Design and realization of metasurfaces with tunable friction law

Antoine Aymard[1)*], Emilie Delplanque[1)], Davy Dalmas[1)] and Julien Scheibert[1)]

[1)] Univ Lyon, Ecole Centrale de Lyon, ENISE, ENTPE, CNRS, Laboratoire de Tribologie et Dynamique des Systèmes LTDS, UMR 5513, F-69134, Ecully, France
*Corresponding author: antoine.aymard@ec-lyon.fr

We describe a design method to create dry, rough interfaces with predefined frictional behavior. It consists in decorating an elastic substrate with well-controlled spherical asperities. Their individual frictional properties are determined through a preliminary calibration. Those properties are then used within an inversion procedure able to pass from (i) a desired evolution of the friction force as a function of the normal law to (ii) the altitudes and curvatures of the asperities that will provide such a friction law. We illustrate this approach by producing surfaces offering various preset shapes of the friction law: power law, linear, two-branched affine.

Keywords: metamaterials, asperity models, rough interfaces

1. Introduction

Many everyday device-based tasks, from table tennis spinning shots to robot grasping, involve dry friction. Fine control of this friction is highly desirable. Because of the complexity to model the friction of random rough surface [1], designing surface to offer a preset friction law is currently out of reach. Here, we overcome this limitation by introducing a novel design strategy.

2. Methods

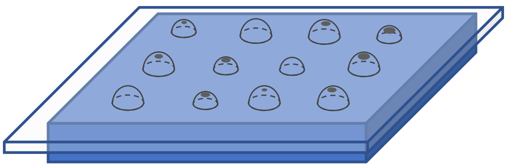

Fig. 1: sketch of the considered model rough surfaces.

Our strategy first relies on a simplification of the interface, so that the roughness is set on only one of the two solids, and consists of spherical asperities (Fig.1). The latter are brought into contact with a rigid smooth counter-surface. The individual micro-contacts have well-known tribological properties, characterized through a preliminary calibration step similar to that performed in [2]. In those conditions, designing an interface to match a preset friction law thus consist in finding the geometrical properties of all asperities. As a consequence, the problem becomes much simpler, while leaving enough possibilities to access a wide range of friction laws.

The desired friction law is the input of an inversion step whose outputs are the curvature and height of the asperities composing the simplified rough surface. For the inversion we model single microcontacts as independent, elastic and adhesive.

In practice, an aluminum mold, fulfilling the geometrical description resulting from the inversion step, is prepared by micro-milling with a sphere-ended cutting tool with the same radius as the desired asperities. A rough elastomer sample is then prepared by crosslinking a commercial PDMS (Sylgard 184) between the mold and a glass slide.

The properties of the interface created between the realized elastic surface and a glass slide are tested on a laboratory-built tribometer. The latter provides, besides the macroscopic force and displacements applied to the glass slide, in situ images of the contact interface, from which the real contact area can be monitored.

3. Dicussion

Four surfaces have been realized, all composed of 64 asperities. The observed relationships between the friction and normal forces are presented in Fig.2. They are compared with the expected laws, predicted using the geometrical description of the surface realized and the above-mentioned hypotheses of the inversion step. Figure 2(a) shows, for asperities of radius of curvature R=1mm, that we can for instance obtain either linear of power-law-shaped friction laws. Figure 2(b), instead, shows that we can pass from a linear law (blue) to a law with two different affine branches (black). This is obtained through a change in the radius of curvature of a subset of the asperities. We emphasize that all observations match quantitatively with the predictions, demonstrating the potential of our design strategy.

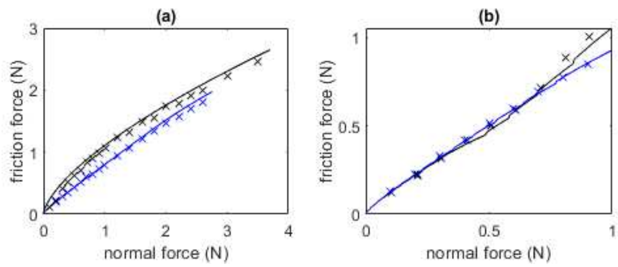

Fig. 2: Examples of obtained friction laws. Dots: measurements. Lines: prediction. (a) Linear- and power-like laws (R=1mm). (b) Linear (R=250mm) and two-branched affine (R=250µm and 1mm).

4. References

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