Lattice Plane Response during Tensile Loading of an Aluminum 2 Percent Magnesium Alloy

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In-situ neutron diffraction measurements of plane specific elastic lattice strains were made during a tensile test of an aluminum 2 pct magnesium alloy. The macroscopic response exhibited a serrated flow curve, evidence of dynamic strain aging. The neutron results are compared to calculations using a self-consistent polycrystal deformation model. The relatively poor agreement with the measured data may suggest that the model has limitations with respect to face-centered cubic (fcc) alloys with low elastic anisotropy.

I. INTRODUCTION

THE residual strain state in aluminum and aluminum alloys has previously been studied using neutron diffraction measurements[1,2,3] and also during loading.[4,5,6] In the present work, the development of lattice strains for eight reflections, both parallel and perpendicular to the tensile axis, are reported for tensile testing of an aluminum 2 pct magnesium alloy. The chemical composition of the material is given in Table I.

The data were obtained using pulsed neutrons and the time-of-flight technique, thus lattice spacings for multiple reflections were readily available. Results are reported for the unique (i.e. excluding second order, unresolved and overlapping reflections) reflections up to the 531 reflection, which is the first reflection with lowest possible symmetry in the face-centered cubic (fcc) lattice. The procedure is described in more detail in Reference 7 for an investigation of lattice strain development in an austenitic stainless steel.

In contrast to stainless steel, aluminum is highly isotropic in its elastic response ($2C_{44}/(C_{11} - C_{12}) = 1.22$ for aluminum compared to 3.21 for stainless steel), thus the spread between reflections is expected to be much smaller than in stainless steel, at least in the elastic region. The accuracy of a neutron diffraction strain measurement is generally about $\pm$ 50 $\mu\varepsilon$ (microstrain or 10^{-6} strain) and the elastic strain at yield in our earlier work on commercially pure aluminum[4] was about 250 $\mu\varepsilon$ yielding an accuracy of about $\pm$ 20 pct of the elastic strain at yield. In an attempt to improve our strain resolution with regard to the yield strain, we opted to use an aluminum alloy (2 pct Mg) that exhibits an elastic strain before yield of about 500 $\mu\varepsilon$. However, as described in Section II, the introduction of magnesium in the aluminum lattice resulted in dynamic strain aging (DSA).

II. EXPERIMENTAL PROCEDURE

The neutron diffraction measurements were made at the Manuel Lujan Jr. Neutron Scattering Center, Los Alamos National Laboratory, using the neutron powder diffraction instrument. The procedure for *in-situ* loading experiments is outlined elsewhere.[8]

The material under study was a cast aluminum 2 pct magnesium alloy that was annealed at 400 °C for 15 minutes prior to the *in-situ* neutron diffraction measurements. The average grain size was 112 μm and the grains were fairly equiaxed, as seen in the optical micrograph in Figure 1. During the neutron diffraction measurements, lattice plane spacings were measured parallel and perpendicular to the tensile axis using detector banks at $\pm$ 90 deg to the incident beam. Each detector subtends 11 deg 2θ over which the diffracted data are integrated, corresponding to an "average" in the strain direction of $\pm$ 5.5 deg.

The sample, a threaded end ASTM standard specimen,[9] was held at constant stress for up to 3 hours at a series of static tensile loads, while neutron measurements were made. The macroscopic response is shown in Figure 2. The vertical steps in the measured stress-strain curve are elastic loading followed by increments of plastic deformation (horizontal steps). This behavior is indicative of DSA. During the elastic loading, dislocations are arrested by the magnesium atoms in the aluminum lattice. The plastic relaxation occurs when the driving force for the dislocations becomes larger than a given threshold and the dislocations can move past the magnesium atoms.[10] No DSA was observed during the holds while the diffraction data were collected. The measurements were performed under load control. Even at room temperature, some relaxation was observed during the neutron measurements, but by using a constant stress (load) on the sample, the lattice spacing should remain constant during the measurement.

Lattice strains as a function of applied load are reported for directions parallel and perpendicular to the tensile axis from the measurements (Figure 3) and from the self-consistent model calculations (Figure 4). The quoted stresses and strains are relative to a nominal load of 5 MPa (used to hold the sample in position). Starting from a nominal tensile stress is preferable since it precludes any small backlash on uptake of the stress that might result in small realignment of the sample. If the sample moves during a measurement, systematic effects associated with the change in scattering geometry can introduce significant apparent strains. The load levels for the neutron measurements are indicated by the symbols in Figure 1 and for the 420 reflection in Figure 3. Error bars

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