Crack Interaction with Microstructure

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Motivation:

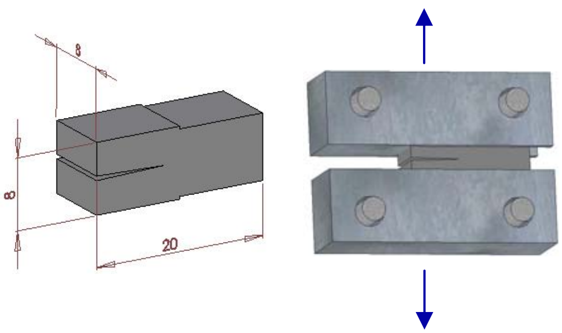
Designing microstructure for damage tolerance requires a detailed understanding of how an advancing crack interacts with the microstructure at multiple length scales. Advances in experimental techniques (e.g. well-controlled straining stages for optical and electron microscopes, FIB and X-ray, synchrotron and neutron diffraction) and new and powerful computational methods (finite element analysis incorporating cohesive elements at the continuum level, discrete dislocation (DD) methodology at the mesoscopic level, and coupled atomistic/continuum methods that transitions atomic level information to the mesoscopic level) have made it possible to begin addressing these complex problems.

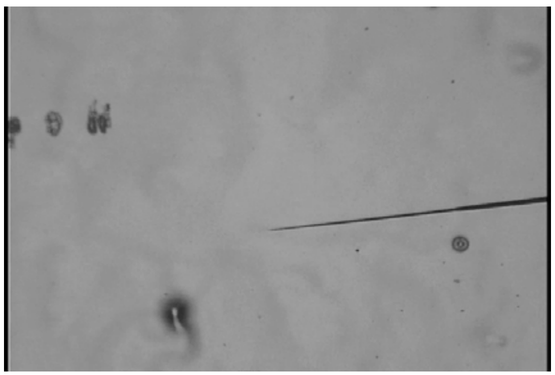
Some examples reflecting recent research activities include:

- Crack Interaction with Grain boundaries in Zinc Bicrystals (Experiments and Computations)
- Crack Growth along a grain boundary in Columnar Grained Sn thin film (in-situ TEM)
- Crack growth within a grain in an Al alloy (in-situ TEM)
- Crack-tip recrystallization in a multiphase Mo alloy at elevated temperatures (interrupted tests)

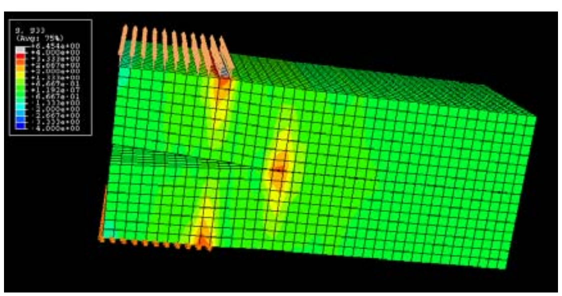
Crack Growth on the Basal Plane in Zn Single Crystals

Sample Geometry and Loading configuration



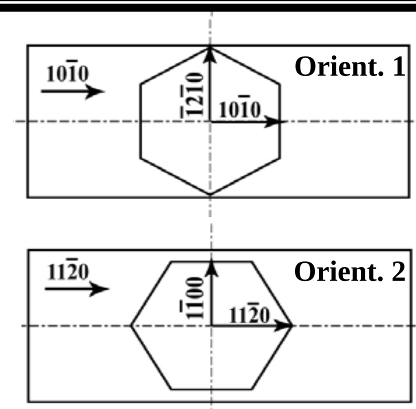


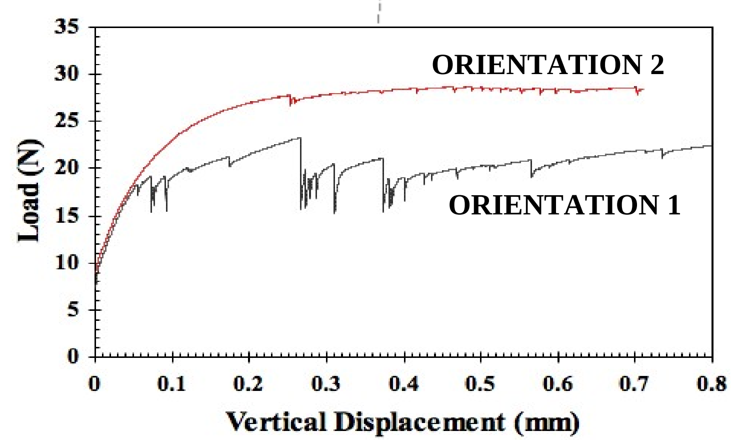
In-situ crack growth movie



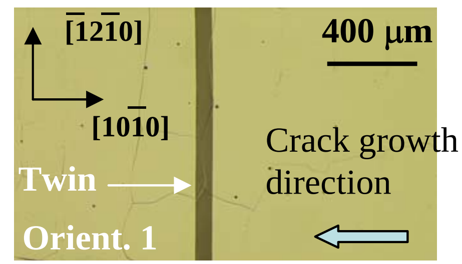
crack growth movie-3D FEM

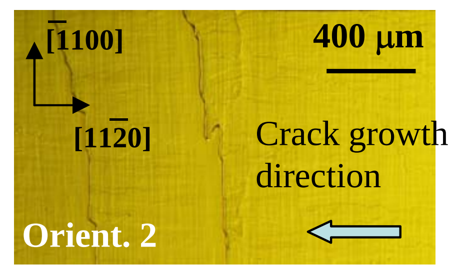
- **Crack growth on the basal plane in the [1010] and [1120] directions was studied using in-situ fracture experiments and FEM.**
- **Crack growth in both instances is discontinuous, being more so in the [1010] direction (see graph below as well as in-situ movie).**
- **Basal slip operates for both orientations, but pyramidal slip is present only in the [1120].**
- **The higher resistance and the smoother crack growth response for "orientation 2" is attributed to the increased plasticity from pyramidal slip.**
- **Fracture surface observations support this argument.**
- **3D FEM incorporating crystal plasticity and cohesive elements capture these details.**

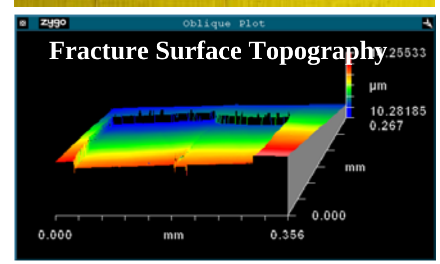




Fracture Surfaces

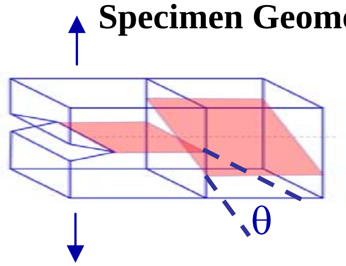






Crack Interaction with Grain Boundary in Zn Bicrystal

Specimen Geometry



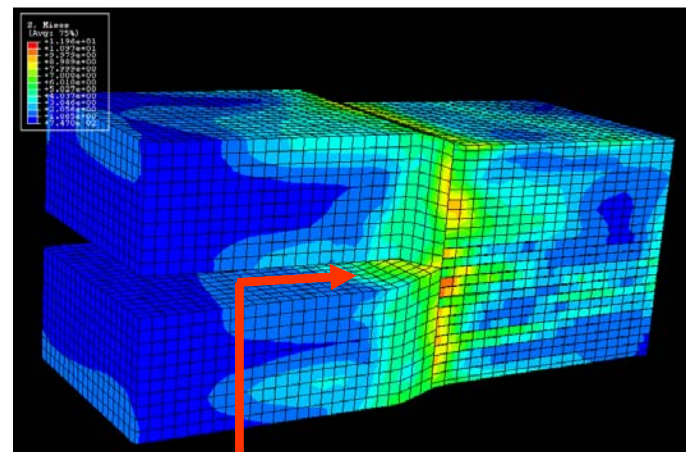
- **Grain 1 - (0001) Mode I Fracture**
- **Grain 2 - [0001] rotated by θ**
- **(0001) plane is shaded**

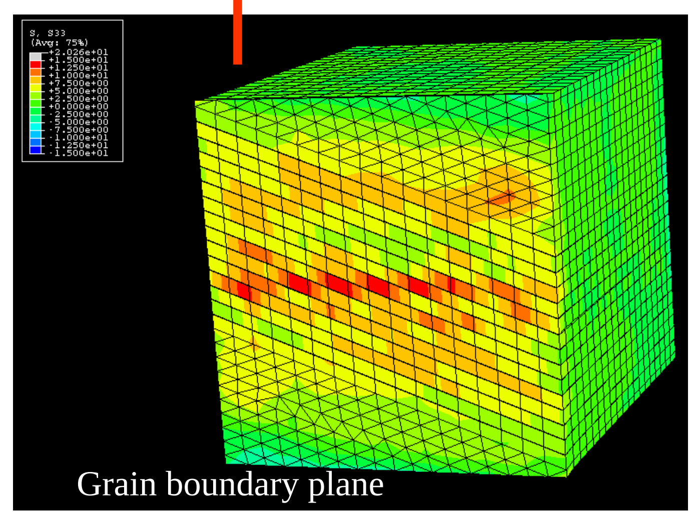
Observations:

- **Twist-misorientation of fracture plane across grain boundary provides significant crack growth resistance.**
- **Multiple cracking and plastic deformation of bridging ligaments are major energy absorption mechanisms.**

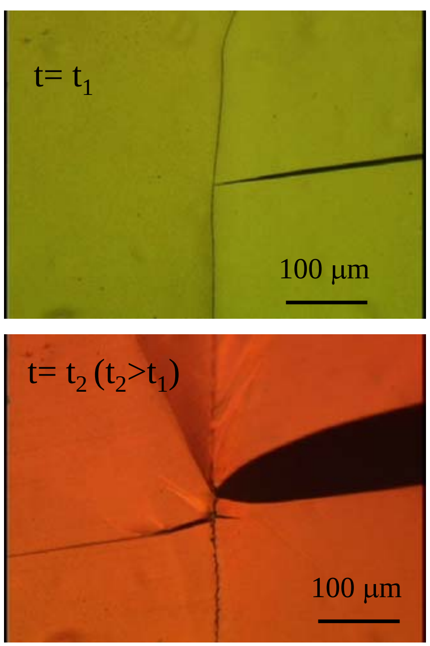
Finite element simulation of crack transmission across a twist grain boundary. Crystal plasticity captures anisotropic plastic deformation and cohesive elements permit crack growth.

FEM crack growth movie





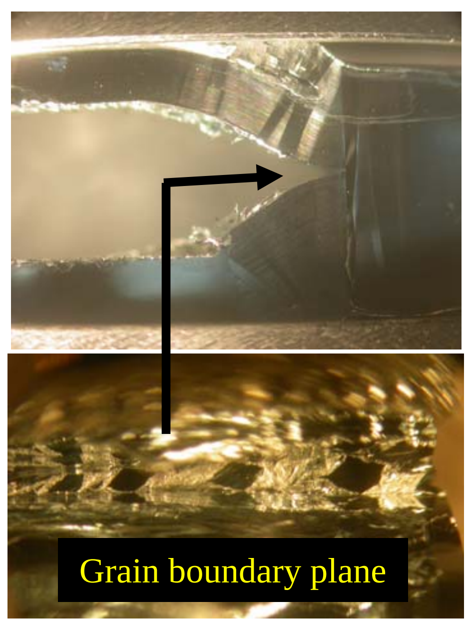
In-situ crack growth experiment showing crack interaction with a grain boundary in Zn bicrystal (*click for movie*)



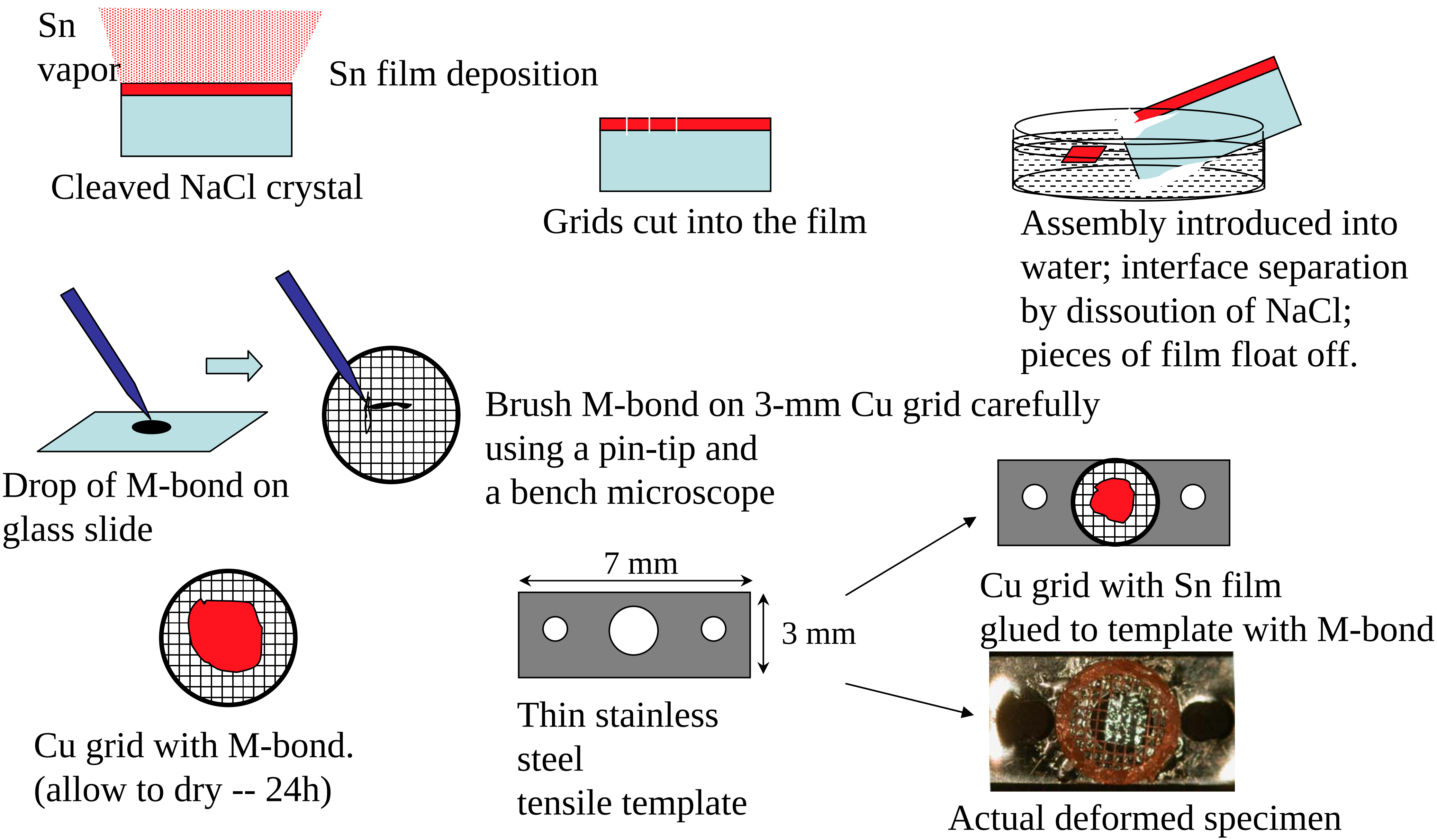
(a) Final specimen configuration.
(b) View of the grain boundary plane – observe the series of internal cracks on the basal planes of the second grain.

(a)

(b)



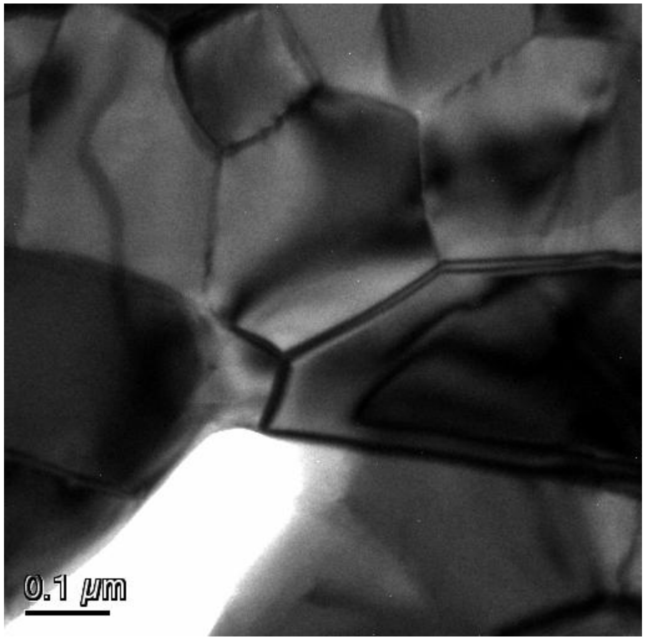
Columnar Grained Sn Thin film:
(Sample preparation for in-situ Deformation in the TEM)



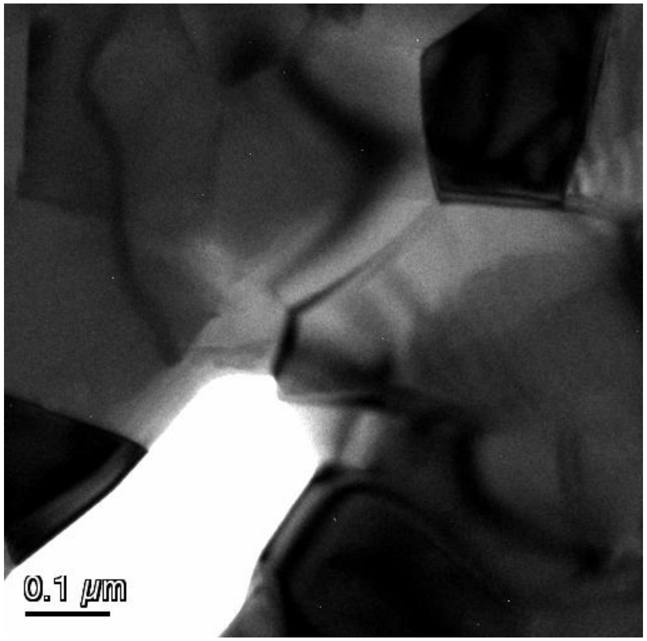
This technique enables a large electron-transparent region of uniform thickness and eliminates the need to perforate the sample.

Grain boundary Separation in Columnar Grained Sn Thin film (in-situ TEM)

(Crack growth is not catastrophic;
no dislocation emission is observed)

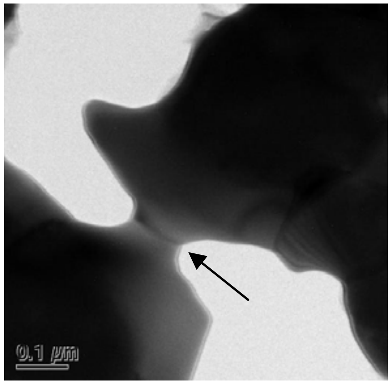


$t = t_1$

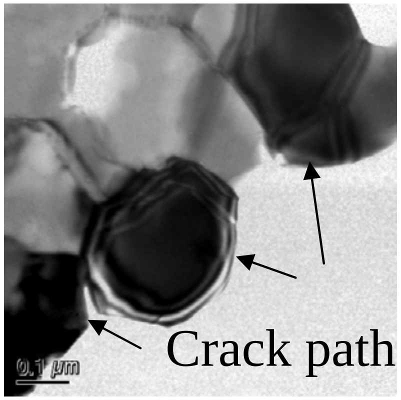


$t = t_2$

Diffusive separation of a grain boundary in Sn at room temperature



Click here for Sn grain boundary separation movie

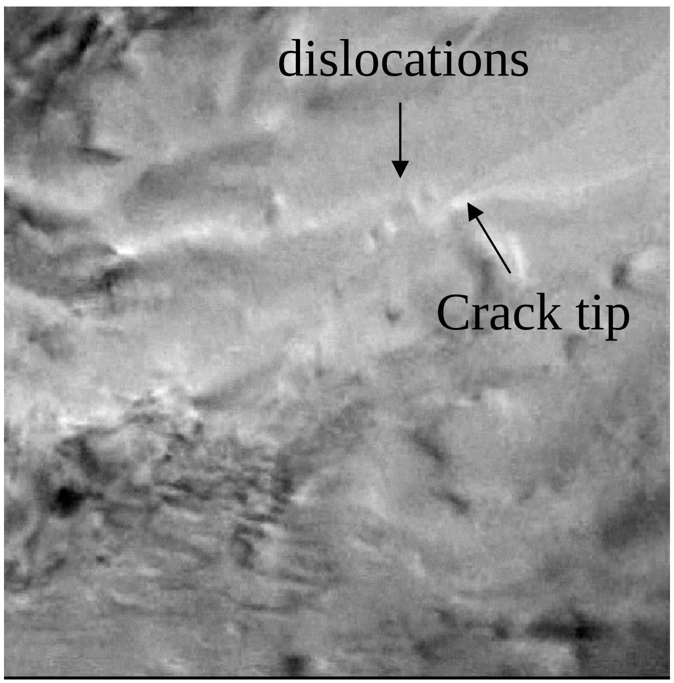


Grain Boundary Fracture

Crack Growth Within a Grain in Polycrystalline Ni and Al (in-situ TEM)

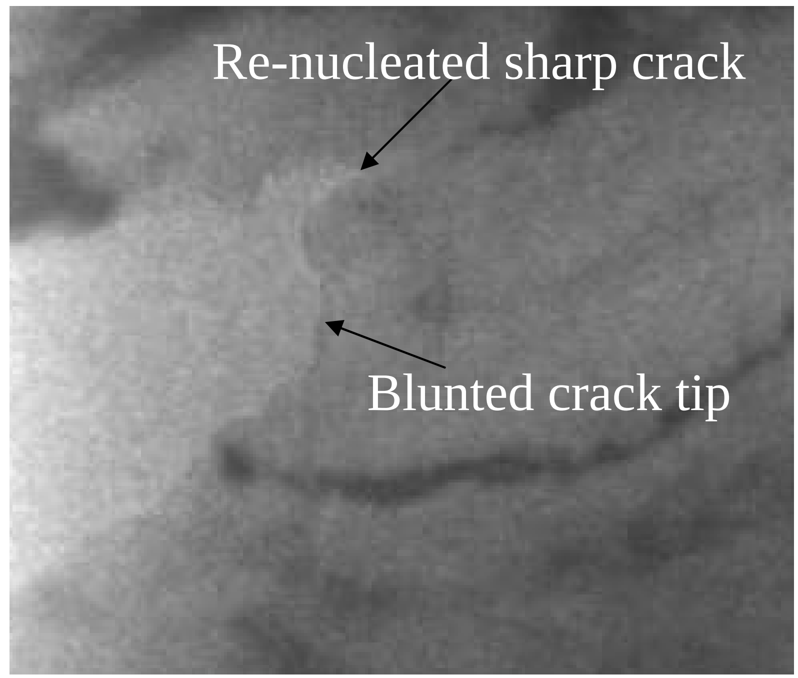
Direct observation of dislocation emission from the crack tip, crack blunting and renucleation of a sharp crack.

Crack growth in an Al alloy:



Click here for Al crack growth movie

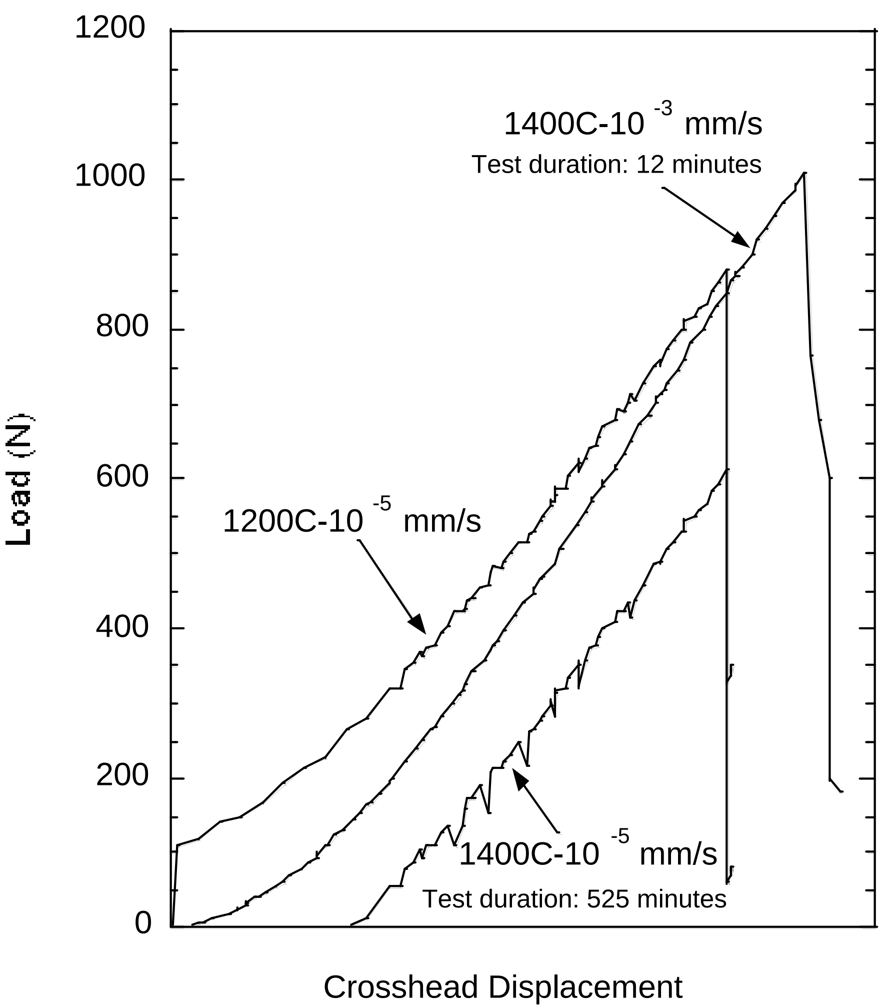
Crack growth in electrodeposited Ni



Click here for Ni crack growth movie

Crack-tip Recrystallization and its Effects on Crack Growth Resistance in a Mo-Si-B Alloy

Multiphase Mo-Si-B alloys are intended for ultra-high temperature applications beyond the capabilities of Ni-base superalloys. Under creep-fatigue conditions, dynamic recrystallization and triple junction creep cavitation occur ahead of the crack-tip, likely triggered by crack tip stresses. In these local regions, fracture shifts from transgranular to brittle intergranular mode, accompanied by rapid crack growth and load drops.



Finite element analysis using real microstructure reveals strain localization in matrix channels between hard second phase particles