

Investigations of Omega Precipitation in Titanium Molybdenum Alloys by Coupling 3D Atom Probe Tomography and High Resolution (S)TEM

A. Devaraj*, R. E. A. Williams**, S. Nag*, R. Srinivasan**, H.L. Fraser**, R. Banerjee*

* Center for Advanced Research and Technology and Department of Materials Science and Engineering, The University of North Texas, UNT Research Park, Denton, Texas, 76207

** Center for the Accelerated Maturation of Materials and Department of Materials Science and Engineering, The Ohio State University, 2041 College Road, Columbus, Ohio, 43210

Titanium-base alloys are used in a number of critical components in aerospace and defense, biomedical, automotive, and a range of other industries. These alloys typically exhibit complex multi-phase microstructures spanning across a range of length scales and also involving a large number of alloying additions. The ω phase is commonly observed in many commercial β or near- β titanium alloys on quenching from the solution treatment temperature in the single beta phase field [1]. These ω precipitates typically have an embrittling effect on the alloy and are therefore considered detrimental for its mechanical properties [2]. However, since ω precipitates are highly refined (nanometer scale) and homogeneously distributed, and due to the fact that they reject β -stabilizing elements, it is possible that they can act as heterogeneous nucleation sites for the precipitation of the equilibrium α phase. This leads to a homogeneous distribution of refined α precipitates that can substantially strengthen the alloy [1,3]. Therefore, the detailed investigation of ω precipitation in the beta matrix of titanium alloys is rather important.

This presentation investigates ω precipitation within the β matrix of simple binary titanium – molybdenum (Ti-Mo) alloys, by coupling 3D atom probe (3DAP) tomography and high-resolution transmission electron microscopy (HRTEM) and HRSTEM. Quenching from β solutionizing temperatures results in the formation of athermal ω precipitates that are typically considered to inherit the composition of the parent β matrix [1]. On subsequent isothermal annealing, coarsening of the ω precipitates is accompanied by the diffusional rejection of Mo. While the as water-quenched Ti-9Mo (at%) samples are nominally homogeneous in composition (shown by the atom map in Fig. 1(a)), a compositional profile across this reconstruction reveals modulations in the Mo content with a wavelength ~ 3 nm, indicating the early stages of phase separation (Fig. 1(b)). This is substantiated by the interconnected nature of the Ti=92at% isoconcentration surface (isosurface) shown in Fig. 1(c). Electron diffraction patterns from the same sample exhibit reciprocal lattice streaking and intensity maxima at the $1/3$ and $2/3$ $\{112\}_{\beta}$ positions (inset in Fig. 1(d)), attributable to the early stages of ω precipitation in this alloy as clearly visible in the dark-field TEM (Fig. 1(d)). Isothermal annealing of this alloy, carried out for different periods of time at 475°C, leads to growth and coarsening of the ω precipitates accompanied by the rejection of Mo from these precipitates. 3DAP results from a sample annealed for 0.5 hours is shown in Fig. 2. Fig. 2(a) shows a Ti=92 at% isoconcentration surface (or isosurface), clearly delineating the ω precipitates, together with the Mo atoms in red. A dark-field TEM image from this sample (Fig. 2(b)), shows coarsened ω precipitates (diffraction pattern inset). A high-resolution TEM image of the β/ω interface, shown in Fig. 2(c), shows ledges present at this interface, suggesting a displacive component in the isothermal β to ω transformation.

References

- [1] M. J. Blackburn and J. C. Williams, *Trans. Met. Soc. AIME*, **242**, 2461 (1968).
 [2] T.W. Duerig, and, J.C. Williams, *Beta Titanium alloys in the 80's: Proceedings of the Symposium, Atlanta, GA, United States*, 19-67 (1984).
 [3] G. M. Pennock, H. M. Flower, and, D. R. F. West, *Titanium '80: Science and Technology*, 1343-1351 (1980).

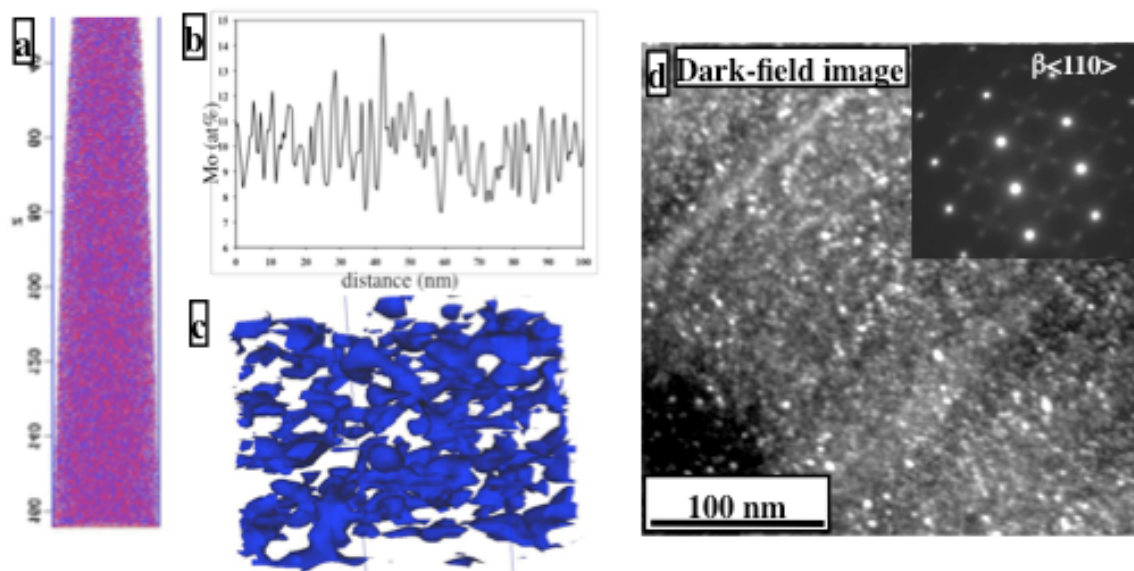


Fig. 1(a) 3DAP reconstruction of Ti(blue) and Mo(red) atoms in the Ti-9Mo alloy after beta solutionizing and quenching. (b) Mo compositional profile across the reconstruction shown in (a). (c) Ti=92at% isosurface in blue. (d) Dark-field TEM image showing nanoscale omega precipitates in the same alloy together with diffraction pattern (inset).

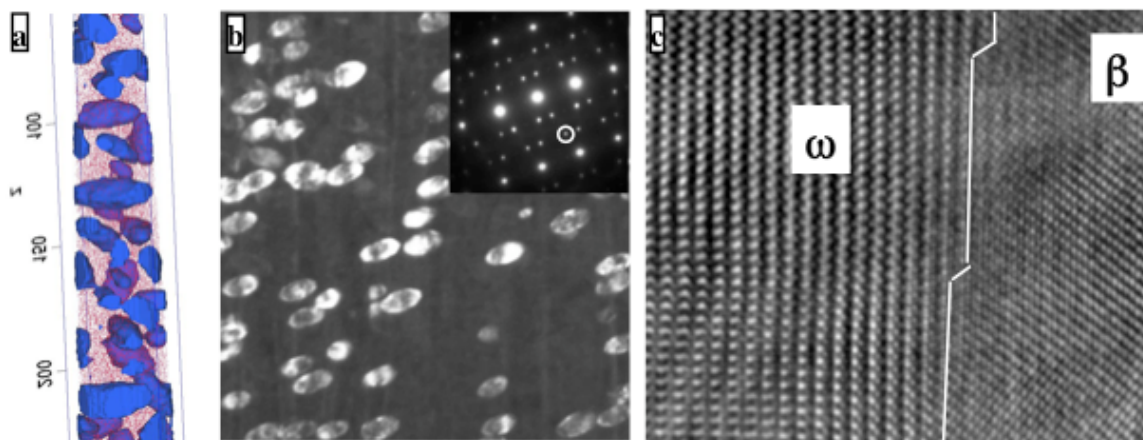


Fig. 2(a) 3DAP reconstruction of Ti=92at% isosurface (blue) and Mo (red) atoms in the Ti-9Mo alloy after annealing at 475°C for 0.5 hrs. (b) Dark-field TEM image showing nanoscale omega precipitates in the same alloy together with diffraction pattern (inset). (c) HRTEM image of β/ω interface showing ledges.