Modeling Fatigue Crack Nucleation in Al 7075
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**Motivation**

Significant part of fatigue life when fatigue cracks microstructurally small, most variability in life occurs during this phase.
- Crack length not observed to be directly related to particle size
- Microstructure in the vicinity of constituent particles has significant effect.
- Variability in microstructurally small crack nucleation and growth related to microstructural variability.

**GOAL**

Predict accurate stress and strain (slip) fields at the grain scale for realistic microstructures subject to cyclic loading.

Key Phenomena that should be captured by the model:
- Geometric effects (grain structures)
- Texture effects (orientations)
- Material hardening
- Particle effects
- Damage accumulation (irreversible slip)

**Methodology**

Methodology focuses on the modeling of grain-scale mechanics and includes development of a constitutive model for crystal plasticity and a finite element formulation for polycrystals. The constitutive model is informed by experimental observation and is based on underlying phenomena.

**Constitutive Model**

A crystal elasto-viscoplastic model is employed to capture the response of Al 7075-T651.

Decomposition of the deformation gradient into elastic and plastic parts.

Velocity gradient given in terms of the slip rate on each slip system.

**Plastic Slip Model**

The crystal plasticity model captures slip-system activity and the interaction of dislocations with precipitates (Orowan looping).

A power law relates rate of shearing on slip systems to resolved shear stress.

Evolution of resistance to plastic slip (hardening) is based on the Orowan looping mechanism.

**Finite Element Formulation**

The finite element implementation allows for the modeling of realistic grain structures. A three-dimensional formulation with additional pressure variable is utilized for stability.

Governing equations:

\[ \sigma : \varepsilon = 0 \]

Corresponding weak forms (total Lagrangian) with interpolation functions:

**Implementation**

Constitutive model and finite-element formulation were implemented in C++.

Key features of the formulation:
- Finite strain
- Stable mixed displacement/pressure formulation
- State update routine for elasto-viscoplastic crystal constitutive model
- Consistent tangent formulation for fast convergence

Finite-element driver:
- Utilizes MPICH for parallel processing
- PETSc software package used for solving global system of equations

**Results**

Finite-element analysis of an actual polycrystal of cold-rolled Al 7075 with an embedded particle. The model geometry was obtained from experiments run at Northrop Grumman. The grain geometries are extruded through the length of the unit cell, while the particle is only extruded a short distance. The model is used to determine the damage that ultimately leads to the particle cracking.

**Sponsor**

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