Understanding the state of polycrystalline structural alloys using high energy synchrotron x-rays

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As the demand for efficient, high-performance machines increases, quantifying the state of materials and understanding their micro-mechanical behavior are ever more important for designing and building these machines. High energy synchrotron radiation is an attractive tool for investigating the state and the micro-mechanical behavior of polycrystalline structural alloys. In this talk, two techniques will be presented.

In the first part of the talk, a method for quantifying the residual stress field in a polycrystalline material is described. An experimental setup that combines monochromatic high energy x-ray diffraction and a set of conical slits is described. The set of conical slits allows the non-destructive measurement of lattice strains for diffraction volumes located inside the material and is used to measure the strain pole figures (SPFs) for material points located inside a polycrystalline component. Full three-dimensional residual stress field is determined by a bi-scale optimization scheme. In this scheme, the residual stress field satisfies the SPF measurements at the crystal length scale. It also satisfies equilibrium and imposed boundary conditions at the macroscopic length scale. To demonstrate the new method, a polycrystalline shrink-fit sample with a three-dimensional stress gradient was manufactured from a low solvus high refractory (LSHR) Ni-based superalloy. The residual stress field determined using the new method compares favorably with an analytic approximation of the stresses within the shrink-fit sample.

In the second part of the talk, a framework for understanding the micromechanical behavior of individual crystals embedded in a polycrystalline aggregate using synchrotron x-rays and polycrystal finite element simulation is described. A method for simulating diffraction spots from individual virtual crystals using the information obtained from a polycrystal finite element simulation is described. To demonstrate the method, a set of high energy diffraction data were collected while applying a uniaxial tension on a high strength copper specimen. The diffraction data were analyzed to determine the orientations and the stresses of the crystals in the diffraction volume. The crystal orientations were used to instantiate a virtual polycrystal and a slip-based polycrystal finite element simulations were performed. Using the information obtained from the finite element simulations, a set of virtual diffraction spots is generated. These virtual diffraction spots are compared to the experimental diffraction spots.