Multi-Dimensional Characterization of Nanostructures in Titanium Alloys using 2D Aberration-Corrected STEM and 3D Atom Probe Tomography

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Microscopy and Microanalysis, **30** (Suppl 1), 2024, 245–246
https://doi.org/10.1093/mam/ozae044.110

Microscopy AND Microanalysis

Meeting-report

Multi-Dimensional Characterization of Nanostructures in Titanium Alloys using 2D Aberration-Corrected STEM and 3D Atom Probe Tomography

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Titanium (Ti) alloys are critical structural materials in the aerospace field to design lightweight aircraft for better fuel efficiency and reduced CO_2 emissions. These alloys are essential due to their extraordinary combination of great mechanical and physical properties, especially their high specific strength (strength-to-weight ratio). The strength of titanium alloys is mainly determined by the precipitation strengthening, the precipitation of hexagonal closed packed (hcp) structure α precipitates in the body centered cubic structured β matrix. The size, morphology, and distribution of hcp α precipitates can influence the strength of titanium alloy significantly, due to their influence on the motion of dislocations. Our recent studies have shown that the preformed nanostructures, including hexagonal structured ω phase, orthorhombic structured O' phase, and ordered orthorhombic structured O" phase, can significantly influence the subsequent α precipitation [1-3]. It has been revealed that the preformed metastable nanostructures can alter the local structure and composition in the nanoscale region near these nanostructures and thus provide extra driving force by modifying the stress field and composition field for α precipitation in titanium alloys [4]. However, there still exits controversy regarding the detailed mechanisms regarding how these nanoscales transform to α precipitates. Thus, there is a critical need to investigate the nanostructures in titanium alloys. In this presentation, we will introduce our latest study of nanoscale ω phase particles in a modeled binary Ti-Fe compositionally gradient sample using multi-dimensional imaging techniques including 2D aberration-corrected scanning transmission electron microscopy (STEM) and 3D atom probe tomography (APT).

In the first part of this work, the 2D morphology and crystal structure of the nanoscale ω phase particles in Ti-Fe compositionally gradient sample was studied by conventional diffraction contrast transmission electron microscopy (TEM) and aberration-corrected Z-contract STEM, using the FEI Talos F200s scanning transmission electron microscope (S/TEM) and Thermo Fisher Scientific (TFS) Themis Z G3 aberration-corrected S/TEM. In Fig. 1(a), clear ω phase reflections can be observed at 1/3 and 2/3 $\{112\}_\beta$ in the <110> $_\beta$ zone axis diffraction pattern, revealing the hexagonal structure of nanoscale ω phase. The cuboidal morphology of ω phase particles of varying diameters can be observed in the corresponding dark field image, in Fig. 1(b). The atomic-resolution high angle annular dark field (HAADF)-STEM image in Fig. 1(b) reveals that the hexagonal structure of nanoscale ω phase particles could be formed by the complete collapse of two of every three $\{111\}_\beta$ planes with the third $\{111\}_\beta$ plane unaltered.

The second part of the present work focused on studying the composition in and near nanoscale ω phase particles in Ti-Fe compositionally gradient sample by 3D APT using CAMECA LEAP 5000XS HR APT. The 8.5 wt.%Fe iso-concentration surface in Fig. 2(a) shows the 3D cuboidal morphology ω phase particles. The proxigram across the ω/β interface reveals that the Fe content decreases to 3wt.% (2.5at.%) in ω from 18wt.%(16at.%) in the β phase region, revealing the solute diffusion between the β phase matrix and ω phase particles [5].

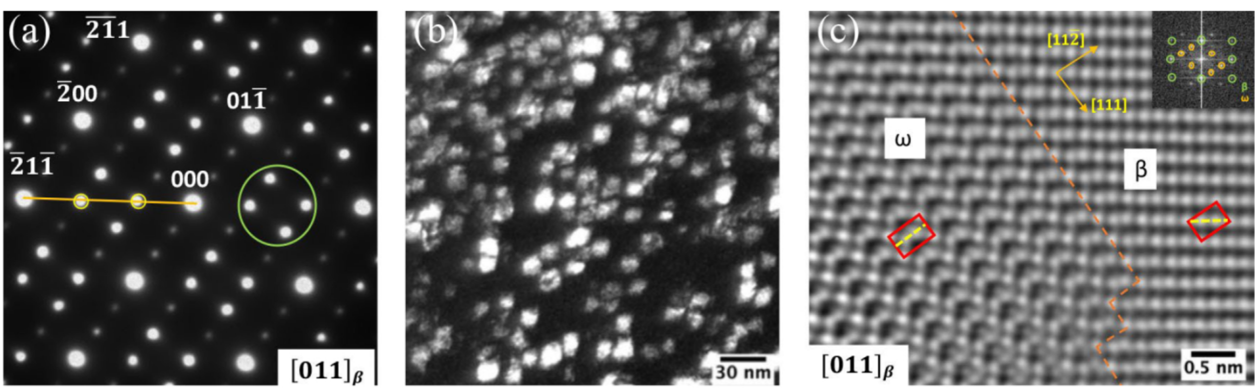

Fig. 1. 2D imaging of nanoscale ω phase particles in Ti-Fe compositionally gradient sample: (a) selected area diffraction pattern showing presence of hexagonal ω phase; (b) dark field image showing cuboidal morphology of nanoscale ω phase particles; (c) atomic resolution HAADF – STEM image showing the full collapse of $\{111\}_\beta$ planes forming ω phase.

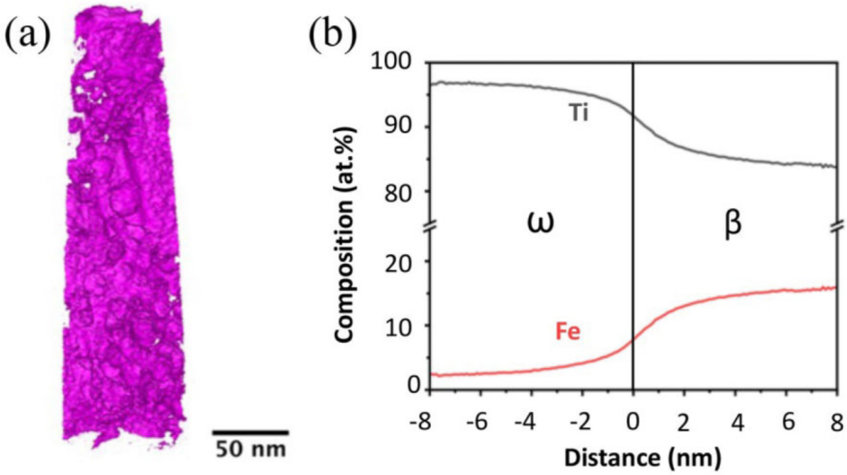

Fig. 2. 3D imaging of nanoscale ω phase particles in Ti-Fe compositionally gradient sample: (a) 8.5 wt.%Fe iso-concentration surface showing the 3D cuboidal morphology of ω phase particles; (b) proxigram plotted across ω/β interface showing the diffusion of Ti and Fe between ω phase and β phase matrix.

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5. The authors acknowledge funding from National Science Foundation, grant #2229724 and #2346524.