ENVIRONMENT-ASSISTED FRACTURE, MY FRIEND: THE CUTTING OF GUMMY METALS

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In this talk we look at fracture through rose-tinted glasses, especially the benefits of controlled environment-assisted disruption of surface plasticity in metals by fracture. In particular, we will consider the science and craft associated with the parting of solids – more specifically, cutting of metals.

It is well known that hard materials are difficult to cut, grind and shape. But what is much less well-known, and quite paradoxical, is that relatively soft metals such as aluminum, nickel, copper and tantalum, are also notoriously difficult to cut, grind and shape – characterized by large deformation forces and poor surface quality. This difficulty has earned them the moniker, “gummy.” Using high-speed, in situ imaging, we show that the fundamental cause of the problem is the tendency of these metals to deform via a highly unsteady, redundant mode of plastic deformation termed sinuous flow. This mode is characterized by large-amplitude folding, thick chips and non-homogeneous straining of the material – resulting in large energy dissipation [1]. We demonstrate that the gummy-metal cutting challenge can be overcome by suppressing the sinuous flow using a unique chemical effect in large-strain plastic deformation of metals [2, 3]. The chemical effect is disruption of surface plasticity, by local surface embrittlement, that is triggered by benign organic media (e.g., inks, adhesive substances), present as 100 to 200 nm thick films adsorbed onto the initial metal workpiece surface. In the limit, even chemisorption of an organic monolayer (one-molecule thick), or fractional monolayer, onto the metal surface is sufficient to cause the embrittlement. By locally modifying the material response in the cutting zone, the media effect a ductile-to-brittle transition in the deformation process: the energy-intensive sinuous flow is now replaced by a fracture-controlled segmentation mode, with 50 to 80% reduction in cutting forces and nearly an order of magnitude improvement in surface finish. Equally importantly, we present evidence to show that the embrittlement is a macroscale consequence of a change in surface stress, and not surface/interface energy, that is induced by the nanometer-scale organic films. Implications of the observations for cutting, shaping and comminution of metals, and environment-assisted cracking phenomena are discussed.

The study shows that fracture, induced in a controlled way, in our case by environment species, can be beneficial for the cutting and shaping of even ductile metals, adding to instances where it has been found beneficial with other materials [4, 5] – from the breaking of rock, to cutting of glass, the cleaving of crystals and even for growing of mushrooms!

References

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