DEVELOPING IMAGE BASED CRYSTAL PLASTICITY MODELS FOR DEFORMATION AND FATIGUE ANALYSIS OF POLYCRYSTALLINE METALS

Somnath Ghosh, Yash Bhandari, Michael Groeber, Sivom Manchiraju

Computational Mechanics Research Laboratory,
Department of Mechanical Engineering,
The Ohio State University,
Columbus, Ohio, USA,
e-mail: ghosh.5@osu.edu

The mechanical behavior and fatigue failure response are governed by microstructural features that include morphological and crystallographic characteristics, e.g. crystal orientations and misorientations, grain boundary geometry etc. The recent years have seen a paradigm shift towards the use of detailed micromechanical models to understand damage mechanisms leading to fatigue failure. Crystal plasticity theories with explicit grain structures are effective in predicting localized cyclic plastic strains. In the crystallographic approach, the mechanical response of polycrystalline aggregates are deduced from the behavior of constituent crystal grains with specific assumptions about their interaction. Modeling cyclic deformation using conventional time increments can be an exorbitant task for crystal plasticity computations. In modeling fatigue, it is however desirable to conduct simulations for a significantly high number of cycles to reach local states of damage initiation and growth. Conventional methods of time integration present numerous challenges due to the variation in time scales ranging from the scale of the entire process to the time resolution required by the damage evolution.

This paper will discuss methods of creating microstructural image-based finite element models for simulating the behavior polycrystalline materials subjected to cyclic loading. It will present a methodology for creating a finite element model of the polycrystalline microstructure, accounting for both morphology (e.g. grain size distribution) and crystallographic orientations. The microstructure simulation process involves serial sectioning together with orientation imaging microscopy using a Dual Beam Focused Ion Beam–Scanning Electron Microscope (FIB-SEM) outfitted with an EBSD system. This is followed by an CAD based grain generation process to construct the 3D polycrystalline microstructure. Steps in this construction include: (i) Slice Alignment, Grain Identification, and Cleanup, (ii) Grain surface fitting, (iii) Solid reconstruction of individual grains, (iv) Intersection and gap compatibility, (v) Meshing and statistical characterization.

Subsequently FEM analysis of the polycrystalline microstructure is done for cyclic loading for a large number of cycles. A multi-time scaling formulation involving two different time scales: a long time scale problem for describing the smooth averaged solution (macroscopic problem) and an oscillatory portion (microscopic problem), will be conducted. The accuracy and computational efficiency of the proposed method will be investigated by numerical experiments.

Keywords: Crystal Plasticity, FEM