In-situ TEM studies of crack propagation

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We have developed a method to control and observe the dynamics of crack propagation in thin lamella inside a transmission electron microscope. So far, we have applied the technique to study fracture in wood cell walls, multilayer films, and steel specimens. Combined with the gas pressure capabilities of our microscope, we can also observe environmental effects on crack propagation.

This talk will primarily focus on the effects of a hydrogen ambient on crack propagation in steels. Identifying the atomic scale mechanisms for hydrogen embrittlement in steels remains a much discussed yet elusive goal. On the one hand, microscopy investigations show that hydrogen enhances dislocation motion, while on the other, the quasi-cleavage morphology of the fracture surfaces and early fracture confirm the embrittling role of hydrogen. We attempt to reconcile these apparently contradictory trends using dynamic studies of crack tip propagation in Cr-Mo low alloy steel lamellae. The first stage of crack propagation in the lamellae involves extensive plasticity and thinning ahead of the crack tip, whether hydrogen gas is present or not in the microscope chamber [1]. However, subsequent stages are strongly changed by pressures as low as 2 mbar of H_2. In the absence of hydrogen gas, extensive plasticity continues, leading to crack tip blunting, void nucleation, crack bridging and necking [1]. In contrast, the crack tip in hydrogen gas remains sharp and propagates by the formation and linking up of {100} facetted staircase micro-cracks, without much associated plasticity. We argue that the mechanisms observed in the thin lamella can be extrapolated to the geometry and stress state of bulk materials and account for their fracture behavior. Evidence for contributions from both HEDE and HELP defect mechanisms will be discussed.

[1] L. Tian, C. Borchers, M. Kubota, P. Sofronis, R. Kirchheim, C.A. Volkert, Acta Materialia 223 (2022) 117474.