MM 4: Topical Session: Fundamentals of Fracture – Micromechanical Fracture Experiments

Time: Monday 10:15–13:00 Location: SCH A 216

Topical Talk MM 4.1 Mon 10:15 SCH A 216

Crack and dislocations interactions: coupling DDD and XFEM — Elena Jover-Carrasco[1], Erik Bitzek[2], and •Marc Fivel[1] — [1]CNRS/SIMaP, Univ. Grenoble Alpes, Grenoble, France — [2]MPIE, Computational Materials Design, Dusseldorf, Germany

The objective of this study is to build a numerical tool which could handle both cracks and dislocations in a dynamic manner. To do so, a 3D Discrete Dislocation Dynamics (DDD) code has been combined to the Extended Finite Element Method (X-FEM) via a strong coupling with the Finite Element software CAST3M. In the original FEM code, the crack advance is computed from the G-θ method which gives access to the stress intensity factors K. In this formalism, θ is the kinematically admissible virtual displacement of the crack and G is the energy release rate at the crack tip. When dislocations are present in the simulated box, they modify the evaluations of the energy and consequently the values of the derived stress intensity factors. These modifications are computed locally all along the crack front which is defined using level set functions. The crack front may locally change its direction of motion depending on the relative values of the stress intensity factors, especially KII. This will then lead to blunting effect of the crack tip.

In this presentation, full details of the coupling will be given. Test cases will then be presented where the behavior of a single dislocation in vicinity of a crack will be compared to atomistic simulations. Finally, large scale simulations of a mode I opening crack will be performed.

Topical Talk MM 4.2 Mon 10:45 SCH A 216

multiscale studies on the fracture behaviors of body centered cubic metal — •Yinan Cui, Zhijie Li, and Zhangtao Li — Applied Mechanics Lab., School of Aerospace Engineering, Tsinghua University, Beijing 100084, PR China

How the plasticity features influence the fracture behaviors of material is a critical question but remains far from well understood. To disclose this mystery, a multiscale plasticity-fracture coupled model is developed, which considers the atomistic-scale dislocation motion mechanism, the mesoscopic scales of discrete crack-dislocation interactions, and the continuum scale of crystalline plastic-fracture response. Body center cubic (bcc) material is chosen as an example to demonstrate the effectiveness of the developed model due to their wide applications and their speical plasticity feactures, such as strong temperature dependence and non-Schmid effect. Several new insights about the fracture behavior of bcc material are gained.

MM 4.3 Mon 11:15 SCH A 216

Micro-cantilever experiments to study the influence of predeformation and He irradiation on the fracture toughness of W single crystals — Stefan Gabel[1], Manuel Köbrich[1], Jan Vollhüter[1], Benedikt Eggle-Sievers[1], Benoit Merle[2], Erik Bitzek[3], and •Mathias Göken[1] — [1]Friedrich-Alexander-University Erlangen-Nürnberg (FAU) — [2]University Kassel — [3]Max-Planck-Institut für Eisenforschung, Düsseldorf

Micro-cantilever fracture testing has been proven to be a very reliable method to determine the fracture toughness at the very small scale. In the work by Ast et al.[1] the influence of the specimen size on the fracture behavior of single and polycrystalline tungsten has been investigated in detail from which it can be concluded that the fracture toughness as analysed with the J-integral approach slightly increases with the specimen size. Here we focus on the brittle-to-ductile transition and the influence of pre-deformation and He irradiation on w single crystals. The fracture toughness is analysed in a temperature regime from 233 K up to 353 K with a FemtoTools in-situ nanoindentation system. Pre-deformation by compression in the <110>direction led to a population of specific glide systems. The results show depending on the sample orientation an increase of the hardness and a slightly higher fracture toughness at low temperatures. Irradiation by He+ ions clearly lead to a decrease of the fracture toughness although the hardness increases. The experimental results will be discussed in comparison with modelling results. [1] *J. Ast, M. Göken, K. Durst, Acta Materialia 138 (2017) 198-211

15 min. break

Topical Talk MM 4.4 Mon 11:45 SCH A 216

Capturing Micromechanical Crack Tip Stress States and Toughening Plasticity in 2D and 3D — •Thomas E. J. Edwards[1], Johannes Ast[1,2], Szilvia Kalácska[1,3], Xavier Maeder[1], Jon Wright[4], and Johann Michler[1] — [1]Empa, Feuerwerkerstrasse 39, 3602 Thun, Switzerland — [2]CEA, 17 rue des Martyrs, 38054 Grenoble, France — [3]Mines Saint-Etienne, Univ Lyon, CNRS, UMR 5307 LGF, France — [4]ESRF, 38000, Grenoble, France

Crack tip toughening mechanisms in metals require plasticity, i.e. slip; the present study sheds predictive light on what local stress states lead to an increased dissipation of mechanical energy through plasticity. It also confirms the notion that the plastic performance of a material cannot be solely interpreted from elastic strain measurements, even if undertaken in-situ, or from post-mortem TEM imaging of dislocation structures. Pre-notched single crystal W microcantilevers were deformed in situ, whilst elastic and total strains at the notch tip were captured correlatively by DIC and HR-EBSD with sub-100 nm resolution. From the basic elastic and total strains and rotations hence measured, as well as post-mortem TEM, the following could be extracted: maps of shear stresses resolved onto individual slip systems, pure plastic strain resolved onto slip axes and GND density - all throughout loading, as well as the total dislocation density of the near-surface layer post-mortem. Further, we demonstrate a novel method to extract the full stress tensor, point-wise in 3D, again with ~100 nm resolution, on micromechanical testpieces under load: nano-beam 3D-XRD computed tomography at ESRF ID11.

MM 4.5 Mon 12:15 SCH A 216

Size effect in fracture mechanics: a detailed investigation regarding crack initiation and growth on the micro- and mesoscale — •Jutta Luksch[1], Aloshious Lambai[2], Gaurav Mohanty[2], Florian Schaefer[1], and Christian Motz[1] — [1]Materials Science and Methods, Saarland University, 66123 Saarbruecken, Germany — [2]Materials Science and Environmental Engineering, Tampere University, 33014 Tampere, Finland

Fracture mechanics are strictly regulated by standards. This includes limitations of specimen size as a function of the plastic zone size that mainly depends on the material itself. Hence, established test procedures are not easily downscalsble to nanomechanic testing. With progress in specimen preparation by FIB and test design e.g. in-situ testing in SEM, there are now ways to investigate a size effect systematically according crack initiation and growth. In the present study nanocrystalline nickel with a grain size of 40-50 nm is used as material to ensure a polycrystalline, quasi-homogeneous microstructure even for small samples. Micro bending beams of different dimensions are made using a FIB in order to study the fatigue size effect. Special attention was layed to introduce a fatigue pre-crack into the sample by cyclic loading with R<0 in a SEM with a nanoindenter. A study of crack initiation stress and number of needed cycles was made. The focus was given on microstructural changes. This pre-crack is then subjected to fatigue (R>0) and crack growth is quantified by the compliance method. In addition, the stress intensity factor is evaluated and related to the crack growth.

MM 4.6 Mon 12:30 SCH A 216

Quantitative measurement of fracture toughness from the bridge notch failure in microcantilever — •Yinxia Zhang[1], Matthias Bartosik[2], Steffen Brinckmann[3], Subin Lee[1], and Christoph Kirchlechner[1] — [1]Institute for Applied Materials, Karlsruhe Institute of Technology, Eggenstein-Leopoldshafen, 76344, Germany — [2]Department of Materials Science, Montanuniversität Leoben, Leoben, 8700, Austria — [3]Microstructure and Properties of Materials (IEK-2), Forschungszentrum Jülich, 52425, Jülich, Germany

Focused ion beam (FIB) milling has been widely used to prepare micron-sized specimens for micromechanical testing, but there are different types of artefacts originated from FIB. One is the imperfections in through-thickness notch geometries of microcantilevers. Bridge notches can overcome some of the problems by, upon loading, thin bridges fail first, creating atomically sharp natural cracks. Even though this bridge failure is widely assumed and predicted by FEM simulations, it has never been observed and quantified experimentally. This study presents the first experimental observation of cracking at the bridge notch and crack arrest before the entire through-thickness notch fails. This is possible by designing very thin bridges and using a very stiff loading rig with superior load resolution. Consequently, we obtained multiple fracture toughness values from one test. Using reported geometry correction factors calculated by FEM simulations, the fracture toughness estimated from the bridge failure was corrected and compared with the one from the failure of the through-thickness notch. The two approaches show consistent results.

MM 4.7 Mon 12:45 SCH A 216

Stable fracture of ceramics in the TEM — Oriol Gavalda-Diaz[1,2], Shelly Conroy[1], Eduardo Saiz[1], and •Finn Giuliani[1] — [1]Department of Materials, Imperial College London, UK — [2]Department of Mechanical, Manufacturing and Materials Engineering, University of Nottingham, UK

Small scale fracture tests have allowed many elements of a microstructure to be tested in isolation such as phase or grain boundaries. In our previous work we have shown that stable fracture tests in the SEM can accurately measure surface energies and the energy of individual grain boundaries. Furthermore, these tests allow the crack path and the effect of crack-defect interactions to be to be studied. However, tests in the SEM struggle to give in-depth information around the crack tip. Therefore, in this work we will demonstrate how it is possible to carry out stable fracture experiments in the TEM via a double cantilever geometry. This will be demonstrated on both silicon carbide and zirconia samples where the different mechanisms of energy dissipation will be discussed. Furthermore, a stable geometry allows additional analysis to carried out during the test, here we will discuss the possibility of using to 4D STEM to map the strain field around the crack tip.