NUMERICAL MODELING OF ADHESIVE WEAR ACROSS SCALES

J.F. Molinari[*1], R. Aghababei[2], L. Frérot[1], E. Milanese[1], T. Brink[1]

[1]*Department of Civil Engineering, Department of Materials Science*
Ecole Polytechnique Fédérale de Lausanne (EPFL), Switzerland
e-mail: jean-francois.molinari@epfl.ch
[2]*Department of Mechanical Engineering, Aarhus University, Denmark*

1. Introduction

Wear, the process of material loss when materials come into contact, takes various forms and is present in literally all engineering applications. It is experienced at disparate scales from single atom removal at the nanoscale, to the eraser of a student leaving rubber debris on paper, and the formation of gouge along a tectonic fault.

Around mid-twentieth century tremendous progress was made in Tribology, the science of interacting surfaces in relative motion. Scientific advances explained the intimate relationship between surface roughness, load, and the real contact area. Due to the complexity of wear mechanisms, scientific progress has arguably slowed down ever since, although there has been a rapid increase in the number of empirical models describing various forms of wear. Recently, with the advent of nanotribology, fundamental discoveries were made regarding friction mechanisms at nanoscale asperities. However, by and large, the dots remain unconnected and our macroscopic engineering-scale understanding of wear remains limited.

We present our recent attempts at developing a fundamental, mechanistic, across scales, understanding of adhesive wear.

2. Coarse-grained atomistic simulations

We begin by summarizing recent numerical simulation results, based on coarse-grained atomistic potentials [1, 2], that capture debris formation at a contact junction. The two mechanisms at play in our simple model are plastic shearing of contacting asperities, and (if enough elastic energy is available) crack propagation leading to debris creation. This ductile to brittle transition was shown to occur at a material-dependent critical contact-junction size [2]. We have shown that, in the simple situation of an isolated micro contact, the final debris size scales with the maximum junction size attained upon shear, and with the total shear-load mechanical work. This permits to draw analogies with Archard adhesive wear model [3], which states that the wear volume is proportional to the normal load, the sliding distance, while it is inversely proportional to the hardness of the softer material in contact.

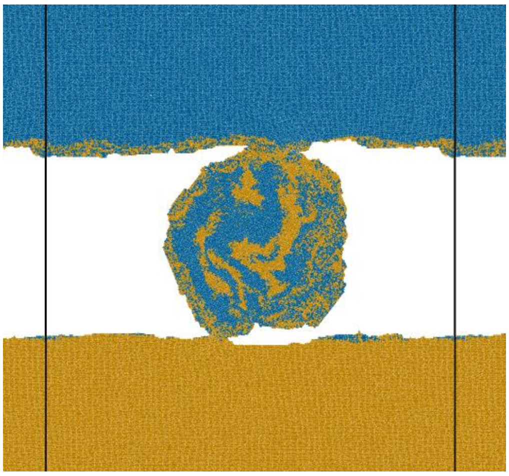

Figure 1: Debris particle rolling between two surfaces under a constant normal pressure. Colours show material particles origin: top material is blue, bottom material is yellow. Black vertical lines indicate periodic boundary conditions

We also discuss recent results regarding the long term evolution of surface roughness. Investigating different initial conditions, e.g. surface geometries, we reveal that after a sufficiently long wear process the initial conditions are forgotten, and the resulting worn surfaces are self-affine. The worn surfaces are characterized by a Hurst exponent between 0.6 and 0.8, suggesting that the process is not random. During the wear process, the debris particle that is formed and wears the surfaces is also investigated (Figure 1). We show that its volume increases throughout the process, indicating that the mechanism of detaching material from the bulk is favoured over detaching material from the particle.

2. Mesoscale wear model

Next, we incorporate this single-asperity understanding in a novel mesoscale model [4], which aims at estimating from first principles the wear coefficient, a notoriously little understood parameter in wear models. We estimate the amount of volume of debris formed for a given applied load, using the probability density of micro-contact sizes. A crucial element of this mesoscale model is the distribution of surface heights, which should evolve as wear processes take place.

In order to obtain a realistic distribution of micro-contact sizes, we model the contact between solids with self-affine rough surfaces [5, 7]. We propose two interpretations of the wear coefficient that are applied to the contact model: one based on Archard's view of the wear coefficient as the probability of debris formation, and one stemming from up-scaling of single asperity wear considerations. Both are based on a Griffith-like criterion that leads to the emergence of a critical length scale governing wear particle formation [1]. These developments allow us to bring physical properties of the interface [1] as well as geometrical and mechanical information into the estimation of the wear coefficient [4], figure 2. This opens the path to many potential developments of this model, including elasto-plastic contact and surface roughness evolution.

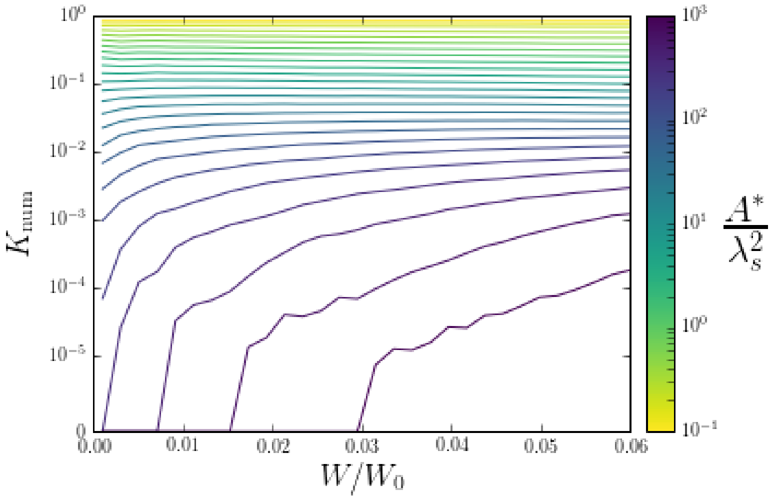

Figure 2: Wear coefficient as a function of the load, for different values of the critical micro-contact area A. The wear coefficient increases with the load up to a constant plateau, which is a characteristic feature of mild adhesive wear [6].*

Acknowledgments The authors acknowledge the financial support of Swiss National Science Foundation, through project 200021_162569.

References

[1] Aghababaei, R., Warner, D.H., Molinari, J.F., "On the debris-level origins of adhesive wear", PNAS, **114**(30), pp. 7935-7940 , 2017.
[2] Aghababaei, R., Warner, D.H., Molinari, J.F., "Critical length scale controls adhesive wear mechanisms", Nature Communications, 11816, 2016.
[3] Archard, J.F., "Contact and rubbing of flat surfaces", Journal of Applied Physics, **24**, 981, 1953.
[4] Frérot, L., Aghababaei, R., Molinari, J.F., "On understanding the wear coefficient: from single to multiple asperities contact", submitted to JMPS, 2017.
[5] Hu, Y.Z., and K. Tonder. "Simulation of 3-D Random Rough Surface by 2-D Digital Filter and Fourier Analysis." International Journal of Machine Tools and Manufacture, **32**, 83-90, 1992.
[6] Burwell, J. T., and C. D. Strang. "On the Empirical Law of Adhesive Wear." Journal of Applied Physics, **23**, 18-28, 1952.
[7] Stanley, H. M., and T. Kato. "An FFT-Based Method for Rough Surface Contact." Journal of Tribology, **119**, 481-85, 1997.