Grain Boundary Decohesion and Particle-Matrix Debonding in Aluminum Alloy 7075-T651 using the PPR Potential-Based Cohesive Zone Model

Albert Cerrone[1], Gerd Heber[2], Paul Wawrzynek[1], Glaucio Paulino[3], Anthony Ingraffea[1]

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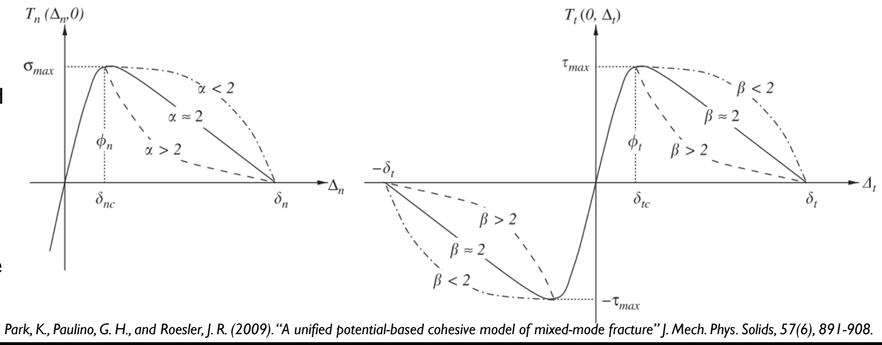
Problem Description

- Majority of a fatigue crack's life spent in the microstructurally small fatigue crack (MSFC) phase. Estimates as high as 90%.
- Grain boundary decohesion (intergranular fracture) and particle - matrix debonding occur in some aluminum alloys.
- To model accurately MSFC behavior in aluminum microstructures, must account for these interface mobilizations.
- Massively parallel finite element analyses are coupled with crystal plastic and cohesive material models to quantify these mobilizations as accurately as possible.

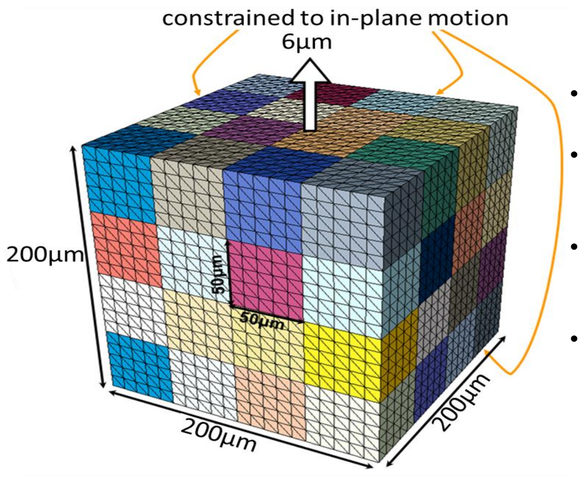
PPR Cohesive Zone Model

- PPR CZM used to account for the interface mobilizations.
- Published in 2009 in 2D. Generalized at Cornell to 3D.
- Unlike other CZMs, PPR is robust in mixed-mode analyses.
- Characterizes different fracture energies, considers different cohesive strengths, and describes various material softening behaviors.



Park, K., Paulino, G. H., and Roesler, J. R. (2009). "A unified potential-based cohesive model of mixed-mode fracture" J. Mech. Phys. Solids, 57(6), 891-908.

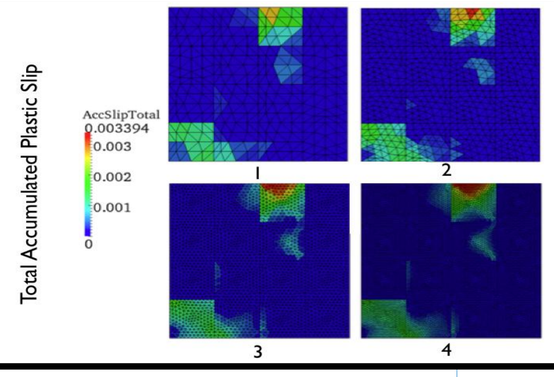
idealized cubical polycrystal



- 64 cubical grains
- cohesive elements discretized along all grain boundaries
- grains modeled as elastic-viscoplastic, rate-dependent FCC crystal plastic
- grains assigned randomized crystallographic orientations

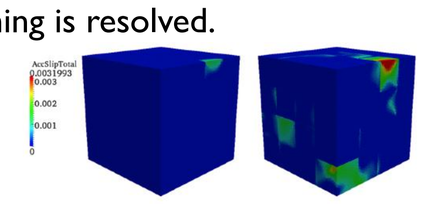
Refinement Study

Mesh ID	# of Bulk Elements	# of Cohesive Elements	# of DOFs
1	4,056	1,152	27,840
2	15,494	2,856	88,386
3	129,900	11,232	615,642
4	504,482	32,022	2,283,576

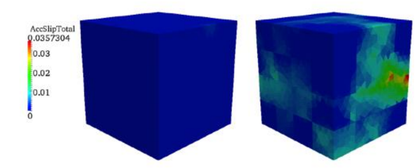


Interplay between plastic slip and cohesive softening is resolved.

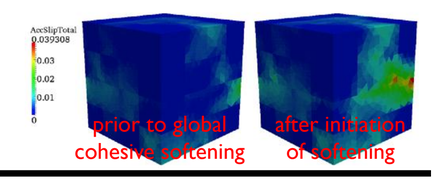
- Plastic slip and global cohesive softening initiate at same time.



- Plastic slip dominates.
- Note change in scale.
- 9% decrease in slip resistance engenders 35x increase in slip.

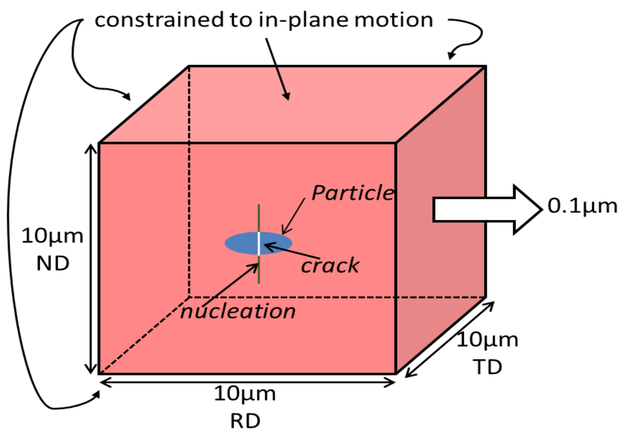


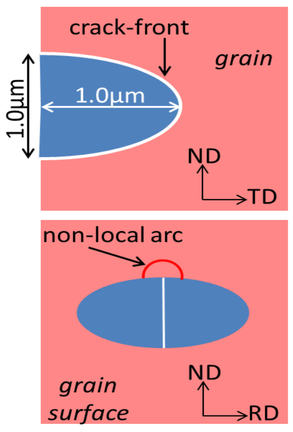
- Cohesive softening dominates.
- High prevalence of slip prior to global softening.



cracked particle embedded in single grain

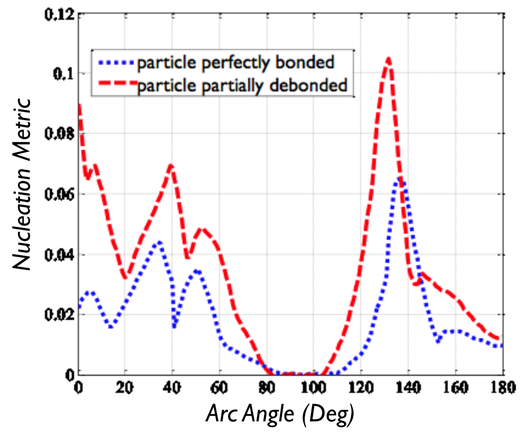
- emulates a grain containing a second-phase particle located at the surface of a notch of a DEN specimen
- cohesive elements placed along grain-particle interface
- slip metric mapped to non-local arc to avoid crack front dominance
- 625,690 bulk elements, 17,956 cohesive elements, 2,669,526 DOFs



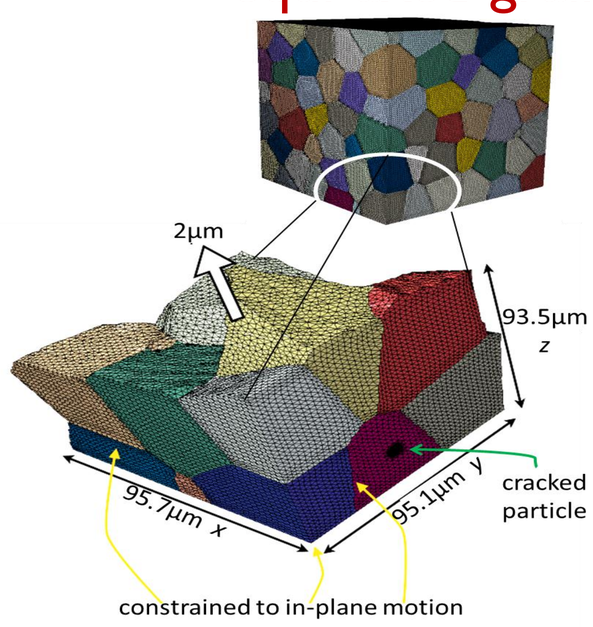


Slip Around Particle

- Slip metric is an indication of the crack's propensity to propagate in a certain direction.
- The plotted nucleation metric is the maximum value of total accumulated slip over each slip plane.
- Slip around partially debonded particle generally higher than around bonded particle.



equi-axed-grain polycrystal



- start with 222-grain, 25-mil DOF synthetic polycrystal
- extract 12-grain, 1.5-mil DOF submodel
- composed of 12 crystal plastic grains and 1 cracked particle
- PPR CZM on all interfaces
- grains assigned randomized crystallographic orientations

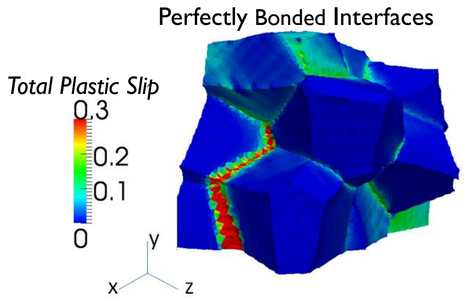
Model-Making Procedure

1) Microstructure Builder (CMU)
2) Surface Mesh
3) Volumetric Mesh
4) Particle Insertion
5) Crack Insertion (FRANC3D)
6) Cohesive Insertion

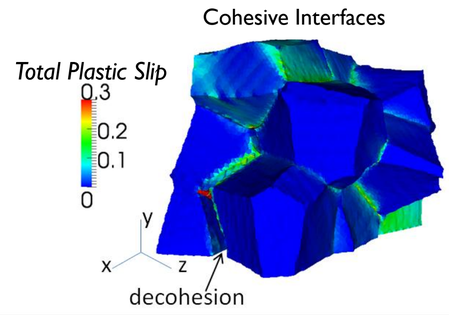
Plastic Slip in Polycrystal

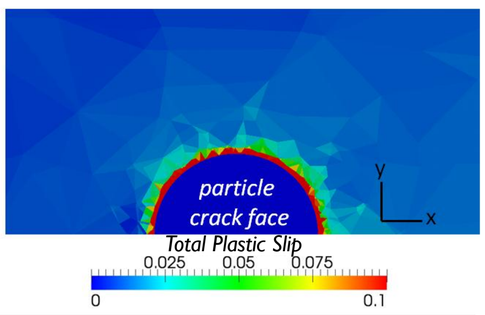
- Stress state at 45% of applied strain.
- Around completely decohered grain boundaries, slip is minimal.
- Around the partially debonded particle, just as in the single-crystal model above, slip is generally higher than around bonded particle.

Perfectly Bonded Interfaces

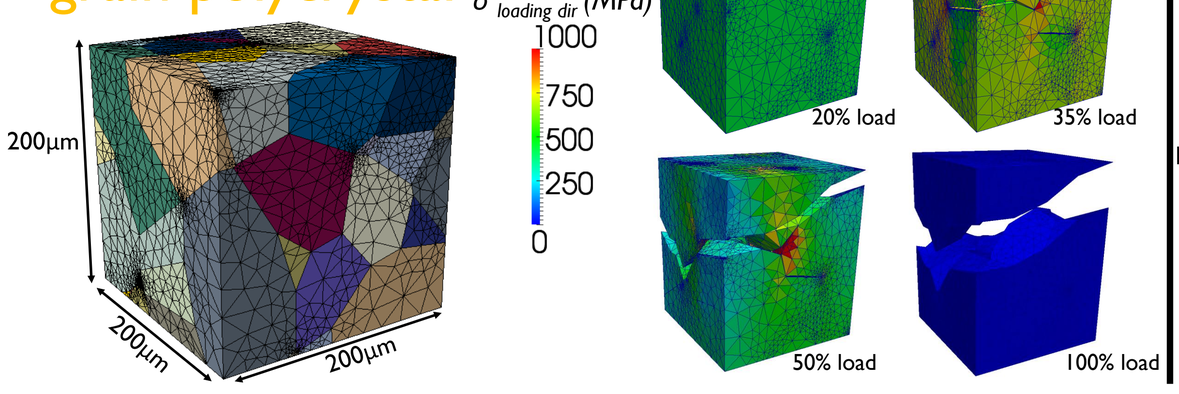


Cohesive Interfaces

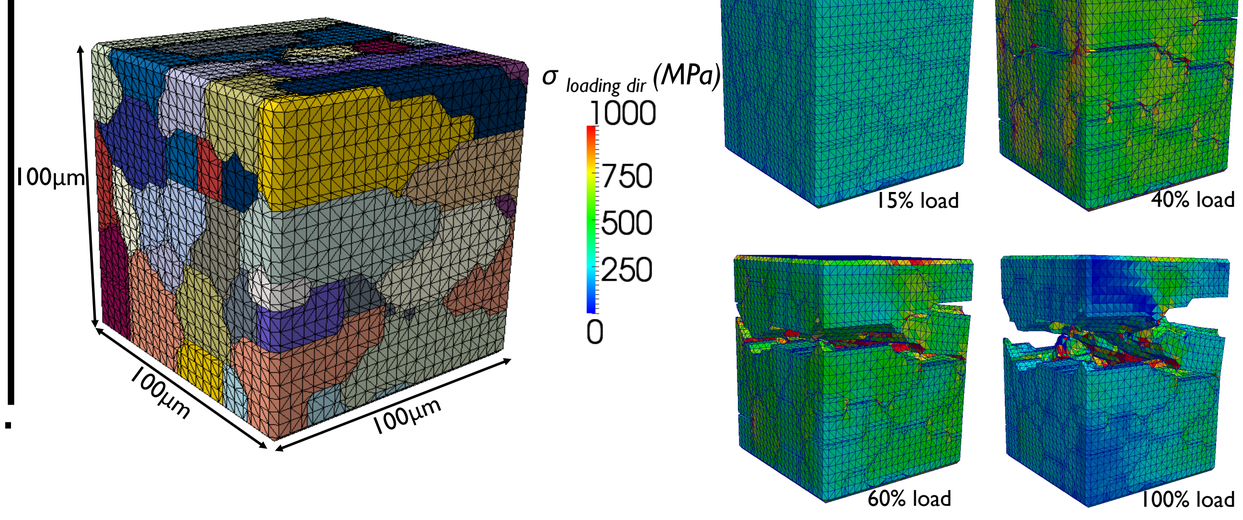




irregular-shaped-grain polycrystal



rolled-grain polycrystal



1 The Cornell Fracture Group, Cornell University, Ithaca, NY 14853
2 The HDF Group, Champaign, IL 61820
3 Dept. of Civil and Environmental Engineering, University of Illinois at Urbana-Champaign, Urbana, IL 61801