Proceedings of Malaysian International Tribology Conference 2015, pp. 78-79, November 2015

Stick-slip motions of polymer gels having multiple artificial asperities

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Keywords: Stick-slip; asperity; contact

ABSTRACT – We report our experimental studies on stick-slip motions between polymer gels having artificial surface asperities. We show that, depending on the density and configuration randomness of asperities, the stick-slip behavior greatly changes: when the asperities are located periodically with sufficient separation, fast and regular stick-slip motions occur, while slow and heterogeneous slip behavior is observed for samples having randomly and densely located asperities. We discuss the condition for the occurrence of complex stick-slip cycles.

1. INTRODUCTION

It is well known that real area of contact is limited in a small portion of nominal area in dry frictional contact, and also well understood that surface asperities play an essential role [1]. There are many papers discussing quasi-static features since pioneering works done by Bowden and Tabor [2], and Greenwood and Williamson [3]. However, very few studies focusing on the dynamical behavior have been reported [4]: this implies that the energy dissipation mechanisms in dry sliding friction are not so clear at present. In this paper, we report on stick-slip friction between soft polymer gels as an experimental analogue of dry frictional contact. Unlike previous studies where silicone rubber with asperities are slid against a flat glass plate [5, 6], multiple asperities of hemi-cylindrical shape were molded on both surfaces of the silicone gels, and friction experiments were conducted by slowly driving the system.

2. EXPERIMENT

2.1 Sample

We prepared silicone gels (CY52-276, Toray Dow Corning, Japan, the shear modulus is about 100 kPa) by mixing pre-polymers A:B = 1:4 (weight ratio), stirring well with a mixer, degassing with a vacuum pump, and then by curing it inside a mold at 90 degrees for 5 hours. Surface asperities having hemi-cylindrical shape with a given radius, height, and location (i.e., density) were put on the frictional surface as a quasi-2 dimensional setup, as shown in Figure 1.

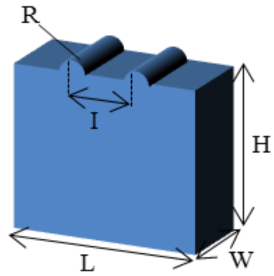

Figure 1 Polymer gel sample for quasi-2 dimensional friction experiments.

2.2 Friction Experiment

Friction experiments were conducted by using Tensile testing machine (MST-1, Shimadzu, Japan). A schematic is drawn in Figure 2. Sliding (driving) velocity V was 0.1 or 1 mm/s. Vertical displacement Δz (not normal load) was imposed in all experiments.

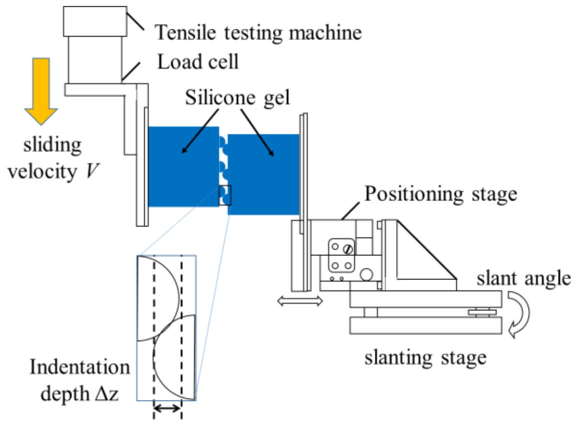

Figure 2 Experimental setup.

2.3 In-situ Observation

Frictional behavior was taken by a high-vision video camera at 30 frames per second from the side of the samples.

3. RESULTS AND DISCUSSION

In order to discuss the effects of having asperities on both surfaces, comparison of Slip distance-Friction force curves between 2 sets of sample pairs is shown in Figure 3: the gel sample pair with one asperity on each surface (red line), and ones with asperity on only one side and without on another side (blue line), i.e., asperity on flat contact. This is approximately the same situation assumed in the conventional theories [2, 3]. It is clearly seen that, unstable slip occurs in asperity-asperity contact while does not in asperity on flat contact. It is also observed that the friction forces themselves are not equal with each other. Considering that friction generates as a consequence of contact and rupture of multiple microscopic asperities, dynamical features are necessary to understand macroscopic frictional behavior, i.e,, conventional treatment with the equivalent surface (surfaces with asperities on both sides are equivalently replaced by one surface with asperities and one flat surface, see [2, 3]) has to be re-considered or modified.

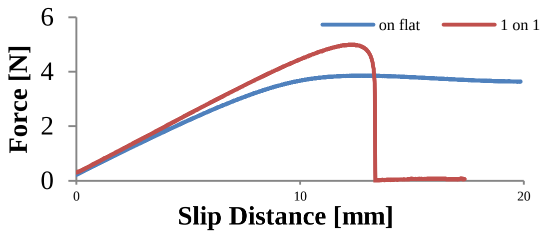

Figure 3 Comparison of Slip distance-Friction force curves measured by one asperity – one asperity contact (red line) and one asperity on flat surface (blue). In this experiment, asperity radius R = 5 mm, gel height H = 100 mm, sliding velocity V = 0.1 mm/s, and Vertical indentation depth Δz = 3mm.

Friction experiments with multiple asperities were also conducted within this setup. Here, number of asperities and randomness in asperity spacing were changed. Figure 4 shows 2 examples:

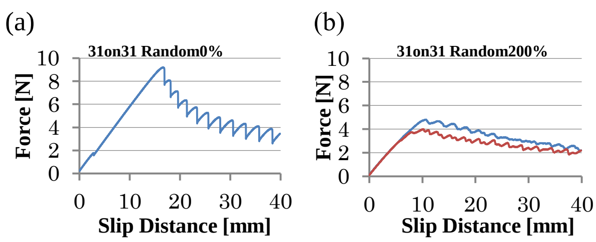

Figure 4 Slip distance-Friction force curves for 2 different sample pairs: (a) 31 asperity – 31 asperity contact with regular spacing on both sides, and (b) 31 asperity – 31 asperity contact with regular spacing on one side and 200% randomness in asperity position (compared to the asperity radius) on another side. In these experiments, R = 1mm, H = 100 mm, V = 0.1 mm, and Δz = 1 mm.

It is seen that fast and regular slip events are observed for sample pairs with constant spacing, while slow and complex slip behavior are seen for random asperity pairs.

Experimental results for different number of asperities and randomness are summarized in Figure 5. Dynamical behavior is strongly influenced by randomness in asperity spacing. The mechanisms responsible for the slip behavior is thought to be the competition between slip weakening (to what extent tangential force drops due to rupture of asperity contact) and the effective stiffness of the system (stiffness of the medium around an asperity). That is, the less the randomness, the more flexible elastic foundation supporting each asperity becomes, and the more the asperity density, the larger total elastic energy is released while the more the randomness in deformation is enhanced for too dense asperities. This suggests that asperity density as well as asperity configuration is important to understand frictional behavior of materials.

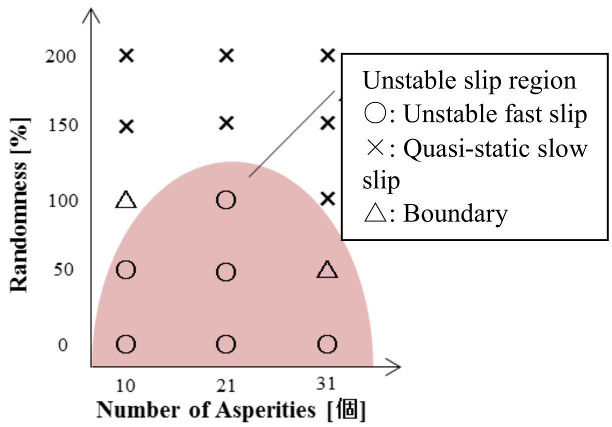

Figure 5 Number of asperities-Position randomness phase diagram.

4. SUMMARY

We conducted stick-slip friction experiments using polymer gels having multiple artificial asperities on both surfaces. Unlike the conventional theories and past experiments, unstable slip due to rupture of asperity contact was observed, and also the stick-slip behavior drastically changed by controlling asperity density and configuration randomness.

5. REFERENCES

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