Measurements of surface displacement field for multi-contact interface of elastomers

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ABSTRACT – This study publishes surface displace measurements in the multi-contact interface between a rough rubber surface made of poly-dimethyl siloxane (PDMS) and smooth hemispherical glass lens. The PDMS plate was driven with a constant velocity until the onset of macroscopic global sliding. During sliding, time changes of tangential load and images of the contact interface were recorded, simultaneously. In addition, based on the digital image correlation method, the evolution of microslip was visualized.

1. INTRODUCTION

In sliding friction of elastomers, partial slippage (i.e., microslip) occurs prior to the onset of macroscopic global sliding. Even before shear force reaches the threshold for the onset of macroscopic sliding (i.e., maximum static friction), microslip can occur, resulting in surface deformation due to large stress heterogeneity. To understand mechanics of friction in rubber materials, in-situ observations of microslips are strongly required.

In this study, we developed a tribotester, which can visualize surface displace fields in contact interfaces based on digital image correlation (DIC) method [1]. From simultaneous measurements of time changes in tangential load and contact images, growth processes of microslips were visualized. In addition, high-resolution measurements quantified small tangential deformations of roughness at multi-contact interface.

2. EXPERIMENTAL DETAILS

Figure 1 shows a schematic of experimental setup. This device employed the contact between an optically transparent rubber plate made of cross-linked poly-dimethyl siloxane (PDMS) (the Young's Modulus: 2.8 MPa) and a smooth glass (BK7) hemisphere lens. The thickness of the PDMS plate and the radius of the glass hemisphere were 3 mm and 5 mm, respectively. The glass hemisphere was fixed directly below an objective lens system. The PDMS plate was connected to a double-cantilever spring that was mounted on the *X*-directional motorized stage via a lever arm. An LED light source was placed under the contact interface, and a CCD camera with a frame size of 1920 × 1440 pixels was attached to the objective lens system.

The normal load F_Z was applied by using a lever mechanics with five kinds of weights. Time changes of tangential load F_X was obtained by the measurements of the double cantilever spring deflection, which was proved by using an eddy current gap sensor at a sampling rate of 10 kHz. The images of contact interface were obtained as the space distribution of transmitted light intensity within the contact region, which was captured by the CCD camera at a flame rate of 26 Hz. Using the DIC method, the captured images were translated to the surface displacement field.

All experiments were performed in an air-conditioned room, where the temperature and relative humidity were approximately 25 °C and 30 %, respectively.

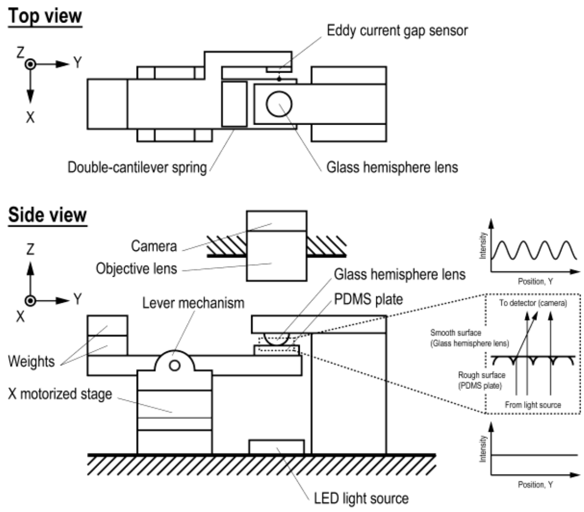

Figure 1 Schematic of experimental setup.

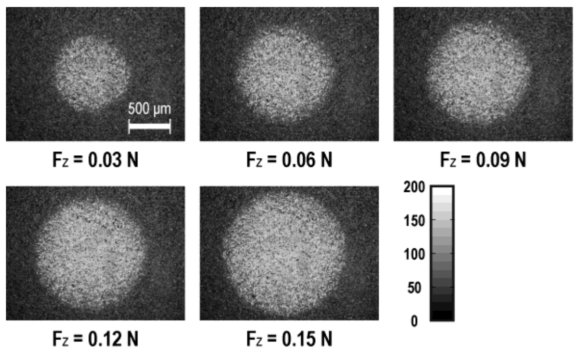

Figure 2 Captured images of contact interface:
Color bar: transmitted light intensity.

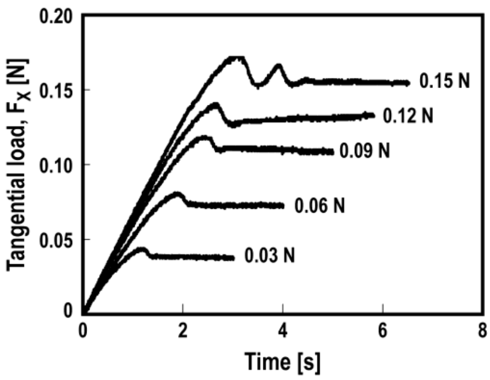

Figure 3 Time changes in tangential load F_X.

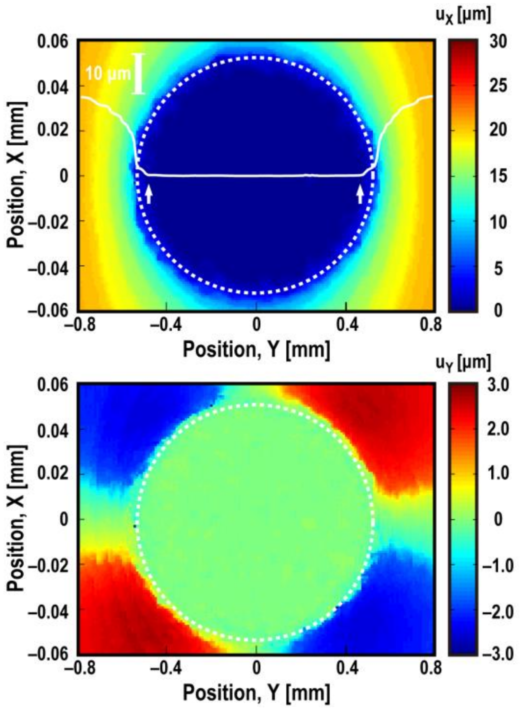

Figure 4 Surface displacement fields u_x and u_y at F_X = 0.09 N: White circles: apparent contact regions. White curves: u_X profile on the horizontal line at $X = 0$ mm.

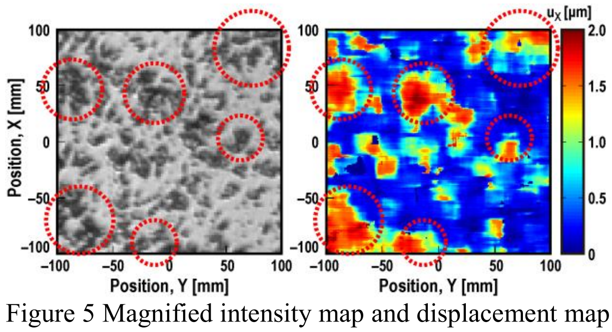

Figure 5 Magnified intensity map and displacement map of u_x around at the center of apparent contact zone.

3. RESULTS AND DISCUSSION

3.1 Visualizing Contact Interfaces in Stationary Tests

Figure 2 shows captured images of the contact interface at five kinds of normal loads. The color bar shows the transmitted light intensity *I*. According to the attributes of the transmitted optical system, white and black regions indicate the real contact and noncontact regions, respectively.

As shown, the apparent contact regions gradually expand with increasing normal load F_Z. Small but connected real contact regions are formed within the contact regions. The number density of the small contacts in the central region was larger than that in the outer region; it attributes to the elliptically distribution of normal contact pressure driven by the Hertz contact theory. From these results, it was found that the transmitted optical method in this study can clearly find the space distribution of real contact regions.

3.2 Measurements of Changes in Tangential Load F_X

Time changes in F_X are shown in Figure 3. It was found that all curves had two distinct loading phases: First, F_X increased linearly, then the slope gradually decreased with time. After the maximum static friction F_s, friction force has a steady value, i.e., kinetic friction force F_k. In sliding friction of rigid materials, the slop of F_X during the first phase should be perfectly linear; therefore, it was found that the evolution of microslip characterizes macroscopic behaviors of friction force.

3.3 Measurements of Surface Displacement Fields

Figure 4 shows typical results in surface displace fields in the *X* and *Y* directions, u_X and u_Y. This figure shows the displacement between $t = 0$ and $t = 1.0$ s at $F_Z = 0.09$ N, see Figure 3. The color bars indicate u_X and u_Y. Even in the apparent contact regions denoted by white dashed circles, small displacement of u_X was observed; the positions of two arrows separates the stick and slippage regions. Thus, we can recognize an annular microslip region surrounding a central stick region, which is well known as Mindlin slip.

Figure 5 shows displacement field of u_X around the center of contact under $F_Z = 0.03$ N. The two images show the intensity profile at $t = 0$ and the u_X field from $t = 0$ to $t = 0.75$. Comparing both images, it was found that the noncontact regions, which are surrounded by red dashed circles, have a relatively large u_X than that in contact regions. It indicates that tangential deformation occurs due to the shear stress. It indicates that the developed system can quantify the tangential stiffness of the roughness layer in multi-contact interfaces.

4. CONCLUSION

Based on in-situ observation of contact interface, we visualized the growth process of microslip in the multi-contact interface between the rough elastomer surface and smooth glass lens. Furthermore, small tangential deformation of the rough layer of the multi contact interface was quantified.

5. REFERENCE

[1] A. Prevost, J.Scheibert, and G Debregeas, “Probing the micromechanics of a multi-contact interface at the onset of frictional sliding,” *European Physical Journal E*, vol. 36, no. 17, pp. 1–11, 2013.