In-situ observation of dynamic recrystallization and related phenomena in the bulk of zirconium alloy

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The nuclear reactor structural material Zircaloy-4 grade R60804 of nominal composition Zr 1.5%Sn 0.2%Fe 0.1%Cr 0.1%O (in weight %) has been tested under thermo-mechanical load on the high energy X-ray beamline 1-ID at the Advanced Photon Source while diffraction patterns were recorded in-situ and continuously on a sub-second time scale. Multiple heating-cooling cycles were run between 690 K and 1280 K under mechanical load increasing stepwise from 0 N to 225 N. The temperature cycles transform the metal from its low temperature α phase below 1083 K through an α+β phase field into its single β-phase of bcc structure stable above 1253 K and back. Initially, the β-phase precipitates in a fine grain breaking also the coexistent α-grains. After α disappears, grain growth is rapid resulting in only a very few sharp spots on the diffraction rings. Upon cooling, the α-phase reappears and grows into the β-grains and the well known Burgers orientation relationship is observed, i.e. the α-{002} orientation aligns with the β-{110} plane orientation, which can be reversed upon subsequent heating. The β-phase being very ductile and soft shows plastic deformation, which escalates at 225 N and a cross section of 30 mm^2. While temperature is increased, first we observe grain breakage into sub-grains due to the deformation process, which recovers dynamically. Plastic deformation is faster at higher temperature when new grain orientations pop up and disappear continuously and the system recrystallizes dynamically. The details and fingerprints for the different stages during an in-situ observation from the bulk of a metallic material measured for the first time.

Keywords: plastic deformation; phase transformation; orientation relationship;