FRACTURE PROPAGATION IN GLASSY POLYMERS: FROM NANOMETER TO CENTIMETER

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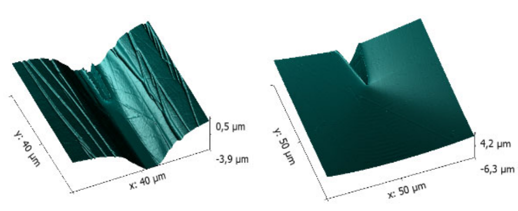
Fracture propagation in glassy polymers has been widely studied in the 1970s and 1980s, but some important theoretical and experimental features are still debated. Some recent experiments carried out in our lab show surprising common features between materials as different as glassy polymers and soft adhesive tapes, suggesting the development of common theoretical tools. Thanks to an advanced use of in-situ atomic force microscopy of a loaded fracture sample, and combining these observations with optical microscopy and digital image correlation, we were able to map the elasto-plastic field around a slowly propagating crack at different length scales ranging from the nm up to the sample scale (cm). Following linear elastic fracture mechanics, the stress field in the neighborhood of the crack tip can be written $\sigma \propto \frac{K}{\sqrt{r}}$, where r is the distance from the crack tip and K is the stress intensity factor. Beyond a critical value Kc called the toughness, an intrinsic property of the material, the fracture can propagate through the sample.

For most polymers, the toughness Kc or the fracture energy are found to be a function of the crack propagation velocity and temperature. This curve generally presents two stable branches with positive slope, associated respectively to a slow velocity steady-state regime and a dynamic regime where the propagation velocity is several order of magnitude higher (close to sound propagation velocity). When the crack is driven in the intermediate unstable velocity regime, stick-slip crack propagation is observed (for example in pressure sensitive adhesives or epoxy resins). Due to the multiscale nature of the crack propagation problem, we combined several experimental methods ad different scales to study the slow steady-state mode I propagation of a fracture in some glassy polymers. Indeed, the Kc dependency with the crack velocity spans on several orders of magnitude. In order provide longlasting stable slow propagation, we used the Double Cleavage Drilled Compression configuration, previously developed for brittle materials such as glasses. We evidenced for the first time in a thermoset a slow steady-state propagation velocity of the order of a few pm/s in the slow velocities regime of the crack propagation. Combining the AFM images of the propagating crack tip at the scale of the micrometric process zone and digital image correlation, the visco-plastic strain fields associated with steady state propagation could be characterized. Moreover, we were able to estimate the energy dissipated in the process zone and in the shear bands whose extension is around a hundreds of micron.



AFM topographic images: PMMA (left) and Epoxy resin (right).