Effect of Surface Roughness on Adsorption Force and Smooth Sliding in a Vacuum

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We evaluated the sliding friction coefficient under changes of load from 0.98 mN to 196 mN at pressures of 10^5 Pa and 10^{-5} Pa. The friction of type 304 austenitic stainless steels as typical vacuum materials was measured, and surface roughness of nano order was prepared by electrochemical buffing and chemical etching. The same value of friction coefficient on samples measured in a vacuum as at atmospheric pressure when surface roughness was prepared to about 40 nm to 1.2 μ m was also found. There is an absorption force of about 20 mN on a sample with a surface roughness of less than about 670 nm at atmospheric pressure. In a vacuum, a sample with a surface roughness under 40 nm also showed adsorption force below 0.98 mN, while a sample with a surface roughness around 100 nm showed higher adsorption force of about 15 mN. It was concluded that there was a range of surface roughnesses without any decrease in adsorption force even in a vacuum.

1. Introduction

Studies on static structural material and dynamic motion material have been conducted to generate a super-clean vacuum atmosphere for a long time. We have successfully developed surface treatment and surface modification for structural vacuum material and have also constructed an integrated extreme high vacuum process using a levitation transport system without sliding motion for long-distance transfer by the meter^{1,2)}. Precise, smooth sliding motion different from long-distance levitation transportation is however required for studying advanced material on an atomic scale. Tribological development is essential to reduce friction and wear as well as out-gassing during sliding motion with such easy control of surface roughness as electrochemical buffing and chemical etching. We have therefore studied vacuum tribology and attempted to build a vacuum friction measurement system to evaluate vacuum friction and to develop advanced vacuum motion materials. A vacuum friction measurement system based on the Bowden-Leben-type system has been successfully developed that can evaluate sliding friction force under a changing load from 0.98 mN to 1.96 N and under changing atmospheric pressure from 10^5 Pa to 10^{-5} Pa. We have shown that the materials with a surface roughness around 100 nm prepared by such surface treatments as chemical etching or electrochemical buffing can offer as smooth sliding in a vacuum as sliding at atmospheric pressure³⁾.

It was thought that surface roughness adsorbs the water layer on the surface of materials and that the water layer adsorbs strongly to the surface, acting as a lubricant even in a vacuum.

We therefore try to estimate the absorption force by decreasing the sliding load with the friction measurement system to study the effect of surface roughness on the adsorption force and to understand the contribution to smooth sliding in a vacuum.

2. Experimental

The samples are 10-mm $\times$ 10-mm $\times$ 1-mm sheets of commercial-type 304 austenitic stainless steel. The surfaces of all the samples were prepared with different surface roughnesses from 40 nm to 1240 nm by means of electrochemical buffing and chemical etching. The respective surface roughnesses (R_y) of the samples were also measured with a surface profile-meter. The main conditions for the measurement are as follows. The sliding probe is a mechanically polished stainless steel. The stainless steel probe ball is 3.18 mm in diameter with a roughness is under 60 nm. The sliding rate is 0.5 mm/s, the sliding length is 5 mm and the load is from 196 mN to 0.98 mN, and the measurement was repeated 5 times on the same line in the same direction. Friction measurement in a vacuum was conducted when the vacuum chamber reached an appointed pressure of 10^{-5} Pa. The friction coefficient was also measured by changing the sliding area in order to discuss change in the surface roughness effected by repeating the friction measurement.

3. Results and discussion

Figure 1 shows changes in the friction coefficient of samples with a surface roughness of 40 nm under a decreasing sliding load.

The increase in friction coefficient is shown in decreasing loads at atmospheric pressure. Ando et al. pointed out that the friction coefficient increases due to the influence of absorption force from such adsorption layers as water on the stainless steel samples⁴⁾.

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Fig. 1 Changes in friction force of type 304 stainless steel samples with a surface roughness of 40 nm at atmospheric pressure and in a vacuum.

Fig. 2 Changes in friction force of type 304 stainless steel samples with a surface roughness from 40 to 1270 nm at atmospheric pressure.

However, no increase in friction coefficient is observed in a vacuum of 10^{-5} Pa, and the friction coefficient remains constant.

This phenomenon might result from a lack of adsorption gas layer.

The existence of the absorption force can be clarified by plotting the friction force and load in a logarithmic graph.

Figure 2 shows the change in the friction force of samples with different surface roughnesses as a function of load at atmospheric pressure with nitrogen gas. As for a

Fig. 3 Changes in friction force of type 304 stainless steel samples with a surface roughness from 40 to 670 nm in a vacuum.

surface roughness of more than about 800 nm, there is little absorption force in Fig. 2-a.

The relation between friction force and load under each condition can be explained by Amontons-Coulomb's law as the linear lines. However, there is an absorption force of about 20 mN for a sample with a surface roughness of less than 680 nm out of the law in Fig. 2-b. It is concluded that a surface roughness of 40 nm has an adsorption force that affects friction force under low loads at atmospheric pressure.

Figure 3 shows the change in the friction force of samples with surface roughness as friction of the load in a vacuum. The sample with a surface roughness of 40 nm also showed an adsorption force below about 1 mN in Fig. 3-a. The sample with a surface roughness of more than 80 nm showed a higher adsorption force of about 15 mN, and the sample did not show a constant friction coefficient in a vacuum in Fig. 3-b. It is therefore considered that the adsorption layer changed by surface roughness can control friction force.

The surface roughness can restrict desorption of the absorption layer with adsorption force and keep friction force small even in a vacuum. It is concluded that a surface roughness of around 100 nm exhibiting similarly low friction in a vacuum as at ambient air is the ideal roughness capable of trapping adsorbed gases strongly as the acting lubricant.

4. Conclusions

We estimated absorption force by decreasing the sliding load with a friction measurement system to study the effect of surface roughness on adsorption force and the contribution to smooth sliding in a vacuum. There is an absorption force of about 15 mN between the stainless steel ball and the sample of surface roughness from 80 nm to about 670 nm in a vacuum.

It is suggested that the structure of the surface roughness at submicron scale can also restrict desorption of the absorption layer and keep friction force small even in a vacuum.

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