MM 25: Topical Session (Symposium MM): Fundamentals of Fracture

Mesoscale Aspects of Fracture

Time: Tuesday 11:45–13:15 Location: TC 006

MM 25.1 Tue 11:45 TC 006

The Topology and Mechanics of the Formation of Fracture Surface Patterns — •Jay Fineberg[1], Itamar Kolvin[1], and Mokhtar Adda-Bedia[2] — [1]The Racah Institute of Physics, The Hebrew University of Jerusalem — [2]Laboratoire de Physique de l'Ecole Normale Supérieure de Lyon, Lyon, France

Fracture of brittle materials is often accompanied by the formation of structure on crack faces whose origin has long remained obscured. The difficulty lies in observing how microscopic structures are formed by rapidly moving cracks. To overcome this difficulty, we study soft brittle gels where crack speeds are significantly lower than in hard materials. Much below the shear wave speed, cracks form faceted surfaces separated by well-defined steps. At higher velocities, the facets give way to micro-branches, frustrated cracks that branch off the main crack. We directly visualize in real time the leading edge of the crack, the crack front, as it forms surface structure. In the faceting regime, steps induce long-ranged deformation along the crack front. Since surface formation costs energy, steps imply locally increased dissipation. We show that steps are stable due to topological defects of the crack front, that quantitatively link local dissipation increases at facets to crack front deformation and explain step persistence. We also show that crack front curvature may feed back to deflect step paths via non-linear focusing of crack fronts, causing steps to converge to form a micro-branch. Thus, our results supply the basis for a unified picture of pattern formation on fracture surfaces

MM 25.2 Tue 12:00 TC 006

Crack front segmentation and subcritical instability in mixed-mode I+III fatigue and brittle fracture — Tristan Cambonie[1], Alain Karma[2], and •Veronique Lazarus[3] — [1]Department of Mechanical Engineering Development (GMD), Institut National des Sciences Appliquées, Lyon, France — [2]Physics Department and Center for Interdisciplinary Research on Complex Systems, Northeastern University, Boston — [3]UME-IMSIA, UMR 9219 EDF-CNRS-CEA-ENSTA ParisTech, Palaiseau, France

When loaded in mode I+III, a planar crack generically segments into an array of "daughter cracks" shaped as tilted facets which further coalesce during propagation.

A linear stability analysis has predicted that the coplanar crack propagation is unstable above a critical threshold $(K_{III}/K_I)_c$ (Leblond et al., JMPS, 2011). We aim here to go beyond this first order linear stability analysis, (i) to investigate whether the instability is subcritical, which should explain the discrepancy with the experiments where the segmentation is generally observed far below the predicted threshold and (ii) to study the non-wavy, hence non-linear, shape of the facets.

The non-linear stability analysis is performed using phase-field simulations. The predictions are compared with fatigue experiments (Lazarus et al., IJF, 2008) performed on plexiglas beams (Chen et al., PRL, 2015). We present also some additional fracture experiments performed either under cyclic or monotonic increasing loading.

MM 25.3 Tue 12:15 TC 006

Fracture properties of silica nanoparticle and clay gels — •Gustavo Gimenes and Elisabeth Bouchaud — PSL Research University, ESPCI Paris, UMR Gulliver, MMN, 6 rue Jean Calvin, 75005 Paris Cedex 05, France

Colloids at low volume fractions can gelate into amorphous solids by their aggregation into a space-filling network. Rheological and mechanical tests over those colloidal gels have shown interesting results such as yield localization and delayed yielding. However, direct observation of their fracture behavior at mesoscopic and microscopic scales is hindered by difficulties in imposing a controlled load on a soft material and by the combination of large deformations and viscoelastic processes.

We use two new experimental setups fabricated with microfluidic technology to study the fracture of aqueous colloidal systems made with silica nanoparticles and synthetic hectorite clay Laponite RD (with diameters around 25 nm). A wide range of behaviors was observed as a function of the ionic strength, particle volume fraction and gel times for both materials, from a linear elastic solid which breaks to a viscoelastic liquid flowing under load. During fracture, the measurement of the displacement fields in the vicinity of the crack tip by Digital Image Correlation and of the crack opening displacement enable the determination of the stress intensity factors and the energy release rates. The comparison of both methods allows us to estimate the size of the non-linear zone, which tends to increase for decreasing ionic strengths. We also evaluate the characteristic time by considering the influence of the crack speed.

MM 25.4 Tue 12:30 TC 006

A mesoscopic study of plastic damage of amorphous materials — •Cesare Cejas[1], Gustavo Gimenes[1], Patrick Tabeling[1], and Elisabeth Bouchaud[1,2] — [1]Microfluidics, MEMS, Nanostructures Laboratory, CNRS Gulliver UMR 7083, Institut Pierres Gilles de Gennes (IPGG), ESPCI Paris, PSL Research University, 6 rue Jean Calvin 75005 Paris, France — [2]CEA-Saclay, IRAMIS, SPEC, F-91191, Gif-sur-Yvette, France

Fracture mechanisms in amorphous systems are still not fully understood. Because of their disordered nature, these materials break involving dissipative processes such as secondary cracking ahead of the main crack tip and local structural rearrangements. The aim of our work is to make and fracture amorphous systems composed of big enough "atoms", so that the above mentioned mechanisms can be observed optically.

Our amorphous materials being soft gels, we use microfluidics both to fabricate concentrated emulsions they are made from, and to investigate their controlled fracture. We synthesize soft emulsion gels based on a difunctional acrylic monomer through photopolymerization in order to get an "atom" size of $\sim 50\mu$m. We vary the rheological properties of these emulsions by regulating conditions for polymerization. Using conventional optical microscopy, we hydraulically fracture these soft gels at controlled low rates and examine both micro-cracking and plastic events, i.e. the local irreversible displacements around the crack tip.

MM 25.5 Tue 12:45 TC 006

Precursors of fracture and failure in hierarchical materials — •Paolo Moretti, Bastien Dietemann, and Michael Zaiser — Friedrich-Alexander-Universität Erlangen-Nürnberg

Hierarchical materials are characterized by repeated microstructural features, which appear at different length scales in a self-similar fashion. Biological materials provide important examples of this type of hierarchical arrangement: connective tissue exhibits a hierarchical fiber organization which at different length scales comprises molecules, microfibrils, fibers, and fiber bundles. We study precursors of failure in hierarchical network models of of hierarchical materials where fibrous assemblies are held together by multi-level (hierarchical) cross-links. Our large-scale simulation study shows that when such structures are loaded towards failure, precursory avalanche activity displays generic scale invariance: irrespective of load, precursor events (avalanches) exhibit broad, power-law distributions of sizes without apparent cut-offs. We argue that this behavior can be traced back to the hierarchical microstrcuture, whose construction parameters can be harnessed in order to tune precursor activity and failure. This complex scenario results in super-rough crack morphologies, with large deflections that are reminiscent of crack shapes as encountered in biological materials.

MM 25.6 Tue 13:00 TC 006

Fracture of solid bodies under high pressure torsion — •Roman Kulagin[1], Yan Beygelzimer[2,3], Andrej Mazilkin[1,4], Emma Tröster[1], Yuri Estrin[5,6], and Horst Hahn[1] — [1]Institute of Nanotechnology (INT), Karlsruhe Institute of Technology (KIT), Eggenstein-Leopoldshafen, Germany — [2]Donetsk Institute for Physics and Engineering named after A.A. Galkin, Kyiv, Ukraine — [3]Laboratory of Excellence for Design of Metal Alloys for Light Structures (DAMAS), Metz, France — [4]Institute of Solid State Physics, Chernogolovka, Russia — [5]Department of Materials Science and Engineering, Monash University, Clayton, Australia — [6]Department of Mechanical Engineering, University of Western Australia, Nedlands, Australia

The widely known method of High Pressure Torsion (HPT) was first proposed and described by P. Bridgman in his motivating article [P.W. Bridgman, Phys. Rev. 1935, 48, 825]. The future Nobel Prize winner was inspired by a tremendous multitude of phenomena in Nature associated with shear under high pressure. In his work, P. Bridgman suggested that HPT results in discontinuities in the deforming material, which are immediately healed under high pressure. Our experimental results will show that in the materials which are deformed by the HPT method, fracture and healing processes occur concurrently. To describe the underlying processes, we will present a model of fracture of a structurally inhomogeneous body. It will be shown that, as a result of the fracture and healing processes, intensive deformation-induced mixing of the constituents of the material takes place.