IN-SITU NEUTRON DIFFRACTION STUDY OF BIAXIAL DEFORMATION BEHAVIOUR OF HEXAGONAL ZIRCALOY-4

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Zircaloy-4 cladding commonly undergoes complex biaxial deformation resulting from the internal pressure of the fission gases and the pellet-cladding mechanical interaction due to fuel thermal expansion during power transients; consequently, stress corrosion cracking (SCC) often takes place. Understanding SCC is fundamental for the design of new nuclear fuel cycles and for increasing fuel burnup. In-situ neutron diffraction has been used to characterize the development of microstrains and to determine the activity and their critical resolved shear stresses (CRSS) of the various slip and twinning modes in the polycrystalline Zircaloy-4 alloy tube during biaxial tensile and interior pressure deformation.

Figure 1(a) and (b) shows the lattice microstrains for the axial components as a function of the axial applied stress at stress ratio of R=0.5. The loading portion is illustrated with solid points and solid lines, and the unloading portion is described with empty points and dash lines. The results show that the response of each lattice microstrain with the applied stress is approximately linear in the initial macroscopically elastic regime. The onset of plastic deformation is marked by the deviation from the initial linear response in the $(10\bar{1}0)$ and $(10\bar{1}1)$ grains in the axial stress vs. axial microstrain curves. Deviations from linearity in the lattice strain vs. applied load curves are thus related to the activation of plastic deformation modes such as slip and twinning. It is observed that an increased slop relative to the initial response represents plastic yielding of $(10\bar{1}1)$ -oriented grains at the stress of 350MPa, indicative of early $(10\bar{1}1)$ pyramidal slip (Figure 1(a)); while, a decreased slop almost simultaneously occurs on the $(10\bar{1}0)$ prism plane at around the stress of 350 MPa in Figure 1(b), indicating an intergranular load transfer from the neighboring yielding grains to the measured grains, which are still in the elastic regime. Under a higher stress of 380 MPa, $(10\bar{1}0)$-oriented grains grains start yielding. This kind of deformation behaviour is further demonstrated by the sign of the residual intergranular strain after the specimen was unloaded to zero stress. That is, the plastically deformed grains will experience a compressive stress after unloading. On unloading to 0, the large residual compressive stress (-10^{-3}) is observed in $(10\bar{1}1)$ grains. In comparison, the less residual compressive stress ($\sim$$-5\times10^{-4}$) is observed in $(10\bar{1}0)$ grains.

The $\{10\bar{1}2\}$ twinning manifests as the sharply variety of the (0002) basal and the $(10\bar{1}0)$ prismatic diffraction intensities in the opposite tendency along the hoop direction during deformation, as shown in Figure 2. The $(10\bar{1}0)$, $(10\bar{1}1)$, and $(2\bar{1}\bar{1}0)$ peaks exhibit a marked increase in intensity between 430 and 572 MPa. It provides the clear information pertaining to the development of $(10\bar{1}2)$ twinning rather than $(10\bar{1}2)$ pyramidal slip during biaxial loading at the equivalent applied stress of 463 MPa.

The CRSS for basal slip, prismatic slip, <**c**+**a**> pyramidal slip, and $\{10\bar{1}2\}$ twinning were determined according to the applied stress vs. microstrain curves. Well before macroscopic yielding, the $(10\bar{1}0)$ prismatic slip and $(10\bar{1}1)$ pyramidal slip are activated at the equivalent stress of about 500 MPa at the stress ratio of 0.5. As the stress ratio increases to 1.0, the $(10\bar{1}2)$ twinning is firstly activated at an approximate stress of 463 MPa. In comparison, $(10\bar{1}0)$ prismatic and $(10\bar{1}1)$ pyramidal planes slips occur at approximate 700MPa, which is much higher than those at R=0.5. The active deformation is the $(10\bar{1}2)$ pyramidal plane, and (0002) basal slip along hoop direction at the stress ratio of 2.12. The observed lattice microstrain evolution during in situ biaxial loading is considered as the fingerprints for the different deformation mechanisms in Zircaloy-4 at different stress ratios.

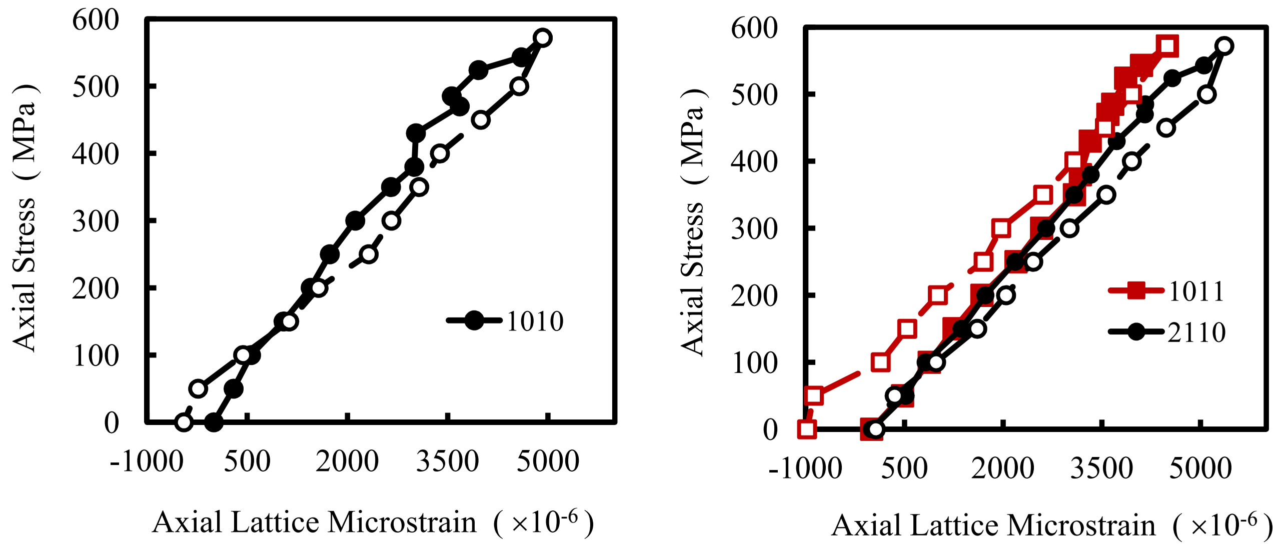

Figure 1 The response of (*hkil*) crystallographic plane-specific axial lattice strains as a function of axial applied stress at the stress ratio of 0.5, (a) (10$\bar{1}$1) and (2$\bar{1}\bar{1}$0) planes, (b) (10$\bar{1}$0) plane.

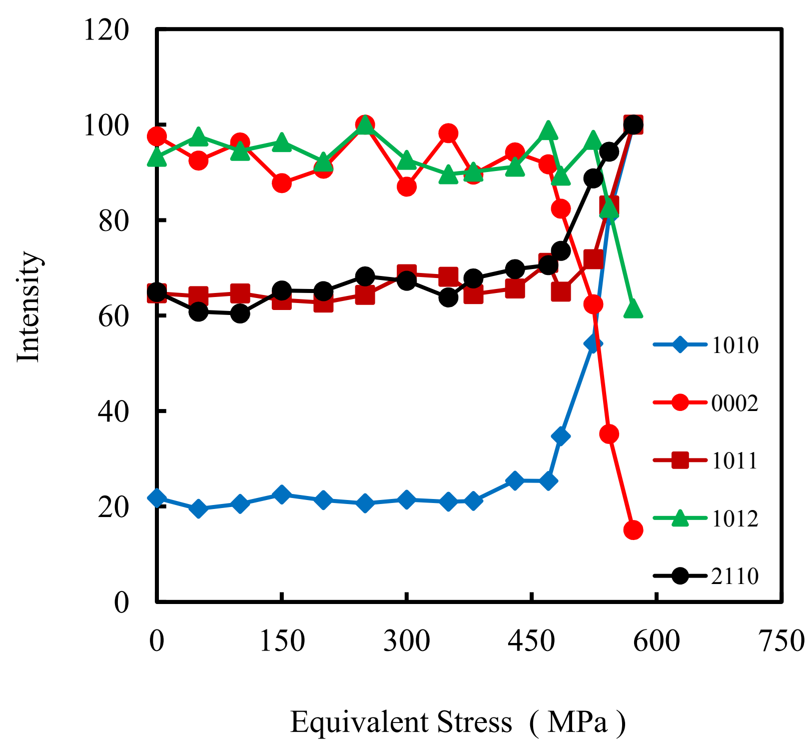

Figure 2 Normalized intensities of diffraction peaks on (hkil) planes as functions of the applied equivalent stress along hoop direction at the stress ratio of 1.0.