Characterization of Small Cracks
Using Single Crystal Plasticity

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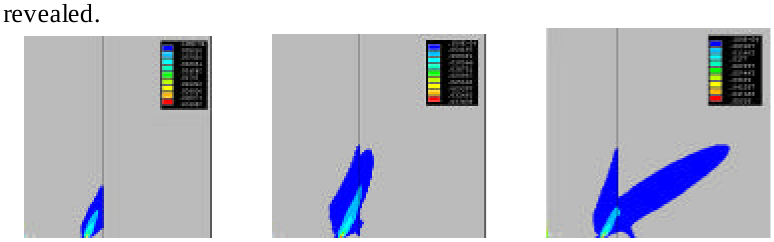
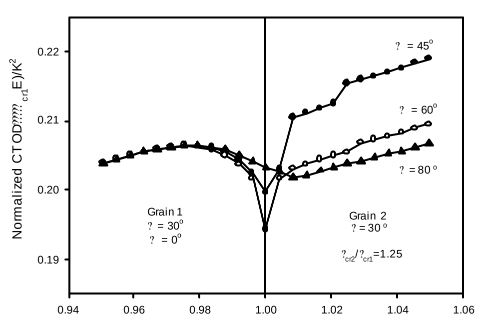
The design of lightweight machine components depends on the ability to correctly assess the total fatigue life of the specific component. In engineering materials, most of the fatigue life is spent in growing a crack from a very small length comparable with the microstructural features up to a length of 1-2 mm. This stage represents a fatigue crack in its microstructurally small stage. During more that two decades, many experiments, starting with that of S. Pearson (1975) in two commercial aluminum alloys, have indicated that the behavior of small cracks is essentially different that that of long cracks. The linear elastic fracture mechanics fails to correctly predict the growth of small cracks due to several factors such as: large scale yielding effects, influences of the microstructure etc. The microstructurally small crack is strongly influenced by numerous microscopical features such as: grain boundaries, inclusion particles, porosity etc. The growth rate of this type of crack in engineering alloys depends on the relative position of the crack tip with respect to these microstructural features. A widely used approach is to consider the inelastic behavior on the material surrounding the crack tip as isotropic. Due to the fact that the microstructurally small crack is of comparable size with the grains, representing regions of uniform crystallinity, the plastic deformation at the crack tip does not occur isotropically. To evaluate the plastic deformation in the near tip region in the small crack regime, the use of single crystal plasticity is proposed. The plastic behavior of the material in this case is described by the double slip model of R. Asaro (1979) that allows for the plastic deformation to occur at the crack tip along two discrete slip systems, primary and conjugate. The double slip model was implemented in the finite element code ANSYS as a user-defined material subroutine. Plastic zones at the crack tip and crack tip opening displacements (CTOD) were analyzed in both cases, when plastic zone was fully encompassed by a single grain and when the crack tip plastic zone extended in two grains. Plastic zone sizes and configurations and CTOD were shown to vary significantly when the crystallographic parameters were varied due to the randomness distribution of these properties in a polycrystalline material. Different regions that sustained single and double slip near the crack tip were noticed. Analytical calculations for plastic zones configurations in the single plasticity case were performed based on the elastic distribution of stresses near the crack tip and good agreement with finite element results were obtained for stresses up to 0.5 of the flow stress. Comparison with the isotropic case based on the von Mises yield criterion with associated flow rule were performed and significant differences were revealed.



Interaction of the plastic zone at the crack tip with the grain boundary and the neighboring grain.



CTOD variation near the grain boundary