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Investigation of Nanoscale Shuffle Transformation in Titanium Alloys Using Aberration-Corrected Scanning Transmission Electron Microscopy

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The shuffle transformation is a distinctive type of solid-solid state phase transformation. In the shuffle transformation, the atom positions are rearranged within the unit cell, creating little or no lattice strain. With the development of advanced characterization techniques, e.g. aberration-corrected scanning transmission electron microscopy (STEM), the nanoscale movement of the atoms involved in the shuffle transformation can be investigated in detail to explore the mechanism of the shuffle transformation. For example, in the last two decades, much research effort has been focusing on studying the nanoscale athermal omega phase formed by the shuffle transformation in titanium alloys [1-2]. The atom configuration in nanoscale athermal omega phase has been investigated using the aberration-corrected STEM in the Ti-12Mo, Ti-20V and Ti-5Al-5Mo-5V-3Cr (all in wt.%) [3-5]. The atomic resolution high angle annular dark field – scanning transmission electron microscopy (HAADF-STEM) imaging has shown the hexagonal structure of the nanoscale athermal omega phase is formed by the shuffle of every two of three adjacent {111} atom planes towards each other leaving the third {111} atom plane unaltered [3-5]. Our recent study of nanostructures in titanium alloys has revealed a novel nanoscale shuffle transformation. In this presentation, the latest investigation of a nanoscale orthorhombic structure phase in titanium alloy, named as O′ phase, studied using the aberration-corrected STEM will be introduced.

In the first part of this work, the crystal structure of nanoscale O′ phase particles was investigated in the cold-rolled Ti-5Al-5Mo-5V-3Cr alloy using the conventional TEM (FEI Talos F200s Scanning Transmission Electron Microscope) and the aberration-corrected STEM (probe-corrected Thermo Scientific Themis Z Scanning Transmission Electron Microscope). The orthorhombic structured O′ phase particles with ellipsoidal morphology were observed in this alloy, shown in Fig. 1(a). The structure of the O′ phase was characterized using Z-contrast HAADF-STEM imaging, revealing the periodic atoms rearrangement along the <011> direction, that atoms on every other {011} planes shuffle along the <01-1> direction to transform the parent body centered cubic structure to the orthorhombic structure, shown in the Fig. 1(b).

The second part of the work to be presented focuses on identifying the difference in the crystal structure between the nanoscale orthorhombic O′ phase and the nanoscale orthorhombic α″ phase in the cold-rolled Ti-5Al-5Mo-5V-3Cr alloy using the aberration-corrected STEM (probe-corrected Thermo Scientific Themis Z Scanning Transmission Electron Microscope). For the first time, conclusive experimental results showing the average percentage of the atom shuffle involved in the nanoscale O′ phase are measured from HAADF-STEM imaging revealing almost no shear. On the contrary, in the nanoscale α″ phase regions, while the atom shuffle involved does not change but the degree of shear involved increases significantly. Thus, the structural difference between the nanoscale shuffle transformation (O′ phase) and nanoscale martensitic transformation (α″ phase) is revealed by the aberration-corrected STEM will be discussed [6].

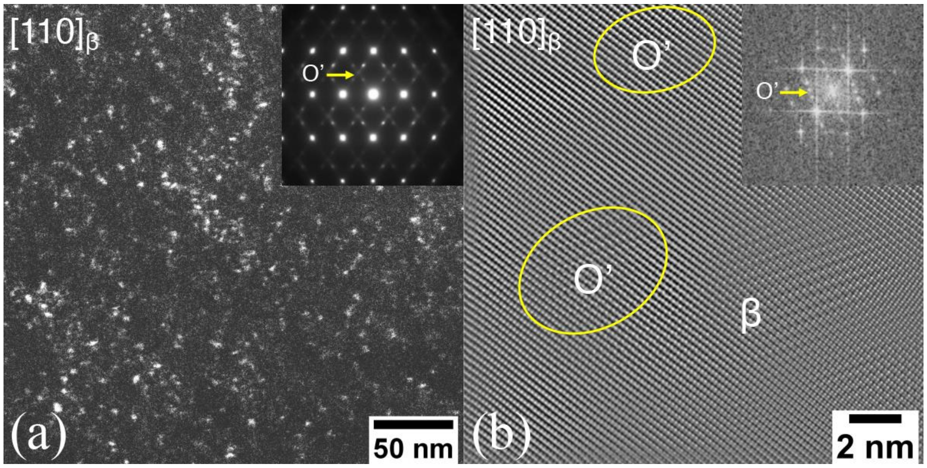

Figure 1. TEM and aberration-corrected STEM results showing the nano-scaled O′ phase particles in the cold-rolled Ti-5Al-5Mo-5V-3Cr alloy: (a) inset selected area diffraction pattern and corresponding dark field image showing the morphology of O′ phase particles, recorded using FEI Talos F200s S/TEM at 200kV; (b) HAADF-STEM image and corresponding inset Fast Fourier Transformations showing the orthorhombic structure of O′ phase, recorded using Thermo Scientific Themis Z S/TEM at 300kV.

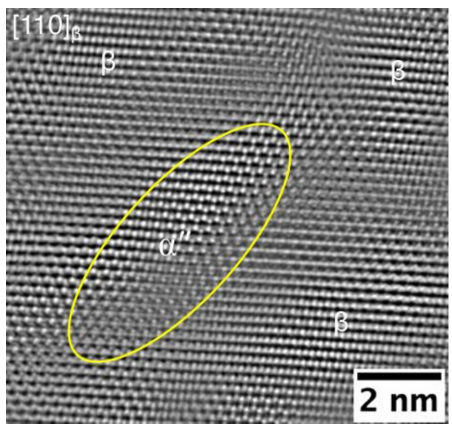

Figure 2. HAADF-STEM imaging showing the atom arrangement in the nano-scale α″ phase particle in the cold-rolled Ti-5Al-5Mo-5V-3Cr alloy, recorded using Thermo Scientific Themis Z S/TEM at 300kV.

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