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Designed high-friction surfaces—Influence of roughness and deformation of the counter surface

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Abstract

The present paper experimentally investigates the prospects of using surfaces with carefully designed topography to design contacts with a high level of static friction. All tests are run under boundary lubricated conditions. Specifically, very high static coefficients of friction (up to $\mu \approx 1.2$) are demonstrated for surfaces covered with sharp pyramids. The test surfaces were manufactured using micromechanical techniques based on photolithography and etching of silicon followed by deposition of CVD diamond. The technique results in exceptionally well-defined surface textures with very sharp and durable diamond pyramids. The possibilities of using such surfaces for gripping and various types of coupling applications are discussed in some detail. A good correlation between the achieved results and theoretical predictions of the ploughing component of friction is demonstrated. The technique showed to be very robust with only minor influence of surface roughness and counter surface deformation.

Keywords: High-friction; Designed surface; Diamond; Gripping

1. Introduction

In many applications a high coefficient of static friction – a good grip – is desirable and in some cases even necessary to ensure a reliable function. Such applications include all types of frictional joints, flange joints, shaft couplings, fastener systems, bolted joints, all dependent on the friction force to keep the relative position or transmit mechanical power. By increasing the coefficient of friction between, for example, the two surfaces in a flange joint, it would be possible to reduce the number of bolts or the size of the bolts, without losing the grip. In this manner a modification of the coefficient of friction becomes a way to make a construction smaller, lighter or cheaper.

It is since long known that the most reliable way of getting a high static friction is by adding a high ploughing component. In sliding friction, a high adhesive friction component may be achieved. Unlike the situation in sliding friction, where the surfaces are "worn clean", any small amount of grease or other contaminant on the surfaces will dramatically reduce the adhesive friction component of static contacts. However, hard tips that have to plough their way through the counter surface add a reliable component to the static friction even in lubricated contact situations.

The addition of a ploughing component is then typically brought about by equipping one of the surfaces with sharp protruding asperities. These asperities can be produced by e.g. grit blasting one of the surfaces (the harder one) or by equipping it with hard, sharp particles. One commercially available solution is called friction shims. These metal shims are equipped with protruding sharp particles on both sides, and are positioned between the two surfaces to increase the grip.

In a recent paper Pettersson and Jacobson has introduced microtextured, extremely well defined and sharp diamond surfaces as high-friction surfaces for fundamental studies and possible future development into applications [1].

In the present paper, the same technique is further examined regarding the possibilities and limitations. A number of aspects of fundamental and applied significance are treated. Can the surface be used repeatedly, or will the surface damage produced by the hard asperities limit repeated use? What is the general effect of surface roughness of the counter surface? Is the friction sensitive to the initial loading conditions or to small misalignments

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between the surfaces? What happens to the coefficient of friction when the mating surfaces also make contact outside the protruding tips? The latter two questions are treated to some detail, and the experimental results are related to a simplified theoretical model. The model presented in [1], suggests that it ideally would be possible to design a surface for any desired friction coefficient between that typical of pure ploughing and that typical of contact against the flat.

1.1. A model for the coefficient of friction versus fraction of pyramid contact

The friction and deformation mechanisms in the contact between hard asperities and softer metallic surfaces have been treated extensively in the literature [2–12]. Typically the models presented treat only the contact between a single asperity and a flat, unscratched counter surface. Here, a simple theoretical model has been used to compare with experimental results and thereby identifying and focusing at the most important features of a real material. The idealised material has no deformation hardening and no material flow around the pyramid indents or other deformation effects. The contact situation is perfectly aligned and the surface is entirely flat.

According to the flow pressure model, the ploughing component of a rigid pyramid shaped tip can be written as:

$$\mu_{\mathrm{P}} = \frac{\text{ploughing force}}{\text{normal force}} = \frac{HA_{\mathrm{P}}}{HA_{\mathrm{N}}} = \frac{A_{\mathrm{P}}}{A_{\mathrm{N}}}$$

where H the hardness of the counter surface, A_{P} the projected ploughing area and A_{N} is the projected load carrying area. This gives a theoretical value of the ploughing friction component at 0.71 for a face first pyramid and 1.00 for a corner first pyramid.

At low loads only the outermost tips of the pyramids indent the surface and all the load is carried directly by the pyramids. At higher loads, the pyramids indent deeper and some contact may appear outside the pyramids.

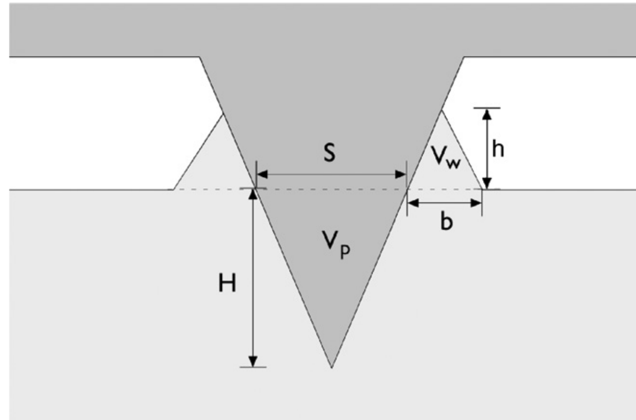

Fig. 2. A simplified geometry for the pile-up around a static indent, assuming that all sides of the ridge have equal height, that the ridge is symmetrical and that the volume of the ridge is equal to the volume of the indented part of the pyramid.

In the simplified, idealised situation, where the pyramid surface contacts a flat, perfectly aligned surface that does not form pile-ups around the pyramid indents, no contact outside the pyramids would occur, until they are fully indented into the flat surface, see Fig. 1(a) and (b). However, in any practical situation we will have pile-up and a number of other deviations should also be expected to reduce this threshold load, as indicated in Fig. 1(c)–(e).

The flow pressure model can be complemented by adding an estimation of the load limit for contact against the pile-up outside the pyramids. A simplified assumed geometry for the pile-ups is given in Fig. 2.

Assuming this geometry, the introduction depth H for first contact can be estimated according to:

$$\frac{s}{H} = \frac{b}{h} \Rightarrow s = \frac{bH}{h}, \qquad V_{\mathrm{P}} = \frac{1}{3}s^2 H = \frac{b^2 H^3}{3h^2},$$

$$V_{\mathrm{w}} = 4\frac{bh}{2}l = 2bh(b+s) = 2b^2 h + 2b^2 H,$$

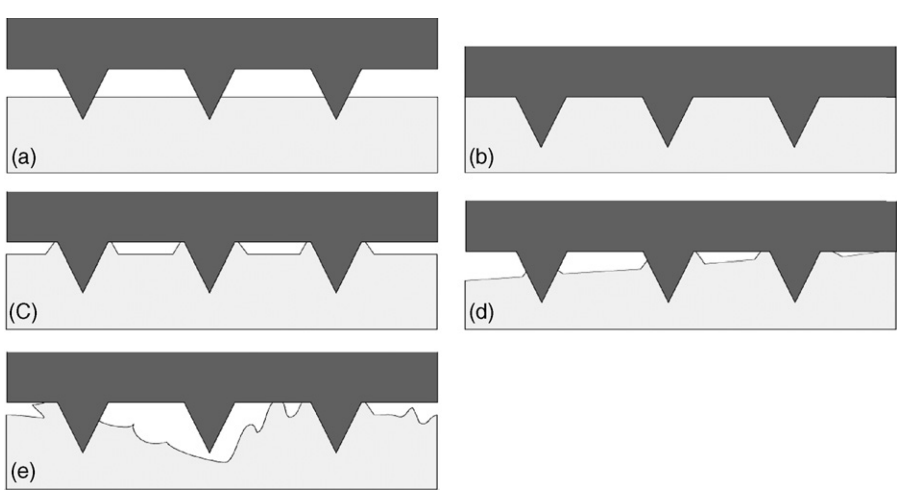

Fig. 1. Alternative contact situations between the microtextured diamond surface and metallic counter surfaces: (a) idealised contact situation, without pile ups, at low load where the entire load is carried by the pyramids, (b) idealised contact situation, without pile ups, at high load where load is also distributed outside the pyramids, (c) situation with pile up, where the ridges carry part of the load, (d) situation with imperfect alignment and (e) situation with rough metallic surface.