Plenary Session III

Wednesday AM
July 18, 2018

Room: Archie Griffin East Ballroom
Location: The Ohio Union

Session Chairs: Marc Legros, CEMES-CNRS; Martin Heilmaier, KIT Karlsruhe

8:15 AM Plenary

Micromechanics of Highly Cross-linked Thermosets: *Laurence Brassart*[1]; [1]Monash University

Highly-crosslinked epoxies are widely used as matrix material in high-performance fibre-reinforced composites, governing several aspects of their behaviour. Yet, attempts to model their viscoplastic response have been limited, as compared to thermoplastic polymers. However, the viscoplastic response of highly cross-linked thermosets, in particular under compression, is very similar to glassy thermoplastics below their glass-transition temperature, exhibiting complex features such as strain- and temperature-sensitivity, post-yield softening followed by rehardening, and severe non-linearity upon unloading. These phenomena can in principle be captured by advanced constitutive models for glassy polymers mixing phenomenological and micromechanical elements. However, this often comes at the price of a very large number of parameters (sometimes more than 30), while the physical basis of such models remains limited. In this work, we develop a micromechanical model to describe and predict the viscoplastic behaviour of the RTM6 epoxy resin. The model relies on the concept of STZ's (Shear Transformation Zones) as the elementary carriers of plasticity, whose activation is sensitive to the local stress, temperature and microstructural state. STZ's interact through the (possibly polarized) elastic stress field, resulting in overall viscoplastic flow. This model involves only 5 parameters to identify, all with a physical meaning. It is rich enough to quantitatively capture all the experimental trends, even the complex rate-reversal phenomenon observed during creep tests performed after plastic deformation at intermediate stress levels. While such a model cannot replace closed-form constitutive models for the treatment of large-scale components, it provides physical insights into the small-scale mechanics and is also useful to identify the parameters in macroscopic models.

8:55 AM Question and Answer Period

9:05 AM Plenary

Metallurgical Aspects of Fatigue Crack Growth Resistance in Steel: How Can We Improve it through Microstructure Control?: *Kaneaki Tsuzaki*[1]; Motomichi Koyama[1]; Hiroshi Noguchi[1]; [1]Kyushu University

Fatigue failures create enormous risks for all engineered structures and human lives, motivating a large number of safety factors in design and inefficient use of resources. To increase the fatigue strength of steel – the most common ductile structural metal – it is important to consider the growth of microstructurally small cracks from three perspectives. First, the fatigue limit does not correspond to the critical stress for crack initiation but rather that for crack propagation. Namely, non-propagating fatigue cracks can exist at the fatigue limit after more than 10 million cycles. Second, the bulk of fatigue life is mostly in the small crack growth stage. Third, the growth of small cracks within steels can be controlled by designing the microstructure and plasticity. Three factors are considered when discussing crack growth behavior in a ductile metal during one loading cycle at a given stress amplitude: (1) crack-tip-deformation mechanisms; (2) plastic deformation around the crack tip; and (3) internal stress evolution in the crack tip and wake. In most metals and alloys, dislocation emission at the crack tip is responsible for crack tip opening and namely crack growth. Thus, we can suppress the crack growth rate by repressing dislocation slip in the region of the crack tip. Regarding internal stress evolution, the formation of compressive stress can suppress crack opening. This presentation introduces some of our recent examples of microstructure control in the vicinity of the crack tip to improve the fatigue crack growth resistance in steels; these include (a) strain-age hardening through dislocations and interstitial carbon atoms interaction in an Fe–C binary steel; (b) nitrogen-enhanced dislocation planarity in a nitrogen-added stainless steel; and (c) martensitic transformation with volume expansion in a TRIP maraging steel.

9:45 AM Question and Answer Period

9:55 AM Break

Advanced Characterization of Deformation Processes V

Wednesday AM
July 18, 2018

Room: Traditions
Location: The Ohio Union

Session Chairs: Josh Kacher, Georgia Tech; Dipankar Banerjee, Indian Institute of Science

10:30 AM Invited

Dynamic Strain Aging during Constant Strain Rate and Creep Tests in Near-a Ti Alloy – IMI 834: *Priyanka Agrawal*[1]; S Karthikeyan[1]; Dipankar Banerjee[1]; [1]Indian Institute of Science

The current work explores the mechanical behaviour in IMI 834 in the temperature range of 350-500C for a microstructure consisting of 80% equiaxed a. Constant strain rate tensile tests carried out at 10-6-10-2 /s show dynamic strain aging (DSA) in the temperature range of 400-450C. Tensile creep tests conducted in a similar temperature range reveals primary creep behavior at 350C with a relatively high stress exponent (>10). At 400C, the creep rates were remarkably less sensitive to stress with a stress exponent of 2-3. Conventional three-stage creep is observed with a high stress exponent (>10) at 500C and higher. TEM observations reveal jogged screw dislocations in slip bands dominating the dislocation structure in both constant strain rate and creep conditions. The experimental work was supported by modeling the interaction of solutes with dislocations. It was estimated that deformation over this domain of temperature and strain rate space is controlled by the motion of jogged screw dislocations. The interaction of solute atoms (both static and diffusing) with gliding jogs was modelled to predict the observed temperature and strain-rate dependence. With increasing temperature (and lower strain rates), the mechanism controlling the glide velocity of jogs transitioned from (a)thermally-activated glide over static solute (Al and Sn) obstacles, to (b) formation of atmospheres of diffusing solutes (Si and C) and breakaway from these atmospheres, to (c)drag of Si and C solute atmospheres. Among the two diffusing solutes, Si is rate controlling at lower strain rates and higher temperatures, while C dominates at higher strain rates and lower temperatures. The match between experiments and model predictions is good. This work establishes a continuum of dislocation mechanisms based on jogged screw dislocation glide determining mechanical behavior over a wide range of strain rates ranging from 10-2 to 10-9 /s and temperatures from 350-500C in engineering titanium alloys.

11:00 AM

Direct Characterization of Atomic-Scale Crack Propagation Path along a Dopant-Segregated Grain Boundary: *Shun Kondo*[1]; Eita Tochigi[2]; Naoya Shibata[2]; Yuichi Ikuhara[2]; [1]Elements Strategy Initiative for Structural Materials, Kyoto University; [2]Institute of Engineering Innovation, The University of Tokyo

In many ceramics, grain boundary fracture always limits their practical capability. Since the fracture is the sequential atomic bond-breaking process, the atomic-scale crack propagation path and the relationship between the fracture path and the grain boundary structure are of primal importance for fundamental understanding of grain boundary fracture mechanisms. There are many possible propagation paths along a grain boundary, especially in the case that the grain boundary core has complicated structures such as dopant-segregated grain boundaries. However, it is still a major experimental challenge to characterize the grain boundary fracture path in atomic scale. In this study, we carried out nanoindentation experiments inside a TEM to introduce a sub-micro scale crack along the dopant-segregated Al_2O_3 grain boundary, and then observed the atomic structures of as-fracture surfaces using scanning TEM (STEM) to determine the atomic-scale crack propagation path. We prepared bicrystals including the Zr-doped Al_2O_3 Σ13 grain boundary. The TEM nanoindentation experiments were performed with a conventional TEM (JEM-2010, JEOL Ltd.), equipped with the double-tilt TEM-Nanoindenter holder (Nanofactory Instrument AB.). For the atomic-scale structural analyses, the aberration-corrected STEM (ARM-200CF, JEOL Ltd.) was used.In the TEM nanoindentation experiments, we introduced a crack along the grain boundary with the length of ~400 nm, and successfully obtained as-fractured surfaces. The atomic structures of the as-fractured surfaces as well as the unfractured grain boundary were directly observed by STEM. Comparing the two structures, the atomic-scale fracture path was determined, where the crack propagated in zigzag within the segregated Zr atom layer. Also, the first-principles calculations reveal the experimentally determined fracture path has the minimum cleavage energy for this grain boundary. The relationship between the atomic-scale crack propagation path and the grain boundary structure will be discussed in the presentation.