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*tribology, friction, micro-machine,
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SURFACE TREATMENT FOR IMPROVEMENT OF COEFFICIENT OF FRICTION ON SLIDING SURFACES

Recently, many micro structure products are used for compact, high precision and others functions in the field of measuring instruments, medical instruments, information processing devices and so on. However, in the small sliding parts of these products, the surface contact pressure becomes lowered and then, higher adhesive force occurs, resulting larger coefficient of friction. On the other hand, in the field of machine tools, lubrication free sliding parts are also demanded for eco-friendly. In this study, the surface treatment for improvement of coefficient of friction for both light load and heavy load applications are investigated. When laser ray is applied on stainless steel surface, CrO_2 layer with small concaves like dimple is generated. This CrO_2 layer is used in light load applications. Next, TiAlN and DLC coating are being used on cutting tools for reducing coefficient of friction and cutting heat. Therefore, these coating materials are used for heavy load and oil free [2]applications. The improvement of coefficient of friction and life of coating are investigated by experiments. It was concluded from the results that; (1) Coefficient of friction for light load application can be reduced by coating CrO_2 layer. (2) Coefficients of friction for heavy load application were reduced by coating TiAlN and DLC layer. (3) Life of both CrO_2 and DLC layers are sufficiently long for practical applications at light load and heavy load respectively.

1. INTRODUCTION

Recently, in the field of measuring instrument, robot, medical industry, information processing, many miniature structures are used for high precision and many other functions. For those miniature structures, the contact pressure between the small sliding surface and the base surface becomes lower and the adhesive force between them becomes distinctive factor. Then the coefficient of friction between both the surfaces becomes dominant because of this adhesive force. This causes large disadvantage for sliding condition and weak functioning occurs at moving parts [1],[2]. On the other hand, in the field of machine tools or construction machines, large size machines require sliding elements without lubrication oil on for environmental friendly.

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In this study, small stainless steel sliding surface is exposed to the YVO_4 laser rays to obtain CrO_2 layer with small concaves like dimple appears on the surface. This creates smaller contact area between surfaces and obtained lower contact pressure between them. Then, the method for reducing adhesive force is proposed and the evaluation for effectiveness for reducing coefficient of friction, stability and life time test are taken. Finally, the applicability of this method on the coating of metal cutting tools for reducing frictional force in cutting using TiALN and DLC coating materials is also investigated.

2. THE MEASURING DEVICE FOR COEFFICIENT OF FRICTION AND GEOMETRY OF SLIDING PART SURFACE

2.1. MEASURING DEVICE FOR COEFFICIENT OF FRICTION

Fig. 1 shows the schematic of the measuring device for coefficient of friction [3], and table 1 shows the experimental condition. The device is composed of electronic scale, linear motion table, pulley, base surface and sliding body (hereafter called boat). Boat and weight are connected with stainless wire passing through the pulley. The frictional force generated between base surface and test piece during the movement of linear motion table is measured for light weight and heavy weight cases using electronic scale. From these measurements, the coefficient of friction μ can be calculated as follow.

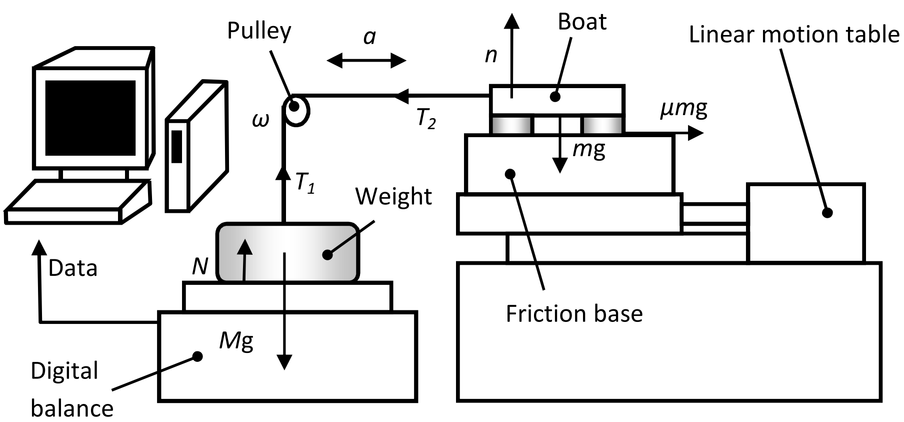

Fig. 1. Schematic view of the equipment for measuring coefficient of friction

$$\mu = \frac{M - M'}{m} \tag{1}$$

Here, M is measurement weight value before moving, M' is the measurement weight value during mov·ing, m is the weight of the boat, μ is the coefficient of friction. For the light weight case, each value used in equation (1) are M =810 g, m = 0.4 g, M' = 809 ~ 810 g and the minimum division of the digital balance used is 0.005 g. At this time, the measurement error for coefficient of friction is calculated by Tailor's expansion method [4] and obtained $\Delta\mu$=1.88·10^{-3} which is small enough. For the case of heavy weight case, the values are M =8014 g, m = 7823 g, M' = 6860 ~ 6880 g and also very small measurement

Table 1. Examination condition

Temperature	20°C
Humidity	65%
Slide speed	3.5mm/sec
Friction base material	S50C
Surface roughness Ra	0.13μm

error of coefficient of friction $\Delta\mu$ =4.12·10^{-6} is obtained. Moreover, 30 measuring times are taken for each experiment and the average expected error obtained for light weight and heavy weight are found to be very small with values $\Delta\mu \div \sqrt{30} = 3.42 \times 10^{-4}$ and $\Delta\mu \div \sqrt{30} = 7.51 \times 10^{-7}$ respectively. The preliminary experiments are taken for the investigation of frictional force between pulley and wire and it is found negligible

2.2. THE SPECIFICATION OF THE SLIDING PARTS

Fig. 2 shows the specification and setting of the sliding parts used in the experiment. The test pieces are circular discs of diameter ϕ8 mm, thickness 1 mm. Two kind of materials, SUS304 2B stainless steel with surface roughness Ra 0.04 μm and S50C (DLC) with surface roughness Ra 0.5 μm are used. Relating to the measurement setting

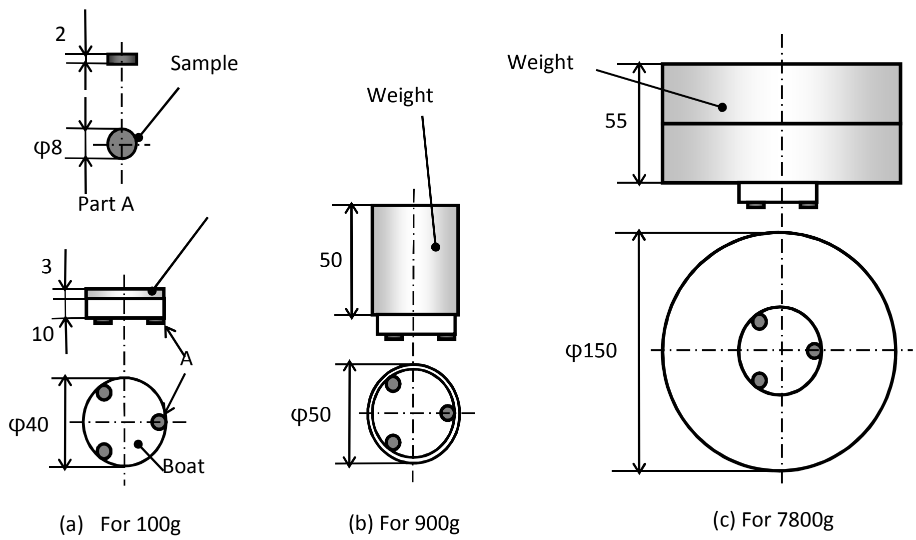

Fig. 2. Schematic view of the sliding parts

a disk of SUS304 2B stainless steel is connected with wire to the balance and slide with its own weight as minimum weight condition. For other cases, varions kinds of weights 10g, 100g, 900g, 7800g are placed on the board and slide to measure the coefficient of friction.

3. COATING FOR IMPROVEMENT OF FRICTION ON ULTRA LIGHT WEIGHT SLIDERS

3.1. SURFACE TREATMENT BY LASER RADIATION

In this section, the improvement of friction on the sliding parts of micro precision measuring instruments and medical instruments are objected to be investigated. Regarding to the contact surface pressure from 70 Pa to 6200 Pa exerting on the micro size sliding parts, an oxide layer with micro concaves is created on the sliding surface by laser radiation [5]. Then, based on the previous research “Coefficient of friction regarding small sliding surface with crater made by irradiation of YAG Laser” [6], the improvement of friction for light weight sliding parts with fine dimpled layer surface is investigated.
Table 2 shows the specification of the laser machine and the condition used for laser processing on the sliding surface. Low laser power YVO_4 normally using for marking applications with LD exciting Q switch type is used. Laser ray is moving along X axis with

Table 2. Specification of laser and its radiation condition

Laser source	Nd:YVO_4
Excitation light source	LD
Wavelength	1.064µm
Mode	TEM_{00}
Average power	5.0W (at 10kHz)
Power at Q switch	40kW (at 10kHz)
Width of pulse at Q switch	10nsec (at 10kHz)
Size of spot	50µm
Focal length of fθ lens	206mm
Scanning speed	Max.118mm/s
Laser power	0.932 ~ 1.572W
Scanning speed	95mm/s
Focal length	206mm
Pitch of spot	20µm
Treatment area	S6mm×L6mm
Number of tracking	1 ~ 20time

Input power	1.78 W
Pitch	20µm
Surface roughness Ra	0.052µm

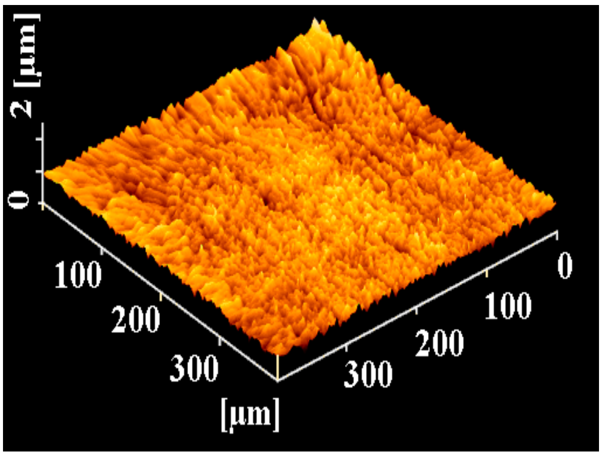

Fig. 3. Photoghaph of surface radiated by laser
(there are many small concaves like dimple)

uniform speed and scanning along Y axis. The pitches of the laser radiated sports are made to be uniformly distributed by automatic controlling. The laser conditions are taken for input power, number of tracking, tracking pitch, height of table and sports distribution as parameters. The input power is from 1.08 ~ 2.05 W, tracking pitch is 5~70 μm and although the number of tracking is changed there was very small effect on the concave formation and it is made to be fixed 1 time. At that time, the surface roughness Ra is 0.05 ~ 0.065μm. The laser treatment condition at which the smallest frictional coefficient is obtained and the photograph of treated surface is shown in Fig. 3. This surface condition is used in the experiments.

3.2. CHARACTERISTIC OF FRICTION FOR LIGHT WEIGHT

Fig. 4 shows the frictional coefficient for the micro sliding parts with using light weight and Fig. 5 shows the standard deviation of frictional values at this condition. The stability of the sliding characteristic can be known from standard deviation values.

In Fig. 4, the result for SUS304 2B test piece without coating is also included. In the experiment with using lubrication oil (ISO VG56), the contact pressure of the sliding surface become lower and the coefficient of friction become dominant and it is about 40. This is due to the comparably large adhesive force between friction base and the sliding surface as the load become smaller. It can be seen that the behavior of the sliding part become unstable when the load become light weight.

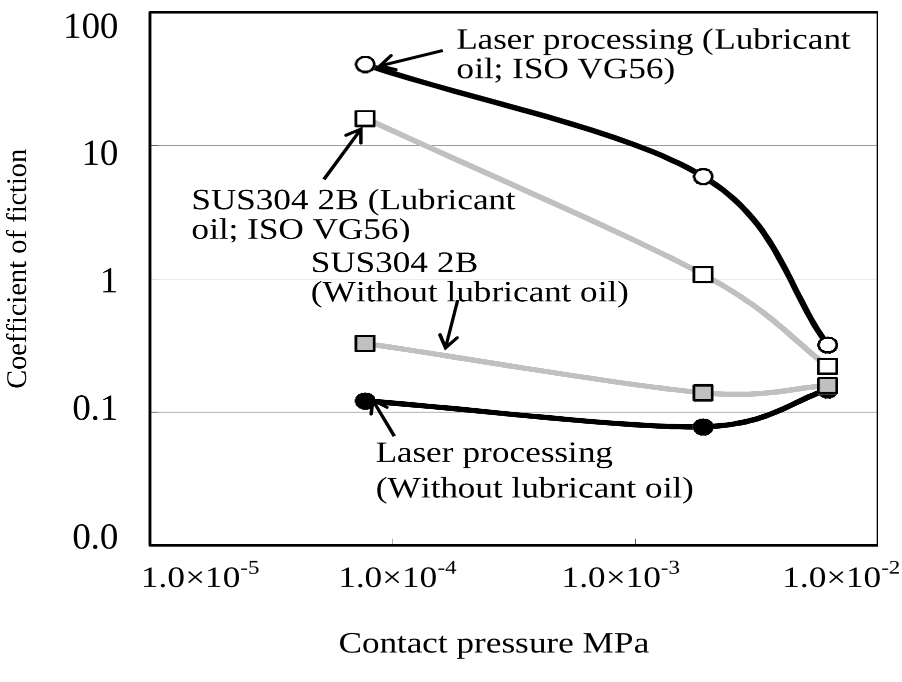

Fig. 4. Relationship between contact pressure and coefficient of friction at light load

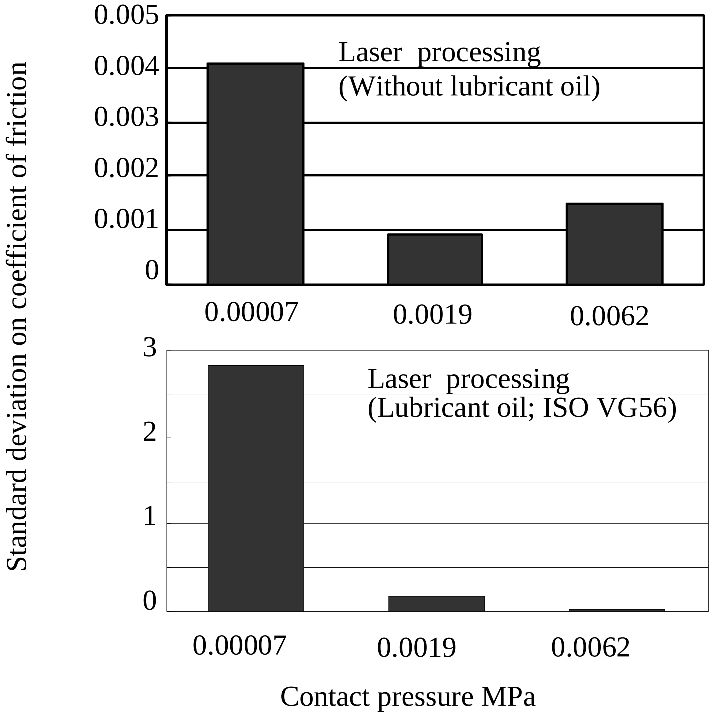

Fig. 5. Relationship between schematics of concave and standard deviation on coefficient of friction at light load

This phenomenon also exhibits for the part with using micro machines and it is needed to make improvements. In the other hand, for the case of without using lubrication agent, there is no sign of adhesive force effect and not much changing in coefficient of friction for both testpieces. There is not much difference in coefficient of friction for both test pieces at contact pressure 6200Pa, and there exist some difference in coefficient of friction as the contact surface pressure decreases. From this fact, it can be known that the surface treated by laser in this research is effective for application under 6200Pa pressure. Moreover, the value of coefficient of friction is about 0.1 and it is quite small with stable behavior of standard deviation less than 0.005.

The adhesive force between sliding surfaces by friction of metal to metal is mainly effected by the surface tension of lubrication oil on the contact surfaces and van der Waals force. This force effects till the space between sliding parts is about 10 times larger than the lattice space of crystals [7]. Even though, the edges of rough surface will have more or less plastic deformation depending on changing in load, the space between base surfaces and edge having about 10 times of lattice space of crystals could not change much. Moreover, the position of the existence of adhesion force could change by changing in load as shown in Fig. 6. However, it can be considered that this changing in position could not effect on the magnitude of adhesive force. In the case of contact pressure changes from 100 Pa to 1 Pa, the only the force effecting between the sliding surfaces reduces 1/100 time and the adhesive force is almost no change. Therefore, for the test piece with very small dimension of the sliding surface and dominant effect of adhesive pressure, even though the coefficient of friction is changed, the adhesive force is being still largely affected between sliding surfaces and thus, the effect of coefficient of friction between surfaces is not very high.

Especially, it can be considered that the laser treatment method could well control the van der Waals force effectively. We thought that the results in Fig. 4 are attainded.

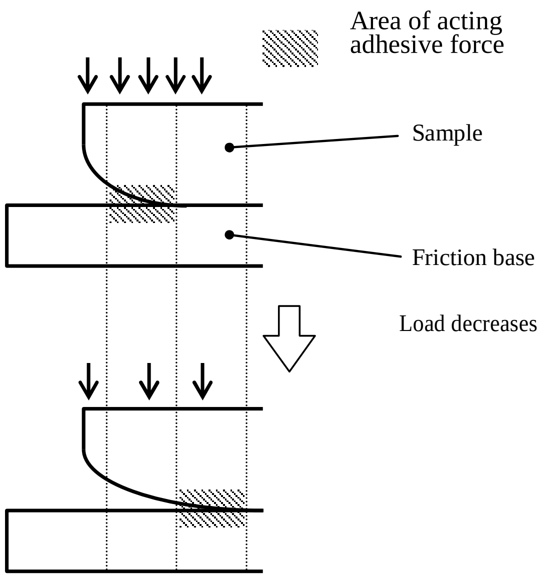

Fig. 6. Area of acting adhesive force

3.3. THE LIFE OF LASER TREATED SURFACE

Fig. 7 shows schematic of the coating life testing apparatus for light weight application. A disc of 300 mm is set to be rotated with 470 min^{-1} and the sliding micro part is put on the disc holding with cylindrical holder. The sliding distance is calculated from the radius of sliding position where micro sliding part is placed, revolving speed and rotation time. The contact pressure is set 1900 Pa and this is 27 times of the minimum load 70 Pa. The wear rate is periodically measured using AFM taking maximum wearing height. Moreover, the temperature of the micro sliding part is measured using infra red measuring device.

Fig. 8 shows the relation between sliding part and wear height for light load test. For sliding with light load 1900 Pa, even the sliding distance reached over 20000 m, there exist only 10% wear. Thus, it is expected that there will be much longer life for using minimum load 70 Pa. From this fact, it can be considered that the laser treated surface with concaves is applicable for long wearing resistance. Although there is a range of contact pressure at which problem occurs with adhesion force, the laser treated concave shaped surface is applicable for the practical use for long life. Moreover, the steady state temperature during wear test with light weight was risen for only 5 Kelvin.

The hardness of the sliding part material SUS304 2B after YAG laser treated with 3μm CrO_2 layer is 220 HV and it is 10% increased compare with original hardness 200 HV. Therefore, this laser treated surface with small concaves is applicable for using in small sliding parts with light load.

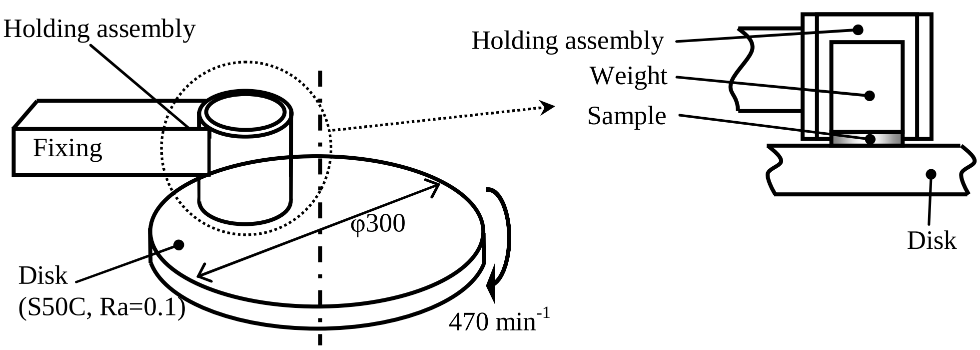

Fig. 7. Schematic view for the instrument of life test at light load

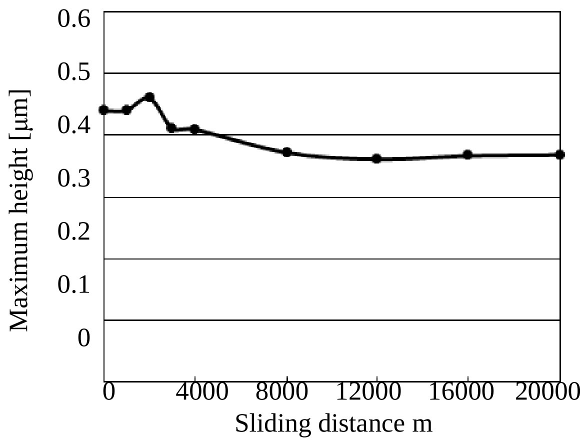

Fig. 8. Results of the life test at light load

4. COATING FOR IMPROVEMENT OF FRICTION ON HEAVY LOAD SLIDERS

4.1. APPLICATION OF TiAlN AND DLC

In this section, the investigation for the improvement of sliding characteristic of the heavy load sliding surface of machine tools is taken using the maximum load of 0.5 MPa (5 kgf/cm^2). Most of the sliding surfaces of machine tools are using pressure range from 1 kgf/cm^2 to 5 kgf/cm^2. The tool coating materials TiAlN and DLC are applied on sliding surfaces and the characteristic of stability of frictional coefficient is investigated.

The TiAlN layer of 2.4μm thickness is coated on the SUS304 2B disc as shown in Fig. 2. The mechanical properties and photograph of surface topology is shown in Fig. 9. DLC layer is the carbon amorphous layer composed of carbon or hydrocarbon with enough strength for using over 10 Pa pressure. It is generally being applied in many applications for high hardness, low frictional coefficient and high wearing resistance. Here, hydrocarbon gas is altered into ion using plasma discharging in the vacuum and this hydrocarbon ion is made high speed collision on the base plate with using negative bias voltage. And then, the coating layer is created using chemical vapor deposition method (CVD method). Fig. 10 shows the mechanical property of DLC and the photograph of surface topology.

Film thickness	2.4 μm
Hardness	843HV (65.4HRC)
Surface roughness Ra	0.047μm

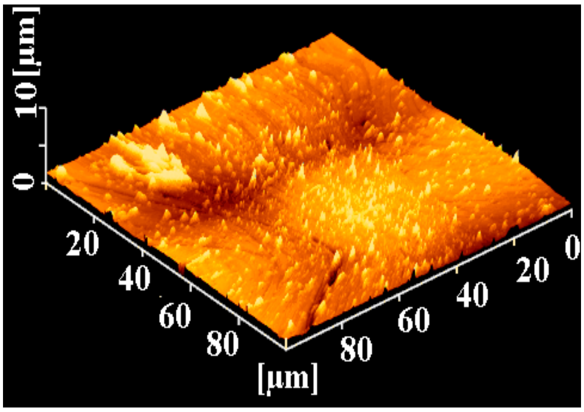

Fig. 9. Photoghaph of TiAlN used in the experimen

Film thickness	6 μm
Hardness	544HV (51.9HRC)
Surface roughness Ra	0.6 μm

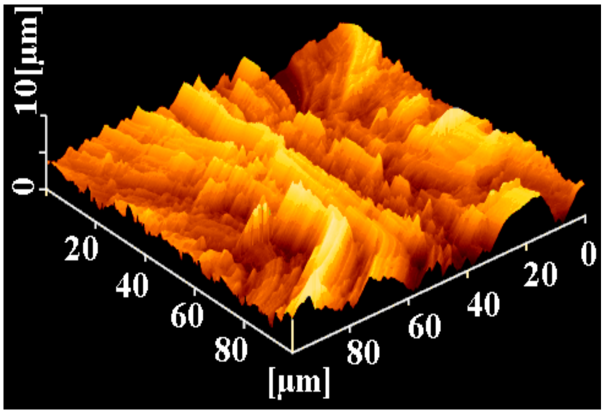

Fig. 10. Photoghaph of DLC used in the experiment

4.2. CHARACTERISTIC OF FRICTION WITH HEAVY LOAD

Fig. 11 shows the result of coefficient of friction for micro sliding parts with heavy load and Fig. 12 shows the standard deviation of coefficient of friction values. The value

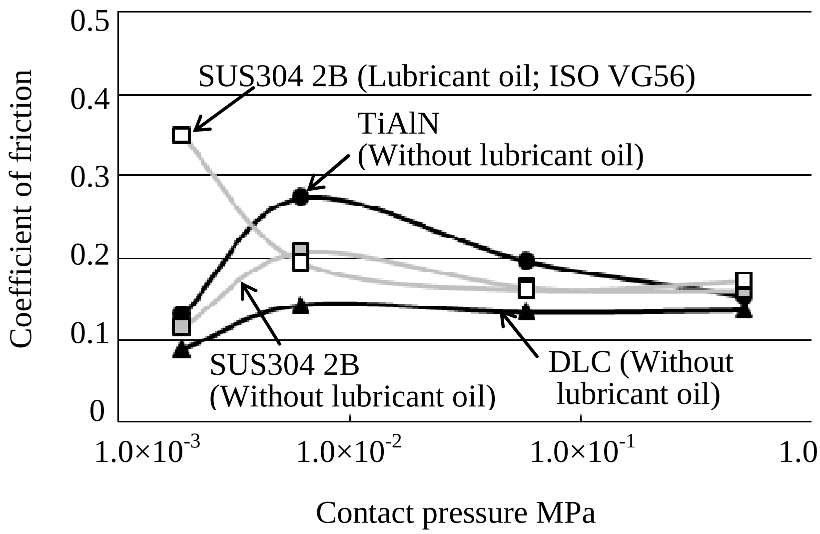

Fig. 11. Relationship between schematics of concave and coefficient of friction at heavy load

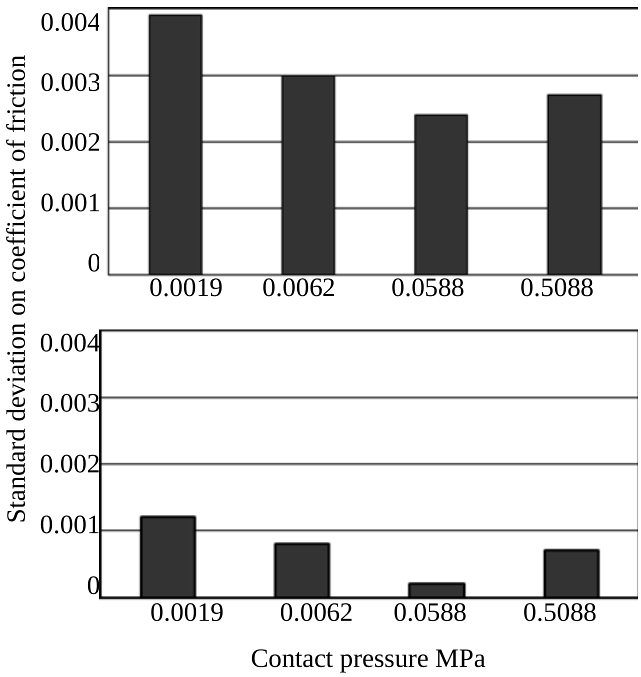

Fig. 12. Relationship between schematics of concave and standard deviation on coefficient of friction at heavy load

of coefficient of friction without using lubrication agent (ISO VG56) is quite small with value about 0.1 for TiAlN and DLC materials. Moreover, the sliding characteristic is quite stable with effective using of TiAlN and DLC solid lubrication coating.

4.3. LIFE OF TiAlN AND DLC COATING

Fig. 13 shows the schematic of the life test apparatus for heavy load sliders with TiAlN and DLC coating. To supply heavy load, a sliding base 100 mm diameter disc is attached to the spindle of a lathe and rotate at 85 min^{-1} and the micro sliding part is attached to a spring mounted tool post is kept in contact with rotating disc and then, supply the contact pressure of 0.5 MPa (5 kgf/cm^2). Here also the sliding distance is calculated from radius of sliding position, revolution of disc and revolving time. The wear rate is measured periodically using probe type layer thickness measuring device. Moreover, the temperature of the micro sliding part is also measured with infra-red measuring instrument.

Fig. 14 shows the relation between surface roughness Ra and the sliding distance for heavy load test. It can be seen that defoliation of DLC coating is only about 20% after sliding over 20000 m. For the case of TiAlN, although there exists only 10% wear, the scratches on both coated layer and base plate surface occurred. This can be considered due to the high hardness of the coating layer affected on the surface. TiAlN and DLC materials are being used well for coating of metal cutting tools and it can be expected that it is applicable for sliding parts of the metal cutting machines tools.

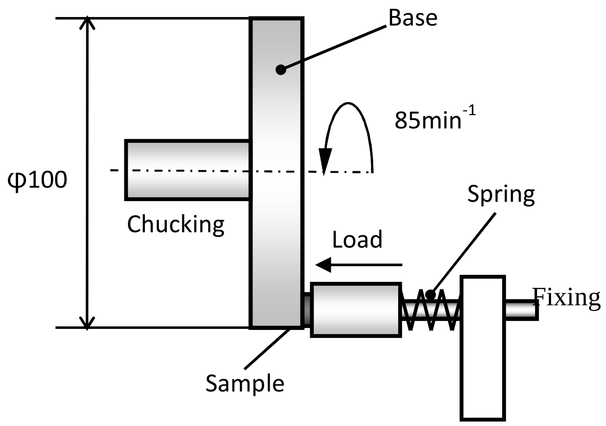

Fig. 13. Schematic view of the instrument for coating life test

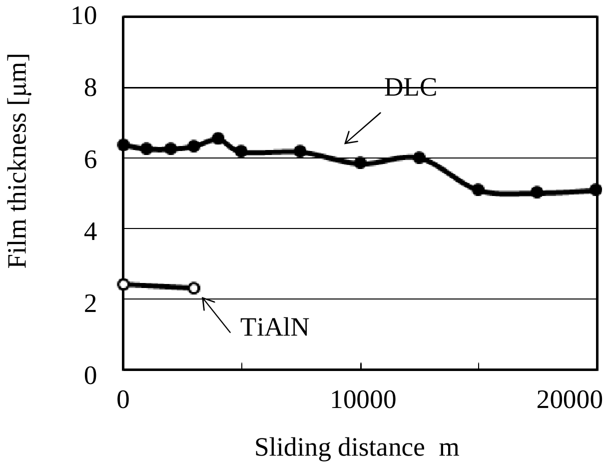

Fig. 14. Results of the life test

From the above facts, DLC coating is effective for the application on sliding parts with heavy load for long life without using lubrication oil.

5. CONCLUSION

From this research, it can be concluded that,

(1) The concave shaped surface by laser treatment is effective to improve frictional behavior of micro sliding parts with light load.

(2) DLC coated surface is effective for improvement of frictional behavior of sliding parts with heavy load.

(3) The proposed surface technologies of (1) and (2) are both applicable in industry with long durability.

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