Influence of local chemistry in the elementary mechanisms of deformation

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In multi-constituents metallic alloys, the influence of the local stoichiometry on the mechanical properties is crucial and the subject would benefit from a study combining TEM spectroscopy and imaging techniques.

For example, the addition of few percent of Cu, Mg, Si or Li has been used for a long time in aluminum alloys to improve the mechanical properties. Nickel and titanium alloys also benefit from the incorporation of different atoms. The effects of solutes are various, the most direct effect being the hardening by solid solution or by nano-precipitates formation. The effect can also be indirect through stacking fault energies variations in polycrystalline superalloys for example. Influence on mechanical properties of precipitates, grain boundaries and other defects require the knowledge of local chemical composition in these alloys. Quantifying the local chemistry in metallic alloys requires the use of spatially resolved method, such as atom probe tomography or transmission electron microscopy, and the use of STEM-EDS, STEM-EELS and STEM-HAADF techniques in order to identify and quantify the interaction between the local chemistry and the elementary mechanisms of deformation can be of great help.

We first performed experiments on a nickel-based polycrystalline superalloy with two ageing conditions dedicated to aircraft high pressure turbine disks with very different creep resistances. These alloys consist of a nickel-rich gamma matrix and gamma prime precipitates with various elements (Cr, Co, Fe, Al, Mn) present both in the matrix and the precipitates. There is no significant difference in the nickel-based superalloy microstructure between the two ageing conditions that could explain the difference in creep velocity. Thus, STEM-EDS and STEM-EELS were performed to get a local chemical analysis of the precipitates and the matrix. We were able to show that the sample with the highest creep velocity had a higher concentration of Cr in the matrix. This result was corroborated by a TEM in situ straining experiment showing in the same sample a greater number of partial dislocations. Indeed, Cr promotes the formation of partial dislocations by reducing the stacking fault energy.

In the case of aluminum alloys, the structural hardening due to the nano-precipitation and its evolution during natural or artificial aging is complex. Among other metallic elements included in these alloys, copper may have an influence on the creep characteristics. The study of various alloys after different aging conditions has been conducted. Two kinds of aluminium alloys were studied: recent 2xxx series currently used in aeronautics and old alloys (Duralumin family) from a Breguet 765 Sahara airplane from 1958. The correlation between copper content in the aluminum matrix, precipitates and mechanical behaviours could be established thanks to high resolution microscopy associated with spectroscopies (STEM-EDS and STEM-EELS).