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Temperature-dependent plastic behaviour of pure Ti and Co: in situ thermo-mechanical tests under electron back-scattered diffraction and X-ray diffraction coupled with scale transition modelling

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Abstract

Metallics materials with a hexagonal close packed (HCP) structure exhibit pronounced plastic anisotropy which leads to various deformation mechanisms, including crystallographic slip and mechanical twinning. The activation of these modes depends on several factors such as the c/a ratio, microstructure features (texture, grain size/ morphology, phases), and most importantly, temperature. Despite its central role in governing the competition between deformation modes, temperature-dependent information remains limited in the literature. The present study aims to investigate the temperature-dependent plastic behaviour of two hexagonal metals: pure Titanium (Ti), a single-phase HCP material, and pure Cobalt (Co), which combines HCP and face-centred cubic (FCC) phases. To this end, both materials are subjected to in situ thermo-mechanical loading under X-ray diffraction (XRD) and electron back-scattered diffraction (EBSD). The objective is to gain deeper insight into their thermal, elastic and plastic anisotropies and to analyse how deformation mechanisms evolve in plasticity with temperature. EBSD provides microstructural information such as grain size, misorientations, texture and phase ratio, offering valuable insight into the deformation mechanisms activated during thermo-mechanical loading through the associated microstructure changes. XRD gives access to the elastic strain fields of different grain groups, thereby revealing the development of intergranular deformation. These experimental data are then compared with predictions from a scale transition model based on a self-consistent approach, enabling identification of the deformation mechanisms/systems activated at each temperature. In situ tests are performed using a temperature-controlled tensile device allowing simultaneous heating and mechanical loading, operated either inside the SEM or on the XRD goniometer. In situ tensile tests at room temperature on Co show a linear decrease in FCC phase fraction with increasing logarithmic strain. Analysis of intergranular boundaries misorientations suggests that the strain-induced transformation, from the retained FCC phase to HCP phase, is initially driven by basal slip during the first work-hardening stage, and later by twinning in the second stage. In contrast, room-temperature plastic deformation in Ti is accommodated exclusively by slip, with negligible twinning activity. In situ thermo-mechanical tests under EBSD have also been performed on Co up to 500 °C (beyond the HCP→FCC austenitic transformation) and on Ti up to 300 °C to characterize the evolution of active deformation mechanisms at higher temperatures, and have been complemented with in situ XRD experiments to determine strain pole figures. These experimental data were used to challenge and refine an elasto-plastic self-consistent model. Particular attention has been devoted to the relationship between internal strain evolution, EBSD results and the activity of the competing deformation systems.

Keywords:

Hexagonal materials In situ analysis Thermo-mechanical loading EBSD XRD Scale transition modelling