A Grain Subdivision Study on a Cyclic Deformed Nickel-Based Superalloy Using Synchrotron X-Ray Micro-Beam Diffraction

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Statement of Purpose

Nickel–based superalloy is a practical important structural material used as a corrosion resistant component. A major issue for using superalloys, which to manufacture a specific design of pipe-lines or tanks for chemistry, is the understanding of its fatigue life and its associated behavior. The fatigue endurance must ensure that the superalloys serve the duties for their expected life. To address this purpose, the knowledge of the fatigue fracture mechanics has to be developed. The current study focuses on the atomic structures which are responsible for fatigue fracture by using micro-beam technology at the synchrotron X-ray source. The penetration of the high energy X-ray can reach about 50 micrometer. As a result the atomic structures of the cyclic deformed superalloy can be studied as a function of the distance within one grain and from adjacent grains.

Experimental procedure

The testing nickel-based superalloy is HASTELLOY® C-22HS™ alloy (Ni-21Cr-17Mo in the weight percentage). The alloy is designed to be used at corrosive conditions. The alloy is mill annealed at 1,080^{o}C to minimize the formation of precipitates and to achieve

a single-phase, faced-centered cubic (FCC) alloy (*Huang et al.* in press). The subsequent heat treatment, as 705°C/16 hours/furnace cooling (FC) and 605°C/32 hours/ air cooling (AC), produced uniformly distributed precipitates in the FCC matrix as characterized by a transmission-electron-microscopy (TEM) study (Lu *et al*., 2007) and neutron-diffraction (*Huang et al.,* 2007.) The mechanical properties changed after this heat treatment where the yield strength of the specimens increased relative to the annealed condition. The average grain size of this alloy is about 70 μm. The testing specimens are cyclic deformed until failure for synchrotron X-ray measurements. The low-cycle-fatigue experiments were strain-conducted with a minimum strain ($\varepsilon_{min.}$) and maximum strain ($\varepsilon_{max.}$) of 1% and -1%, respectively (R = -1). The frequency of the loading cycle was 0.5 Hz. Synchrotron x-ray diffraction (XRD) experiments were conducted to study the pre-deformed specimen. The high-energy (115 keV) X-ray diffraction experiments were performed at the Advanced Photon Source, Argonne National Laboratory. An undeformed specimen was prepared as a reference. Measured slices were cut from the center of the mechanically-tested specimens after low-cycle-fatigue test. The cut materials were, then, polished to remove the oxides and other additives to eliminate contaminations associated with the sample preparation.

Results

The polychromatic X-ray microbeam provides the local structural information (*Barabash et al.,* 2005) from the Laue pattern which reflects the number of geometrically necessary dislocations (GNDs). Figure 1 shows the Laue patterns obtained from (a) the undeformed and (b) cyclic-failure specimens. The differences of these Laue patterns demonstrate that the plastic deformation results in the formation of the alternating regions with high and low GND densities. The quantitative dislocation density distributions of the undeformed and the cyclic-failure specimens obtained from the microbeam diffraction will be presented in the conference.

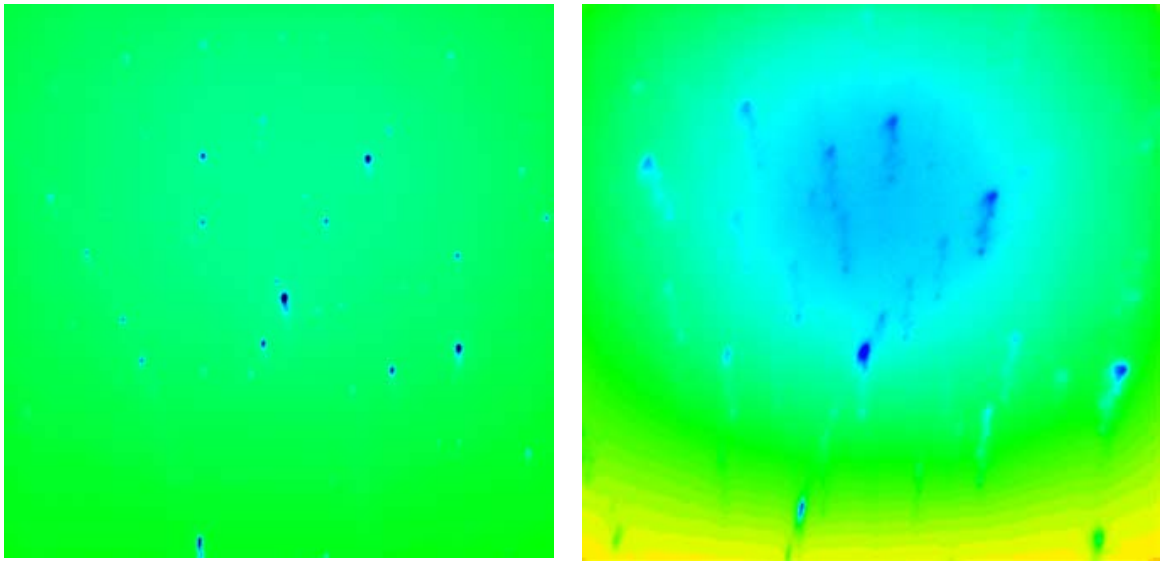

Figure 1. The Laue patterns obtained at (a) undeformed and (b) cyclic-failure of aged specimens.

Relevant conclusions

The inhomogeneous plastic deformations of the cyclic-failure specimen were observed using the synchrotron X-ray. The synchrotron-microbeam characteristics of the cyclic-failure have been presented to describe the atomic structure for understanding the cyclic effect on this nickel-based superalloy. The knowledge of evolutions of dislocations and texture-orientation within one grain and from adjacent grains could discover the fatigue behavior, and, hence help the industry to design the alloys.

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