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FRACTURE TOUGHNESS MEASUREMENT WITH MICROSCOPIC CHEVRON-NOTCHED SPECIMENS

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The fracture toughness of a material is, in theory, a rather well defined mechanical material property; for ideally brittle material, it is the stress intensity of a sharp crack present in the material at the moment when crack propagation becomes unstable. Measuring the fracture toughness of materials, however, has always been difficult, mainly because meeting the conditions under which the property is well defined can be a challenge. In testing of macroscopic samples the validity of measurements is most often deduced by confronting results of various established testing protocols and sample configurations with criteria derived on the basis of analysis and extensive experimentation, including round-robin test campaigns. At microscopic scales, where specimen dimensions are typically of few micrometers and defined sample geometries more difficult to produce, there are few established test protocols, a fact which is evidenced by significant variations in measured values of the toughness of various given materials. Yet determining the fracture toughness of materials at the microscopic scale is an important issue, which is driven for example by the need to conduct failure analysis and prevention in modern “small scale” technologies, thin film industry and/or micro- or nano-electro-mechanical systems (MEMS/NEMS).

The principal tool for shaping microscopic specimens for fracture toughness measurement out of virtually any piece of material is the focused ion beam (FIB). For some materials it is possible to use alternative methods, *e.g.,* lithography, to shape the general specimen; however, the fabrication of sharp notches to serve as a precrack in the specimen is almost regularly done with the FIB. This approach has drawbacks, however, because FIB milling is well known to alter materials along machined surfaces, and also because FIB milled notches are not sharp cracks but always have a finite tip radius.

To circumvent these problems associated with FIB-milling of fracture toughness specimens, we explore testing configurations that contain a chevron notch: beam-like samples with a notch that contains a triangular ligament and subject to bending, such that the stress concentration at the apex of the triangle is first able to initiate the crack at a load that is lower than that corresponding to the onset of crack instability. Subsequently, by increasing the load, the initiated crack is driven to traverse the notch. Initially, the crack does so in stable manner due to its increasing crack front width, up to a moment of instability at which the sample suddenly breaks. Provided there is limited plasticity in the sample, its fracture toughness is evaluated at the moment of crack instability (corresponding to the peak load in the test), at which point preceding stable crack growth ensures the existence of a sharp crack. The method has been successfully demonstrated by testing chevron notched micro-cantilever beams with rectangular cross sections FIB-milled into fused quartz or nanocrystaline alumina [1]. We present this work, together with recent developments of the method in which newer sample configurations are explored, aiming to ease sample preparation and testing. Efforts to extend the method towards the testing of anisotropic materials, including single crystal silicon and single crystal TiC are presented. The lack of a need for pre-cracking, and the fact that the measurement is obtained at a moment when the unstable, sharp crack presents a majority of its front remote from FIB- induced damage, are advantages that make this technique rather attractive for measuring the fracture toughness of brittle materials at the micro-scale.

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