Atom probe characterization of strengthening effects in the Ni-based superalloy Inconel 718

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Nickel-based superalloys are regarded as one of the most complex of all materials developed by engineers [1]. The outstanding high-temperature strength of these alloys is the prerequisite for the mechanical design of aircraft engines or gas turbines. Their resistance to mechanical loads up to 1,000 MPa at temperatures exceeding 80 % of the homologous melting point is achieved by the precipitation of nano-scaled secondary phase particles. This study focusses on the superalloy Inconel 718, which is strengthened by ordered γ'- (Ni_3(Al,Ti)) and γ''- (Ni_3(Nb)) precipitates. However, the characterization of the detailed precipitate morphology including volume fraction, size and composition at the nanoscale remains challenging and requires advanced microscopy.

We present a comprehensive, multi-scale approach to reveal the processing-structure-property relationship of Inconel 718 including light optical and scanning electron microscopy, backscatter electron diffraction, transmission electron microscopy, and atom probe microscopy [2]. The latter has been proven to be a more powerful tool than high-resolution transmission electron microscopy to study precipitates at the nanoscale. In voltage-mode atom probe microscopy, the retained crystallographic information allows accurate and reproducible data reconstruction for limited volumes of Ni-based alloys. Larger, and therefore statistically more significant volumes are obtained with laser-assisted atom probe although a precise reconstruction is challenging due to the loss of crystallographic information. Our combined approach of both modes applied on the very same specimen promises accurate data reconstruction of representatively large volumes.

To characterize the detailed precipitate morphology, an advanced iso-surface method is introduced where the concentration threshold of Al + Ti, and Nb is refined through the local concentration gradients. These findings are compared to the more commonly used proximity histogram method. One of our key findings is that γ'- and γ''-precipitates may form duplets and triplets, with stacking sequences depending on the explicit thermo-mechanical history, achieving yield strength increments up to 10 % [3]. Thus, numerous new interfaces between precipitates and surrounding matrix are created. We devised an approach to determine the interfacial areas of γ'-matrix, γ''-matrix and γ'-γ'' from cross-sections, which are required for modelling the strength as a function of the thermo-mechanical processing.

Our approaches to atom probe microscopy may be applicable to advanced characterization of other precipitation hardened structural materials such as Mg-, Al- or Fe-based alloys.

References:

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