ASPERITY CONTACT SIMULATION IN A MICROTESTER

C.P. Hendriks and D. Landheer
Department of Mechanical Engineering, Eindhoven University of Technology
PO Box 513, 5600 MB Eindhoven, The Netherlands

Summary

Microfriction mechanisms of silicon and steel are investigated with a pin on plate type microtester. Preliminary results show a transition from a low friction regime ($\mu = 0.05 - 0.10$) to a high friction regime ($\mu = 0.20 - 0.25$). Hertz theory indicates that this transition coincides with the onset of plastic yield in the sample surface.

Introduction

Selecting materials for dry running or boundary lubricated contacts is difficult. A reliable method for predicting the friction and wear behaviour of a material combination is still not available. The main problem is the interfacial shear between interacting roughness asperities, which is completely unknown. The mechanical deformation of the surfaces is accessible to calculation, but the results depend strongly on the interfacial shear strength.

Asperity contact simulation on the microscale, therefore, is necessary to investigate the nature and magnitude of the interfacial shear. Several researchers have investigated abrasion resistance in microscale experiments [1,2,3]. In these experiments, the microcontacts are plastically deforming. In general, the transition from mild to more severe wear regimes is strongly related to the transition from elastic to plastic deformation of the microcontacts.

The main objective of our research, therefore, is the simulation of elastic-plastically deforming asperity contacts. In the present report, we describe a newly developed microtester, followed by the first results obtained with the preliminary apparatus.

The microtester and test procedure

A schematic diagram of the pin on plate type apparatus is shown in figure 1[1]. The 5 μm radius diamond tip is mounted on a double parallel-leaf spring unit, which is moved in Z-direction by a piezo. When the sample plate is translated against the tip, the spring-deflections depend on the normal load and the friction force on the tip. The spring-deflections are measured by focus-error-detection (FED) type optical heads. Calibration of the apparatus is not finished yet. Therefore, the tip forces are calculated by multiplying spring-stiffness and spring-deflection. Optical head 1 is mechanically fixed to the piezo, thus indicating zero normal load when the tip is not in contact with the sample. Furthermore, optical head 1 and the piezo are in feed back, maintaining a constant normal load during sample translation.

The test procedure is as follows. Starting at 1 mN, the sample is translated in X-direction at constant load and speed, one time forward and backward. Then the normal load is increased, and again the sample is translated forward and backward. This is

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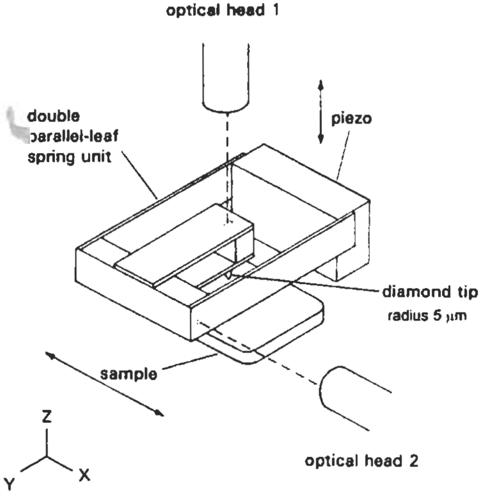
[1] Working principle is basically similar to the modified SPM described by Lu [4]

repeated several times on the same track. Spring deflections, piezo translation and X-position are recorded simultaneously. Afterwards, the wear track is inspected with AFM, SEM and light microscopy.

Materials, mechanical properties and surface roughness of the samples are shown in table 1. Test conditions are shown in table 2.



load range : 1 - 10 mN
force resolution : 10 μN
optical head resolution : 10 nm

parallel-leaf spring unit
material: nickel
horizontal leafs : 4.0×1.5×0.03 mm
vertical leafs : 2.5×1.5×0.03 mm
lateral stiffness : 0.25×10^3 N/m
normal stiffness : 1.1×10^3 N/m

Figure 1 Schematic diagram of the microtester

Table 1 - Sample properties

	Si	stainless steel 12CrNi 17 7
hardness $H_{V\,100g}$, kgf/m^2	1132	510
roughness R_q, AFM 100×100μm, nm	10	20
elastic modulus, GPa	107	210

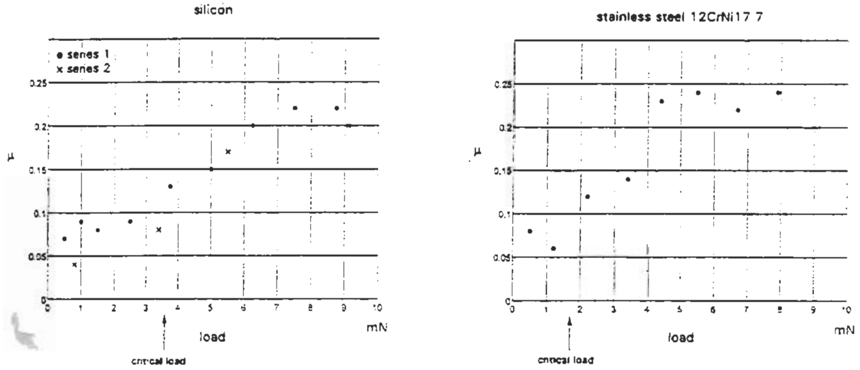
Table 2 - Test conditions

speed	100 μm/s
temperature	20 °C
track length	1 mm
load	1 - 10 mN
atmosphere	air

Results and discussion

Figure 2 shows the coefficient of friction versus normal loading force. Clearly, a transition from a low friction regime to a high friction regime appears on both silicon and steel. The transition point is indicated by 'critical load'. Figure 3 shows the topography of the wear tracks in the high-friction regime. The wear tracks are smooth furrows, resulting from plastic deformation of both the silicon and the steel. Removal of material is not observed. The cross sections of the wear tracks are similar to the tip geometry.

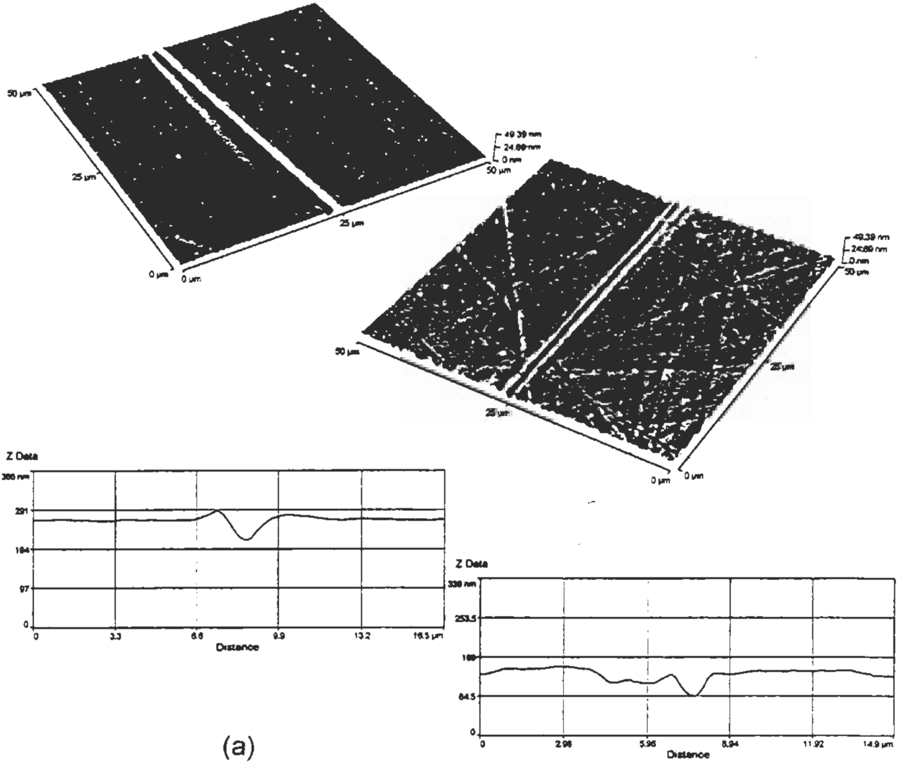
Very recently, a similar transition in the friction behaviour is observed in the microscale experiments of Xu [5], where a 10 μm radius diamond tip is sliding against single-crystal silicon. During this transition, the wear mode is reported to change from 'no removal of material' to 'microcutting of feather-like wear particles'.



(a)

(b)

Figure 2 Average coefficient of friction μ during the forward translation. (a) silicon, critical load 3.6 mN (b) steel, critical load 1.7 mN



(a)

(b)

Figure 3 Topography and cross section of the wear track (AFM). (a) silicon (b) steel

From the observations, it appears that the transition from the low friction regime to the high friction regime is caused by the transition from elastic to plastic surface deformation. In this case, the critical load would indicate the onset of yielding. According to Johnson [6], the onset of yielding in sliding contacts is also determined by the interfacial friction. However, when $\mu < 0.25$, the onset of yielding is predicted by:

$$(p_m)_{yield} \sim H_V/3$$

where p_m is the mean Hertzian contact pressure. Using the hardness values of table 1, the onset of yielding is predicted at $p_m = 3.8$ GPa for the silicon, and $p_m = 1.7$ GPa for the steel. At the critical loads in figure 2, the calculated Hertzian contact pressures are $p_m = 4.4$ GPa and $p_m = 5.2$ GPa respectively. Predicted and calculated pressures are of the same order of magnitude, although the calculated values are somewhat larger, especially for the steel.

To obtain accurate results, more tests must be reproduced with the calibrated apparatus. However, two effects may be proposed already. First, if the contact length scale becomes small compared to the defect size scale, 'apparent' material hardness increases. Second, the Hertz theory may not be valid in the tip-sample contact. Especially the sub-micron roughness of the sample promotes yielding, due to stress concentration.

Conclusion

The microtester enables simulation of elastic-plastically deforming microcontacts. Preliminary results show a transition from a low friction regime ($\mu = 0.05 - 0.10$) to a high friction regime ($\mu = 0.20 - 0.25$), both on silicon and steel. Hertz theory indicates that this transition coincides with the onset of plastic yield in the top surface layer of the sample material.

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