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Short communication

AN EXPERIMENTAL STUDY ON THIRD-BODY PARTICLE TRANSPORT IN SLIDING CONTACT

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Abstract. *An experiment is designed to study the third-body particle transport in a rough contact. To study the influence of particles in a pure form, it is assured that the first bodies have no contact and the sliding is very slow, so that the process can be considered as quasistatic. An example of sliding contact of a 3D printed "rough body" on small spheres artificially located on a rubber layer is presented. The trajectory of particles during the sliding is captured for studying their movement and the correlation to the fluctuation of normal and tangential force.*

Key Words: *Third-body, Particle transport, Friction, Experiment*

1. INTRODUCTION

The mechanics and physics of surfaces and interfaces of solid materials determine the tribological properties of contacts. Formation of wear debris, chemical reaction, heat transfer, local melting, material transfer and other thermo-mechanical, electro-mechanical coupling phenomena may occur in the interface region [1]. Due to these complicated processes, it is meaningful to study mainly only one or two aspects under some specific conditions, for example the orientation of atom layers in structural superlubricity [2], the effect of boundary layer formation in the running-in process [3], or the formation of wear debris due to adhesion [4, 5]. In the present study, we focus on the wear particle transport. It has been found that the wear particle flow is essential for the formation, modification, and transformation of loading structures or films as well as the resulting macroscopic friction and wear rate [6, 7]. To make a step towards understanding of this behavior, we isolate the effect of the presence and dynamics of interfacial particles from others such as wear and consider only the particle transport at the interfacial space and its influence on the friction.

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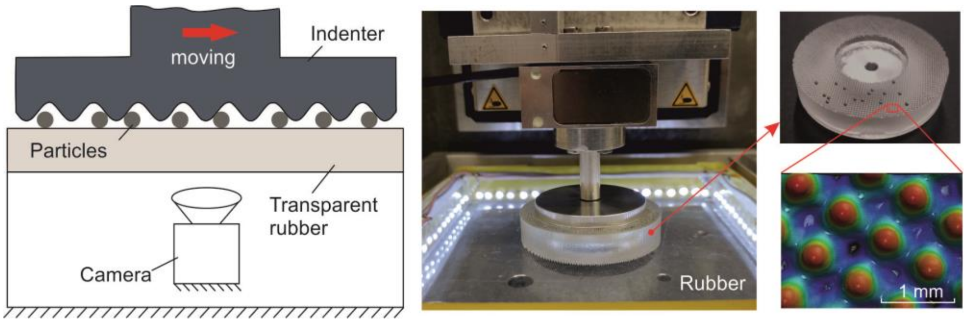
For this sake, an experiment of a tangential contact between a body with regular waviness and a rubber layer is designed following these concepts: (1) third-body particles are artificially located on the surface and they are much harder than first-bodies; (2) tangential movement of the first-body is very slow; (3) first-bodies have no direct contact. The former two conditions ensure the absence of wear. The latter one simplifies the contact. Similar measures were used in a recent study on the dynamics of third-body friction [8].

2. Experiment

The experimental setup is illustrated schematically in Fig. 1a (see detailed description in [9, 10]). An indenter with rough surface is moved under displacement-control by two linear motors M-403.2DG for the motion in vertical and horizontal directions separately. A 3D force sensor ME K3D40 is installed to measure the normal, tangential and lateral forces. The particles are located on a flat transparent rubber sheet TARNAC CRG N3005, under which a digital camera with resolution 1600x1200 pixels is fixed to observe the movement of particles. In this experiment, we used a 3D printed indenter made of photopolymer (elastic modulus 2 GPa) having two-dimensional waviness generated according to a harmonic function $A \cdot \sin(2\pi x/\lambda) \cdot \sin(2\pi y/\lambda)$ with amplitude $A = 0.25$ mm and wavelength $\lambda = 1$ mm, as shown in Fig. 1c. Stainless-steel spheres with diameter 1 mm were used as third-body particles. The rubber sheet with thickness 5 mm is very soft with elastic modulus $E \approx 0.324$ MPa [9, 10], so it easily sticks due to adhesion to the glass plate below (Fig. 1b).



a) b) c)

Fig. 1 (a) Scheme of experimental setup for sliding contact between a wavy-shaped indenter and a transparent rubber sheet. Metallic spheres with diameter 1 mm are used as third-body particles. (b) Photo of the indenter in contact with transparent rubber sheet. (c) Photo of the 3D printed sample with wavy surface and some small spheres on it. The subplot below shows the surface waviness of the indenter under a microscope.

In the experiment, the indenter was pressed on particles, while the indentation depth was kept constant and equal to 0.5 mm. Subsequently, it was moved slowly with a tangential velocity of 5 μm/s. We define the zero clearance between the peaks of indenter and sphere as the zero indentation depth, as shown in the left panel of Fig. 2. In this case no forces are detected during tangential motion. The contact configuration at the indentation depth of 0.5 mm is illustrated in Fig. 2 right: the particle is trapped between the valley of indenter and the deformed rubber (the indenter and the particle are much harder than the rubber), and there is no contact between indenter and rubber. The tangential force is then induced mainly by the interaction between sliding bodies and particles. The experimental results are presented in the next section.

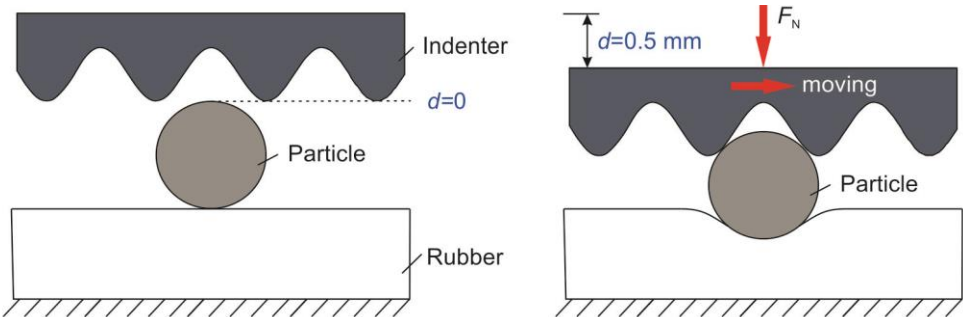
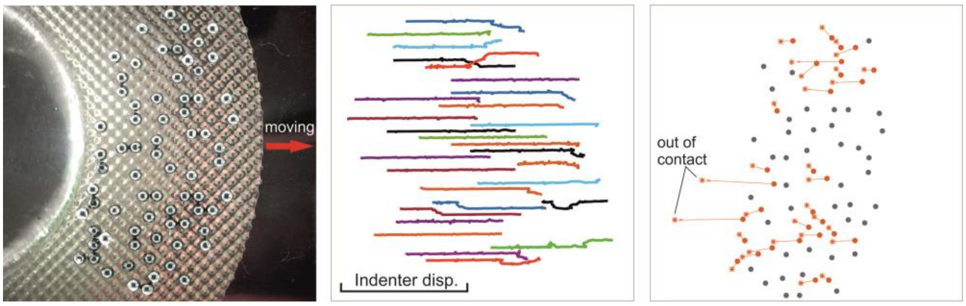


Fig. 2 Sketch of a three-body contact. The left figure shows the state of zero indentation depth at which the tangential force during sliding is zero. The right figure shows the state with indentation depth 0.5 mm. The comparison of particle size and surface waviness of indenter with the indentation depth can be seen in this figure.

3. RESULTS

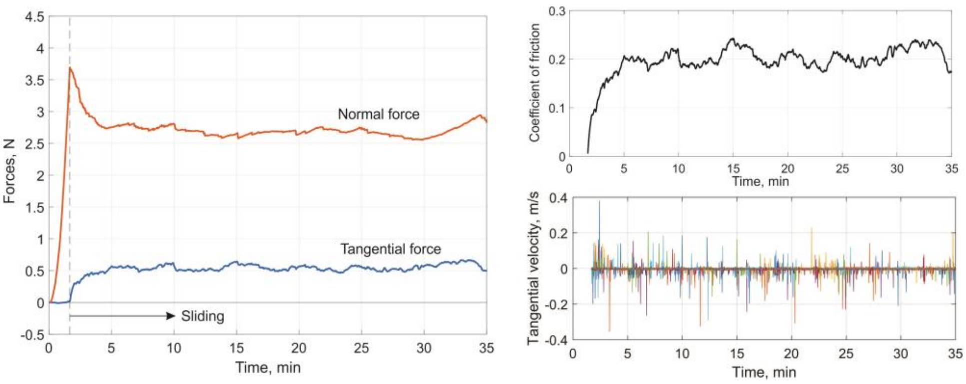
In the experiment 72 spheres with diameter 1 mm were located between indenter and rubber sheet within the camera's field of view. A snapshot during sliding is shown in Fig. 3a. A supplementary video in [11] shows the progress of complete experiment including indenting, sliding forward, sliding backward and pull off. In this analysis we focus only on the part of sliding forward. The indenter is controlled to move tangentially with constant velocity 5 µm/s. The direction of tangential motion was aligned with one direction of the waviness (Fig. 3a). No collision between particles was observed during the sliding. With image processing, trajectories of all particles were determined, some of which are shown in Fig. 3b. It is seen that some particles travel on a straight line having almost the identical displacement as the indenter (in total 10 mm). These particles stay mainly in the same valleys of waviness and moved together with the indenter during the whole process. The black spots in Fig. 3c show these 42 particles. It is noted that some of these particles tried to move over the peaks during the sliding but dropped quickly back to the valleys. The other 30 particles flow from one valley into another one. The red spots and corresponding stars show the particle positions at the beginning and the end of the sliding by taking the indenter as a reference. It is noted that two spheres were squeezed out of contact in the process. It is seen in Fig. 3c that the "black" and "red" particles are clustered.



a) b) c)

Fig. 3 (a) A snapshot showing all particles between wavy surface and rubber sheet. (b) Trajectories of some particles during sliding. (c) Positions of particles at the beginning and the end by taking the indenter as a reference. The black spots are particles moving together with the indenter or failed to move over the peaks, and the red ones are having a relative displacement. The red spots are positions of particles trapped on at the beginning and stars are corresponding positions at the end of sliding.

The normal and tangential force as well as the coefficient of friction are shown in Fig. 4. From the particle trajectories, the instantaneous tangential velocities of particles were determined for analyzing the particle motion (Fig. 4b below). Here tangential direction is the direction of indenter's motion (horizontal direction as marked in Fig.3a). It is clearly visible that the continuous movement of particles is followed by short jumps or a series of jumps. The jump of motion (velocity) is much larger than the indenter's velocity. These jumps lead to a "randomly" fluctuating normal and tangential force shown in Fig. 4a.



a) b)

Fig. 4 (a) Normal and tangential force in sliding contact. (b) Coefficient of friction and instantaneous tangential velocities of particles corresponding to trajectories.

4. CONCLUSION

An experimental study on particle transport in three-body contact was reported. The experiment was designed to eliminate wear by using the soft rubber sheet and a very small sliding velocity and by avoiding the first-body contact. The normal and tangential forces are then induced mainly by the interaction between artificial small spheres and the surface waviness whose size could be individually designed. The particle trajectory was analyzed to find the movement of spheres which can be transferred from one minimum of the wave into another one. The fluctuating normal and tangential force should be correlated to the motion of particles for example the instantaneous tangential velocities. Furthermore, local material property could also play an important role, for example friction, or adhesion such as in this reported case of soft rubber.

It is planned to continue this work by systematically studying the contact and varying the system parameters and shape – starting from the simplest case, a single or few particles [12]. The elastic interaction among particle, wavy surface and foundation could be understood by numerical simulation using for example the Fast Fourier Transform assisted Boundary Element Method in which adhesion or friction could be taken into account and the state of particles (sticking, rolling or sliding) could be identified [13, 14].

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REFERENCES

1. Vakis, A.I. Yastrebov, V.A., Schreibert, J., et al., 2018, *Modeling and simulation in tribology across scales: An overview*, Tribology International, 125, pp. 169–199.
2. Dienwiebel, M., Verhoeven, G.S., Pradeep, N., Frenken, J.W.M., Heimberg, J.A., Zandbergen, H.W., 2004, *Superlubricity of Graphite*, Physical Review Letters, 92, 126101.
3. Zhang, Y., Kovalev A., Meng, Y., 2018, *Combined effect of boundary layer formation and surface smoothing on friction and wear rate of lubricated point contacts during normal running-in processes*, Friction, 6, pp. 274–288.
4. Aghababaei, R., Warner, D.H., Molinari, J.F., 2016, *Critical length scale controls adhesive wear mechanisms*, Nature Communication, 7, 11816.
5. Popov, V.L., Pohrt, R., 2018, *Adhesive wear and particle emission: Numerical approach based on asperity-free formulation of Rabinowicz criterion*, Friction, 6, pp. 260-273.
6. Ostermeyer, G.P., Brumme, S., Recke, B., 2017, *The wear debris investigator – a new device for studying the formation of particles in the contact area*, Proc. Eurobrake, Dresden, EB2017-VDT-019.
7. Ostermeyer, G.P., 2003, *On the dynamics of the friction coefficient*, Wear, 254, pp. 852–858.
8. Deng, F., Tsekenis, G., Rubinstein, S.M., 2019, *Simple law for third-body friction*, Physical Review Letters, 122, 135503.
9. Lyashenko, I.A., Pohrt, R., 2020, *Adhesion between rigid indenter and soft rubber layer: Influence of roughness*, Frontiers in Mechanical Engineering. Section Tribology, 6, 49.
10. Lyashenko, I.A., Popov, V.L., 2020, *The effect of contact duration and indentation depth on adhesion strength: experiment and numerical simulation*, Technical Physics, 65(10), pp. 1695–1707.
11. Li, Q., Lyashenko, I.A., Starcevic, J., 2021, *An experimental study on third-body particle transport in sliding contact (video of experiment)*, supplementary video. https://doi.org/10.13140/RG.2.2.31164.67206
12. De Payrebrune, K.M., Kröger, M., 2015, *Kinematic analysis of particles in three-body contact*, Tribology International, 81, pp. 240–247.
13. Li, Q., 2020, *Simulation of a single third-body particle in frictional contact*, Facta Universitatis-Series Mechanical Engineering, 18(4), pp. 537–544.
14. Rey, V., Anciaux, G., Molinari, J.F., 2017, *Normal adhesive contact on rough surfaces: efficient algorithm for FFT-based BEM resolution*, Computational Mechanics, 60, pp. 69–81.