The first rows of blades in jet engine gas turbines have to withstand harsh thermomechanical conditions. Creep above 1000°C limits the service life of these critical components. Monocrystalline Ni-base superalloys are the material of choice for first row turbine blades. Their microstructure consists of a high volume fraction (~70%) of cuboidal Ni₃Al-based precipitates (γ’ phase: ~0.5 µm edge length, L1₂ ordered structure) which are coherently embedded into an fcc Ni solid solution (γ phase: ~0.02 µm in thickness), which forms a thin channel network in between the γ’ cubes.

While deformation takes place by dislocation plasticity in the softer matrix channels in the early stages creep, differences in the chemical potential between different γ’/γ interfaces can lead to rafting. This process closes families of parallel γ channels. Creep deformation continues via shearing of the γ’ phase by superdislocations. It has been found that γ’ phase cutting can occur by pairs of dislocations of equal Burgers vector \( \mathbf{b} \) [e.g., 1]. Alternatively one can observe superpartials with different \( \mathbf{b} \) [2], depending on both macroscopic (e.g., loading direction) [1], as well as microscopic parameters (e.g. raft direction) [3]. There has been little experimental evidence on the type of substructures that can form when different superdislocations react within a γ’ raft. In the present contribution, different such reactions are studied using a novel three-dimensional (3D) TEM characterization method.

The superdislocation configurations were investigated in the Ni-base superalloy LEK 94, tested at 1000°C under directly applied shear stresses between 100 and 200 MPa. Electron-transparent foils were extracted from the gage sections of tensile and shear samples loaded to plastic strains between 2 and 26%. Superdislocation substructures were analyzed in thicker areas of the TEM foils (>250 nm) in order to include larger interaction zones and reduce stress relaxation effects at the foil surfaces. Burgers vector \( \mathbf{b} \) as well as line vector \( \mathbf{u} \) of the superpartials were determined by implementing the effective invisibility criterion, using conventional (C)TEM as well as scanning (S)TEM. The STEM mode is especially suited for 3D stereo observations of the complicated substructures in thicker regions of the foil [4]. Stereological measurements were carried out with a novel visualization tool developed for the software platform ZIBAmira to reconstruct and visualize the dislocation line segments from stereo-pairs. Figure 1 shows a screenshot of one such reconstruction made from a set of superdislocation reactions found in a sample under tensile loading along the [001] direction at 1020 °C and 160 MPa (at \( \varepsilon = 26\% \)).
upper right of Figure 1 we show the crystal orientations and we use colour coding as indicated in the lower right of Figure 1 to identify their $b$ vectors, as determined by a series of micrograph taken for 9 tilt positions. As a result of the reconstruction, the foil thickness is measured as 286 nm, the total superpartial line length in the marked volume is 7646 nm, of which 2708 nm correspond to superpartials with $b = \pm a/2[101]$ and 3671 to superpartials with $b = \pm a/2[10\ -1]$. Within the substructure, there are 5 superdislocation segments with $b = a[10\ -1]$, one segment with $b = \pm a[101]$ and 7 segments with $b = \pm a<100>$. Probable scenarios of how this and other dislocation substructures form will be discussed in the light of previous results reported in the literature.

Figures 1: 3D Stereo-pair reconstruction of superdislocation substructure in LEK 94 crept to $\varepsilon = 26\%$ ([001] tensile loading 1020 °C and 160 MPa; size of limiting box: 381 x 676 x 1156 nm).

References


