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Fractal surfaces in adhesive wear processes

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Wear of materials plays a key role in the durability of manufactured objects and has therefore an important economic impact [1]. A unified picture of the underlying physics of wear is still far from being reached, because of the numerous mechanisms and complex processes involved. Understanding the physics of wear requires a detailed investigation of the time evolution of frictional forces, debris production and surface roughness. This presentation investigates the long term evolution of rough surfaces of solids under dry sliding and adhesive wear (i.e, when the material loss is mainly due to transfer of particles from one body to another due to large adhesive forces).

While it is known that newly created surfaces by means of crack propagation are self-affine [2], the time evolution of surfaces upon mechanical wear remains an open question. What is known from experimental studies is that self-affinity is preserved for highly abrasive wear [3] and that in other cases the worn surface undergoes asymmetric changes with respect of its original mean plane [4]. Surface roughness is also linked to the wear rate, as rough surfaces are found to deteriorate more in the running-in, up to the point that they have been smoothed enough and the wear rate becomes smaller and constant (the opposite is happening for surfaces that are initially too smooth) [5].

Recent coarse-grained atomistic simulations have reproduced key adhesive wear processes [6], including a ductile to brittle transition at critical contact junction sizes. We adopt this approach to investigate the surface roughness evolution under adhesive wear processes. The simulated system is two-dimensional, with periodic boundary conditions along the horizontal direction to allow for continuous sliding at constant velocity of the top surface over the bottom one. In the early stages of contact, the two surfaces form a debris particle that continuously rolls between them, interacting with them by removing material and deforming them.

The asset of the performed simulations is that they are long enough to allow for a detailed investigation of the surfaces geometry evolution over time. The simulations display a two-regime evolution of the surfaces, characterized by high wear rate at running-in and lower wear rate in later stages of the process. Once the running-in is over, the morphology of the sliding surfaces and of the rolling debris particle are analyzed by means of their power spectral density (PSD). All the analyzed surfaces appear self-affine, and their heights are positively correlated. This type of roughness is consistent with the ones found in faults [7] and, by analogy with gradient percolation models, which hints that short range interactions prevail over long range elasticity [8].

In some cases it is also observed that, after the running-in, the debris particle can heavily perturb the process increasing again the roughness of the mating surfaces, similarly to the running-in conditions. This can be explained analyzing the debris particle geometry and the stress state at the contact interface. In particular, roughness enhancement happens by removal of material from the opposing surfaces when the particle is approximately round, while an irregular non-convex shape favours the presence of stress singularities in the particle itself and thus the deposit of material from the particle to the opposing surfaces.

In this presentation we analyze different initial setups (i.e. different morphology, system size, material properties). We conclude with a discussion on the salient features of the steady-state self-affine morphology. We reveal that the final roughness is independent of the initial state, within the range of parameters studied.

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