Running-in process of Si-SiO$_x$/SiO$_2$ pair at nanoscale

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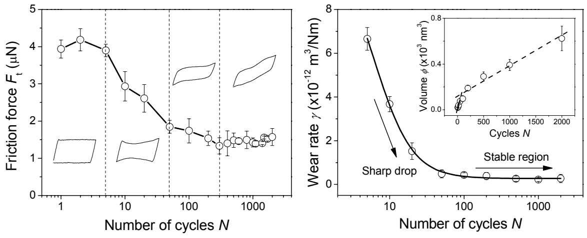
1. Introduction

As a well-known tribological process, running-in is usually defined as the initial operating procedure of friction pair until certain friction force and wear rate have reached a steady state. During a running-in process at macroscale, because the peaks of asperities on rough contact surfaces are removed by mechanical interactions and valleys are filled by wear debris, the average surface roughness of specimens would decrease to a stable state. However, due to the single-asperity contact and possible tribochemical reaction at nanoscale, the traditional running-in mechanism may not be valid during nanowear process [1]. Therefore, it is essential to clarify whether running-in exists in the friction pair of nanoscale devices and how the friction force and wear vary during initial sliding cycles.

In this paper, the running-in process of Si-SiO$_x$/SiO$_2$ pair at nanoscale was investigated by an atomic force microscope (AFM) in ambient air. The mechanism was discussed based on the analysis of the friction-induced reduction of adhesion of the Si-SiO$_x$/SiO$_2$ pair.

2. Results

The nanowear of the Si-SiO$_x$/SiO$_2$ pair exhibited a typical running-in process. As the sliding cycle *N* increased, both the friction force of the Si-SiO$_x$/SiO$_2$ pair and the wear rate of silicon surface exhibited a sharp decrease in the first 50 cycles and then leveled off during the remaining sliding cycles (Fig. 1). After the running in process in the initial 50 sliding cycles, the friction force of the Si–SiO$_x$/SiO$_2$ pair rapidly decreased to 40% of its initial value, and the wear rate on the silicon surface sharply decreased to 10% of its initial value. It was also noted that the friction loops presented four different shapes at various number of sliding cycles (inset of Fig. 1a), which was strongly dependent on the topography of wear scar on silicon surface.



(a) Friction force (b) Wear rate

Fig. 1 Variation of friction force and wear rate of Si-SiO$_x$/SiO$_2$ pair

3. Discussion

During running-in, the sharp drop in friction force of the Si-SiO$_x$/SiO$_2$ pair was mainly attributed to wear of the surface oxide layer and to change in the surface of the SiO$_2$ tip. While the tip slides on the silicon surface, a water bridge will form between the Si–SiO$_x$ substrate and the SiO$_2$ tip surface. As a result, both the friction force and the wear rate exhibited a large value over the initial several cycles. However, when the native oxide layer on the Si–SiO$_x$ surface was removed by the SiO$_2$ tip via water-induced corrosion, the Si–Si network of the Si(100) substrate will be exposed to air, and the silicon surface becomes more hydrophobic due to the reduction of Si–OH groups. Because of the reciprocating scratch by the SiO$_2$ tip, the Si–Si network could be broken by shear stresses transmitted from the Si–O–Si bridges between the SiO$_2$ tip and the silicon substrate [2]. At the same time, the tip surface could become more hydrophobic because of dehydroxylation reactions during this process. Since the transformation of silanol bonds to siloxane bonds is exothermic, dehydroxylation reactions probably occur on the SiO$_2$ tip surface under shear stress during the initial sliding process. The hydrophobization of the contact area on the SiO$_2$ tip and the silicon surface would reduce both the friction force and the wear rate.

4. Summary

The sharp drops in friction force of the Si-SiO$_x$/SiO$_2$ pair and the wear rate of silicon surface during running-in were caused by hydrophobization of the SiO$_2$ tip and the silicon surface, as well as by lubrication provided by wear debris. Unlike mechanical interactions in macroscale devices, tribochemical reactions play a dominant role during running-in of nanoscale Si–SiO$_x$/SiO$_2$ pair.

5. References

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