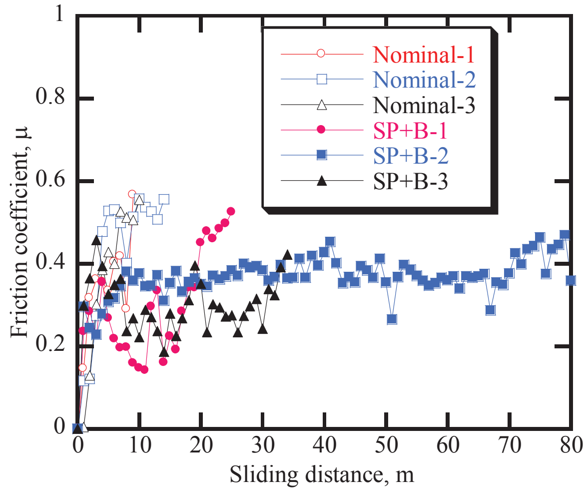



**Fig. 6 Friction coefficient of disc surface without $MoS_2$ as a function of sliding distance**

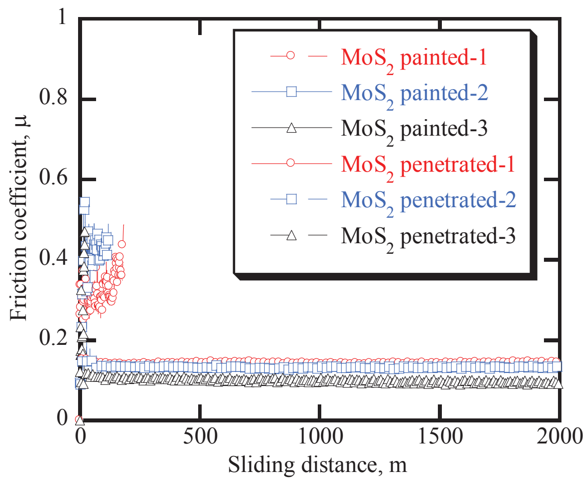



**Fig. 7 Friction coefficient of disc surface with $MoS_2$ as a function of sliding distance (Note that the range of the sliding distance was different to that of Fig. 6 )**

### 3.2 Worn Surface Image and Profile

An optical micro image and a surface profile of discs after the experiment was shown in **Fig. 8**. Comparing with **Fig. 3**, the surface morphology was different except in the result of $MoS_2$ penetrated disc: The larger adhered region was found and the nominal surface profile such as the groove and the dimple were removed. In addition, the painted $MoS_2$ was disappeared. In the $MoS_2$ penetrated disc, the adhered area was small and the most of dimples stored $MoS_2$ were found.

An optical micro image and a surface profile of rings after the experiment were shown in **Fig. 9**. Similar to the disc surface morphology, the adhesion layer was found on the ring surface except in the result mated with $MoS_2$ penetrated disc.

SEM/EDX analysis showed that the built up region on the ring corresponded to the transfer of the titanium and that the transfer on the ring mated with the $MoS_2$

penetrated disc was small. Because of the higher density, it is concluded that the penetrating $MoS_2$ has sufficient adhesion strength against the stress acted at the interface between the ring and the disc during the experiment. Therefore, it was estimated that the survived $MoS_2$ resulted in the restriction of the titanium transfer to the steel ring was restricted and that the friction properties became stable without seizure occurrence.

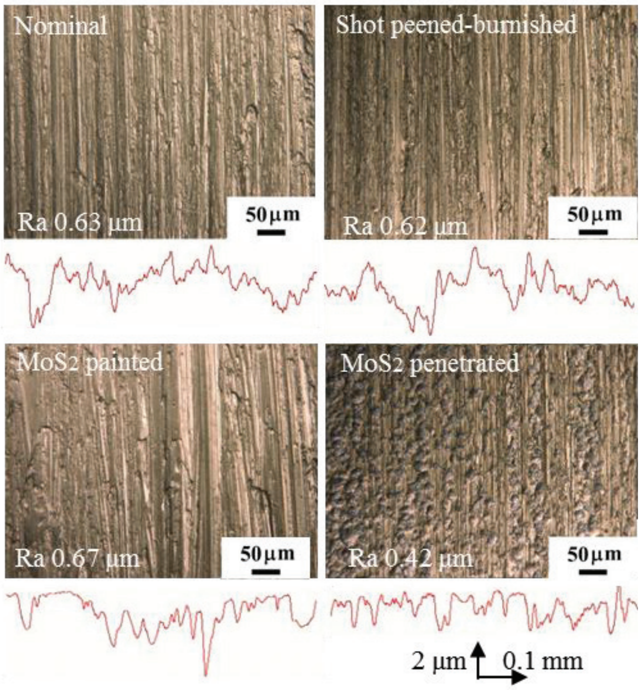



**Fig. 8 Optical micro image and surface profile of discs after the experiment (The sliding direction corresponded from top to bottom of the image)**

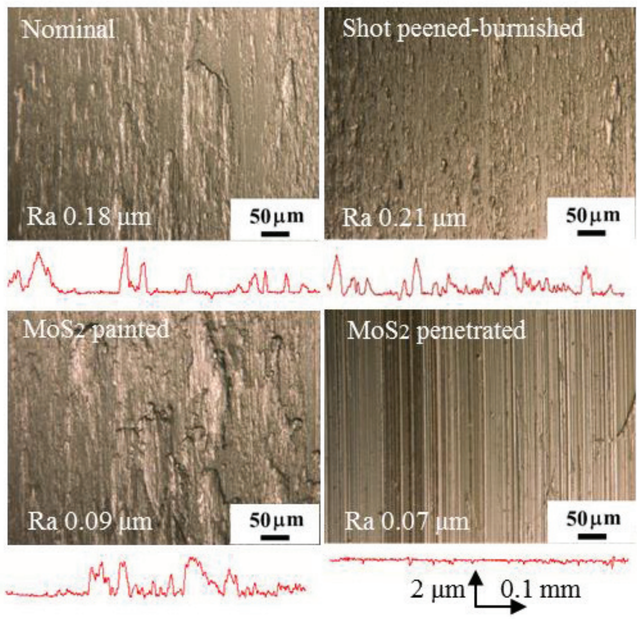



**Fig. 9 Optical micro image and surface profile of rings after the experiment**


## Summary

The surface modification technique based on the surface plastic deformation process consisted from a micro shot peening and a roller burnishing was proposed and was applied to titanium disc specimen. The resulted surface morphology was dispersed micro dimples filled with dense molybdenum disulfide and was relatively flat. The tribological properties evaluated with a ring on disc type testing apparatus showed that the friction coefficient was lower and stable without seizure. It is estimated that the molybdenum disulfide prevents the titanium transfer.


## References


[1] Boyer, R. R., An overview on the use of titanium in the aerospace industry, Materials Science and Engineering: A, Vol. 213, No. 1-2 (1996), pp. 103–114, International Symposium on Metallurgy and Technology of Titanium Alloys.

[2] Croccolo, D., Agostinis, M. D, and Vincenziet, N., Influence of tightening procedures and lubrication conditions on titanium screw joints for lightweight applications, Tribology International, Vol. 55, No. 4, (2012), pp. 68–76.

[3] Abdel-Aal, H.A. Nouari, M., and Mansori, M. E, Influence of thermal conductivity on wear when machining titanium alloys, Tribology International, Vol. 42, No. 2, (2009),pp. 359-372.

[4] Boving, H.J. and Hintermann, H.E., Wear-resistant hard titanium carbide coatings for space applications Tribology International, Vol. 23, No. 2,(1990), pp. 129-133.

[5] Miyoshi, K, *et al*, Wear behavior of low-cost, lightweight TiC/Ti–6Al–4V composite under fretting: Effectiveness of solid-film lubricant counterparts, Tribology International, Vol. 41, No. 1, (2008), pp. 24–33.

[6] Martins, R.C., Moura, P. S. and Seabra, J.O., $MoS_2$/Ti low-friction coating for gears, Tribology International, Vol. 39, No. 12, (2006), pp. 1686-1697.



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