

Meso-Scale Dislocations and Friction of Shape-Complementary Soft Interfaces

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The interface between two surfaces patterned with complementary shapes such as arrays of ridge-channel structures or pillars accommodates relative misorientation and lattice mismatch by spontaneous production of dislocation arrays. We show that relative sliding of such an interface is accomplished by dislocation glide on the interfacial plane. An exception is the singular case where the lattices are perfectly matched across the sample dimension, in which case sliding is accompanied by motion of edge-nucleated defects. These are meso-scale analogs of molecular sliding friction mechanisms between crystalline interfaces. The dislocations, in addition to the long-range elastic energy associated with their Burgers vectors, also cause significant out-of-plane dilation, which props open the interface locally. For this reason, the sliding friction is strongly pressure-dependent; it also depends on relative orientation of patterns. Sliding friction can be strongly enhanced compared to a control showing that shape-complementary interfaces can be engineered for strongly enhanced pressure- and orientation-dependent frictional properties in soft solids

Keywords (from 3 to 5 max): tribology, dislocation, shape-complementary, soft materials

1. Introduction & Discussion

Modifying surface mechanical properties such as friction and adhesion by near-surface architecture is of great interest as a paradigm for designing unique functionality in surface mechanical properties of materials. Nature has provided many fascinating examples of surface attachment structures in biological organisms that provide unique adhesion and friction properties. Inspired by this, much scientific effort has been devoted in developing the bio-mimetic and bioinspired structured surfaces over last two decades, and fruitful achievements have also been obtained by many research groups.

Although considerable progress has been made on designs of microstructures for controllable adhesion and friction, it has been mostly for one-sided surface structures, usually against a generic flat surface. Natural contacting surfaces often exist as designed complementary pairs. Examples include the interlocking between insect hard claws and rough substrates, the attachment structures in the dragonfly head-arresting system, the hydrogen bonds between two nucleotides on opposite complementary DNA or RNA and the celebrated case of loop-clasp designs that led to the development of Velcro. Studies of pairs of ridge-channel surfaces showed that for complementary shapes adhesion can be enhanced by up to a factor of 40 while for non-complementary surfaces it is reduced by a factor of about 0.25, i.e., with selectivity of a factor of 160 [1]. Misorientation on complementary interfaces is accommodated by line defects, appearing as visible striations, that are essentially meso-scale twist boundary screw dislocations. While these dislocations permit surfaces to adhere for small misorientation, they carry elastic energy, the release of which attenuates the adhesion enhancement [2]. The orientation and density of these defects can be accurately described using the geometrical analysis of Moiré patterns [3].

Here, we present a study of friction between two shape-complementary interfaces: ridge-channel and fibrillar. We show that in both cases interfacial slip is

accommodated by dislocation glide. The exception is the singular case in which the surfaces are sufficiently well-aligned for there to be no interfacial dislocations, in which case slip is accommodated by defects that nucleate at sample edges and sweep through the sample. In this manner, friction of shape-complementary interfaces mimics that of atomistic interfaces. In other words, friction is quite different, e.g., we find that it is strongly pressure dependent. We separately considered a third case in which cylindrical fibrils on one side of the interface are complementary to cylindrical holes on the other. In this system, the fibrils are embedded in their matching holes only for the first separation after molding, subsequent to which the pillars do not easily enter their complementary holes. That is, not all shape-complementary interfaces work in the manner we study here.

We present a detailed theoretical model for the ridge-channel structure. Modeling the core structure of the screw dislocations using the framework of fracture mechanics, we are able to explain quantitatively how friction changes with applied pressure and misorientation. The mechanics of the fibrillar interface is significantly more complicated and our discussion of the mechanisms are based on comparison with simulations of the analogous atomistic systems.

2. References

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