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Chemical element mapping and metrology of γ' and γ'' nanoparticles in Inconel 718 superalloy for aeronautics and power generation.

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Inconel 718 (IN718) is a high strength, corrosion resistant nickel-iron based superalloy used for applications in the temperature range from -250 to 700 °C. Thanks to these properties, IN718 has wide application in power generation, aeronautics and aerospace. Its typical chemical composition of IN718 is: Ni-19Fe-18Cr-5Nb-3Mo-1Ti-0.5Al-0.04C (wt%). The IN718 microstructure consists of a γ matrix (Ni-based solid solution) strengthened by ordered face centred cubic γ' $Ni_3(Al,Ti)$-type and ordered body centred tetragonal γ'' Ni_3Nb-type nanoparticles (Figure 1). The primary strengthening mechanism for this alloy is a precipitation hardening by the γ' and γ'' particles and therefore properly sized and distributed precipitates are critical for good alloy performance. The aim of this study was to describe quantitatively IN718 microstructure, identify γ' and γ'' precipitates and examine their 3D shape and special distribution.

Microstructural investigation of Inconel 718 superalloy after various heat treatment was performed by electron microscopy (SEM, TEM, STEM-HAADF-EDX) and electron tomography techniques (FIB-SEM) taking advantage of recent developments in quantitative electron microscopy. Electron microscopy analyses were performed using a Merlin Gemini II of Zeiss, Tecnai G2 Twin and a probe Cs-corrected Titan G2 60-300 with EDX ChemiSTEM technology, both of FEI. The FIB-SEM tomography investigation was conducted by NEON CrossBeam 40EsB of Zeiss.

The distribution maps of the chemical elements collected by ChemiSTEM show that the γ'' phase contains Ni, Nb, Ti, whereas the γ' phase contains mainly Ni, Al and Ti. Comparing Al and Nb maps brings a clear contrast between the γ' and γ'' precipitates as well as the matrix (Figures 2, 3). This allows to precisely measuring their size and spatial distribution. Moreover, the high map signal/noise ratio brought by the ChemiSTEM optimization makes possible to extract the actual composition of the γ' and γ'' nanoparticles though they are buried in the matrix.

Electron microscopy and FIB-SEM tomography images revealed the 3D morphology of γ' and γ'' precipitates; the γ'' precipitates are nearly disc-shaped, while γ' particles are almost spherical. Tomographic images were used also for estimation of the volume fraction of both phases strengthening the superalloy. It appears that the main difference in the microstructure of the specimens subjected to different heat treatment variants is the presence of γ' + γ'' co-precipitates, what favourably contributes to better mechanical properties of the IN718 superalloy.

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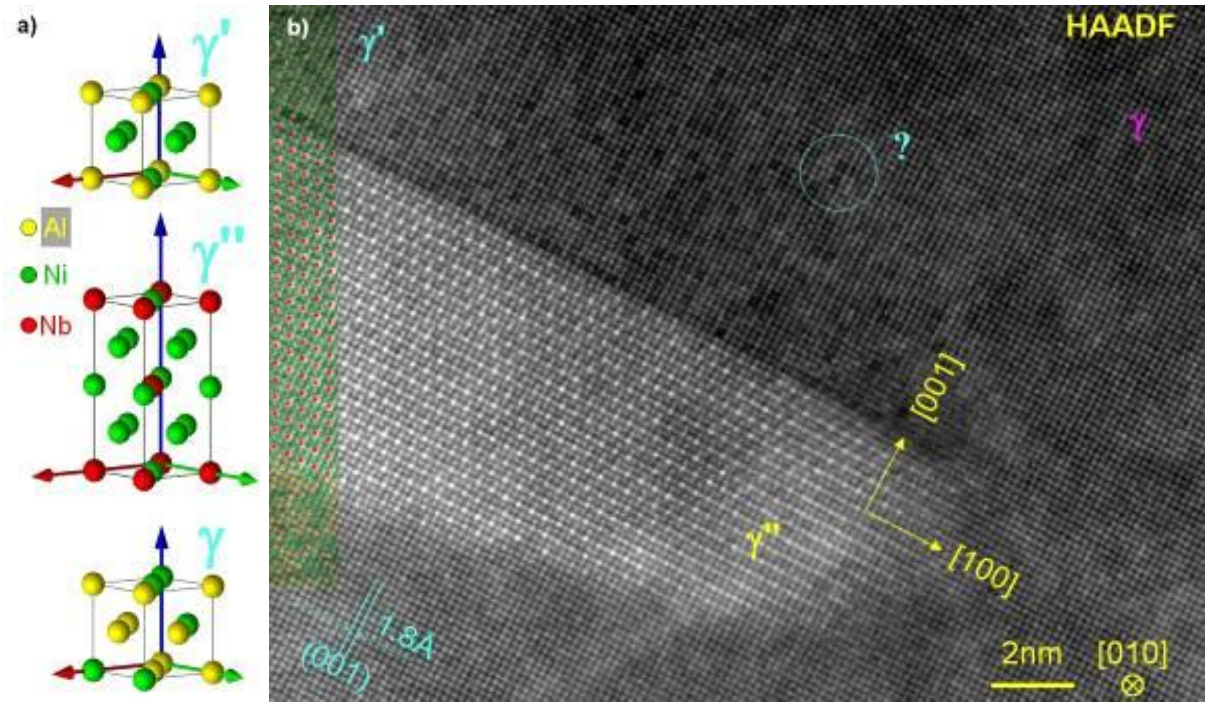

Figure 1. a) ball model of the □ matrix and the □' and □" phases; b) HAADF high-resolution STEM image of □' and □" precipitates in the □ matrix. All interfaces are coherent, but the □'/□" one as well as the □' precipitate contain defects at the atom column scale.

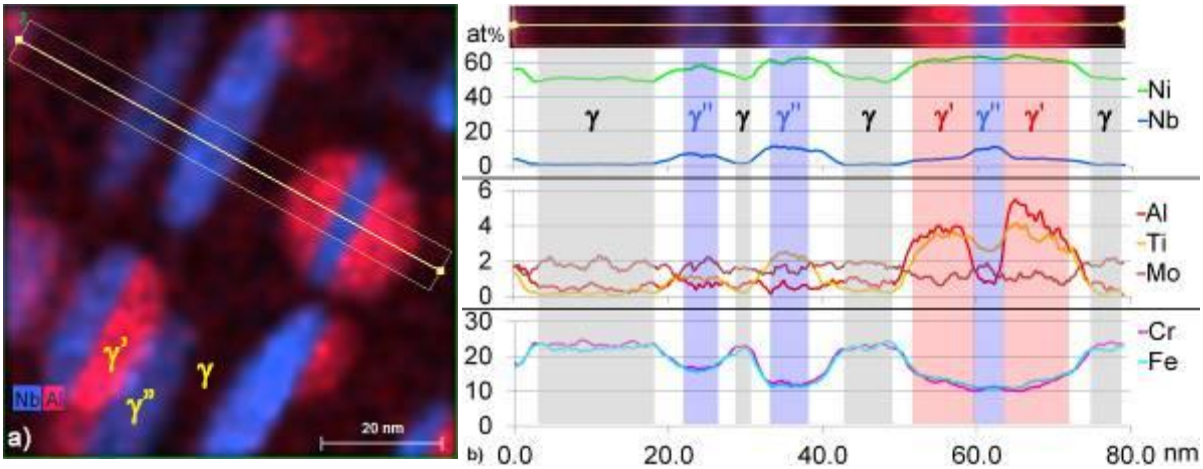

Figure 2. a) EDX ChemiSTEM map of Al (red) and Nb (blue) that distinguishes the □' and □" precipitates; b) Composition changes along a line scan across the three phases. Notice the unexpected presence of Nb in the □' phase.

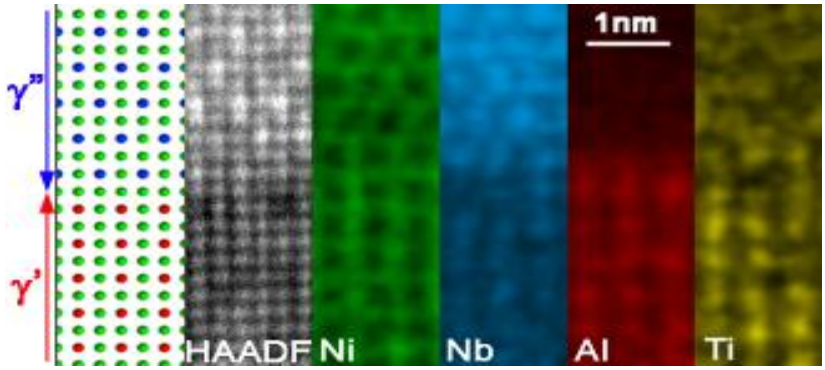

Figure 3. EDX ChemiSTEM maps of a □'/□" interface. The Nb substitute to Al in the □' phase