Correlations between the cooling rate and decomposition pathways in near eutectoid Ti-Cu alloys

R.J. Contieri, E.S.N. Lopes, R. Caram

Department of Materials Engineering

University of Campinas, Campinas, SP, Brazil

S. Nag and R. Banerjee

Department of Materials Science and Engineering

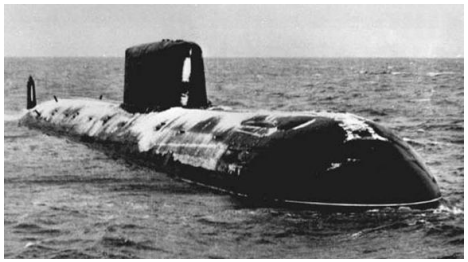
University of North Texas, Denton, Texas, U.S.A.

MS&T'12®

October 7-11, 2012 – Pittsburgh, Pennsylvania

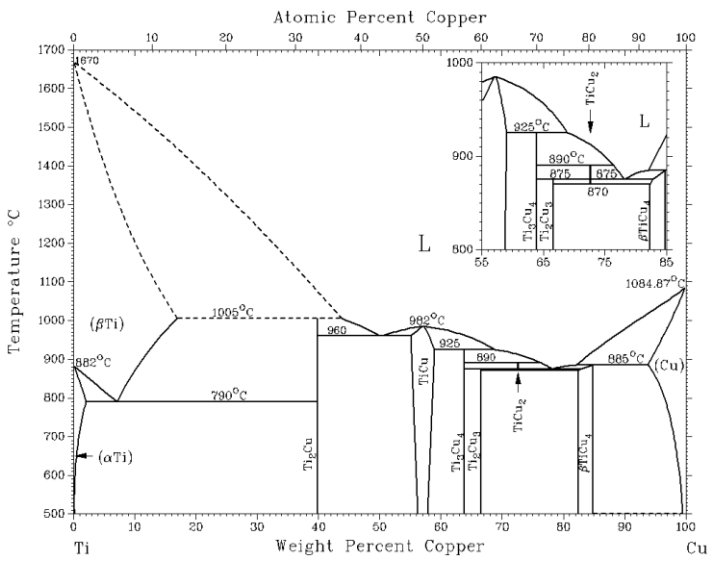
Ti Alloys Applications

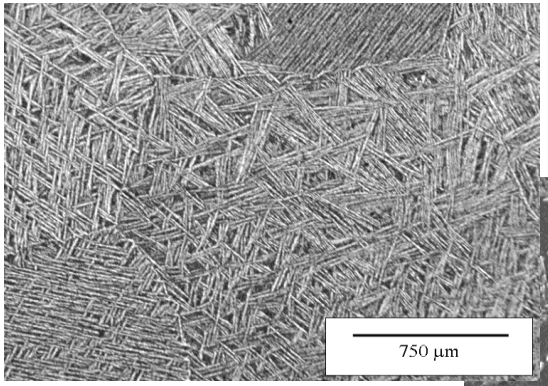
- **Ti: light weight, low elastic modulus, high strength to weight ratio, excellent biocompatibility and remarkable corrosion resistance**
- **Application of Ti alloys in in the aerospace, chemical, dental and medical industries is ever increasing**

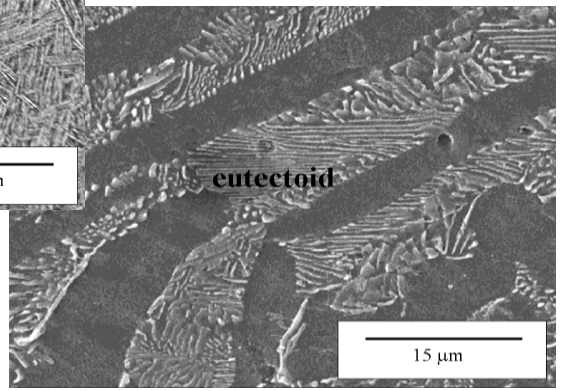




Ti-Cu Alloys

- **Equilibrium microstructure of low Cu content Ti-Cu alloys consists of a matrix of α-Ti and precipitates of Ti_2Cu intermetallic compounds.**







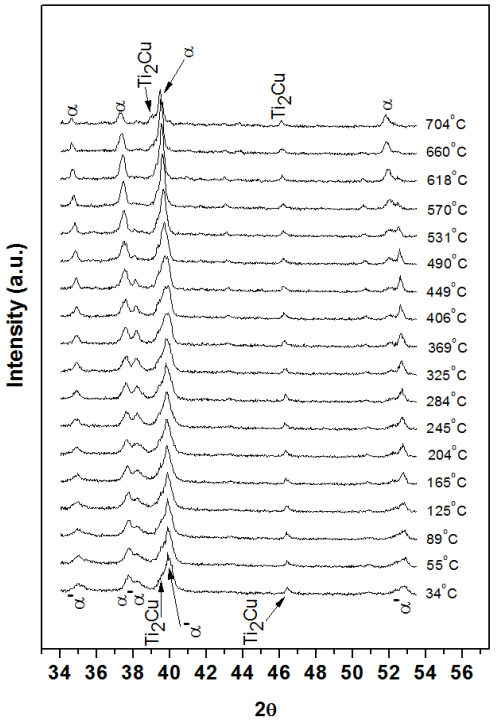
Ti-Cu Alloys

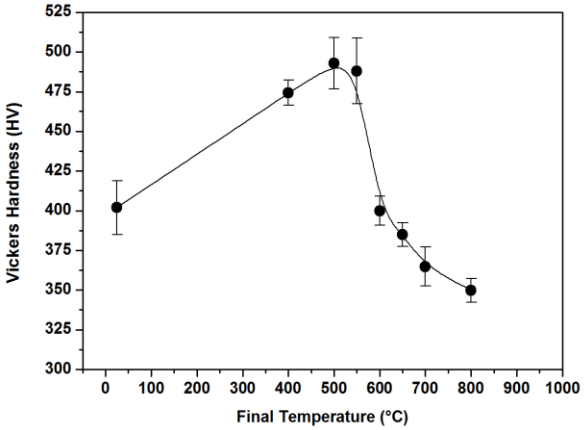
- **Ti-Cu alloys combines good formability and weldability with improved mechanical behavior**
- **Application in gas turbine engines**
- **High solute segregation (large mushy zone) limits Ti-Cu alloys applications**
- **IMI 230 : Ti-2.5Cu (wt%)**

Aging of WQ Ti-7.1Cu

Mechanical behavior of Ti-Cu alloys depends on their microstructure, which is determined by the processing routes applied

Heating Rate
10ºC/mim





Condition	Y. S. (MPa)
Solution and WQ	838 ± 7
400ºC	1140 ± 12
500ºC	1294 ± 8
600ºC	1105 ± 8

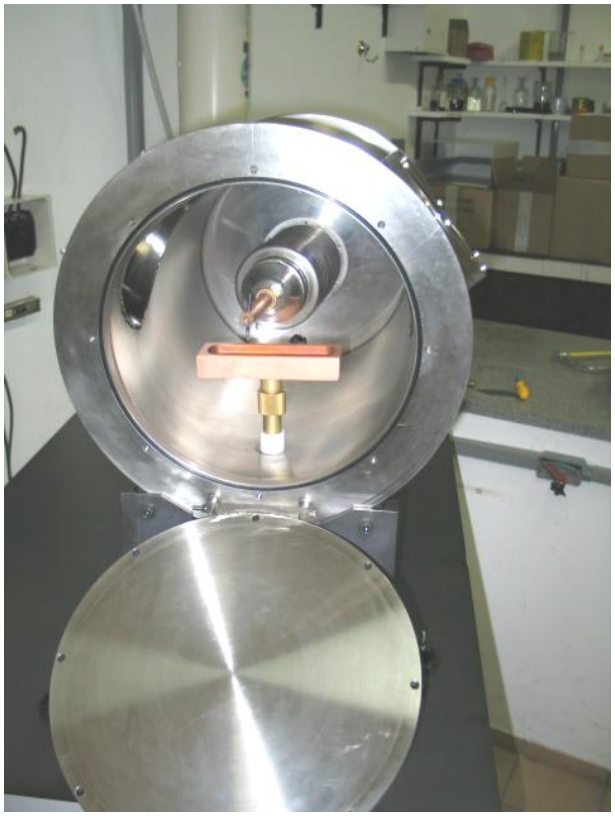
Ti-Cu Alloys

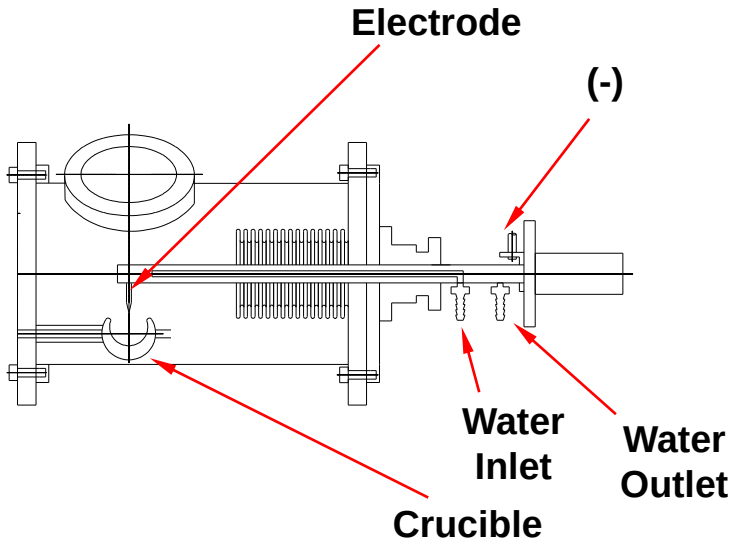
- **Ti-Cu system is an active eutectoid system**
- **Active system: β phase decomposes rapidly into two phases**
- **β phase decomposition is so fast that it can not be suppressed by rapid quenching**
- **Decomposition products form lamellar arrangement (perlite-like microstructure)**

Objectives

- **To discuss the β Phase Decomposition in Ti-Cu and the effects of cooling rate on the microstructure and the solute partitioning in near-eutectoid Ti-Cu samples subjected to continuous cooling**

Experiments

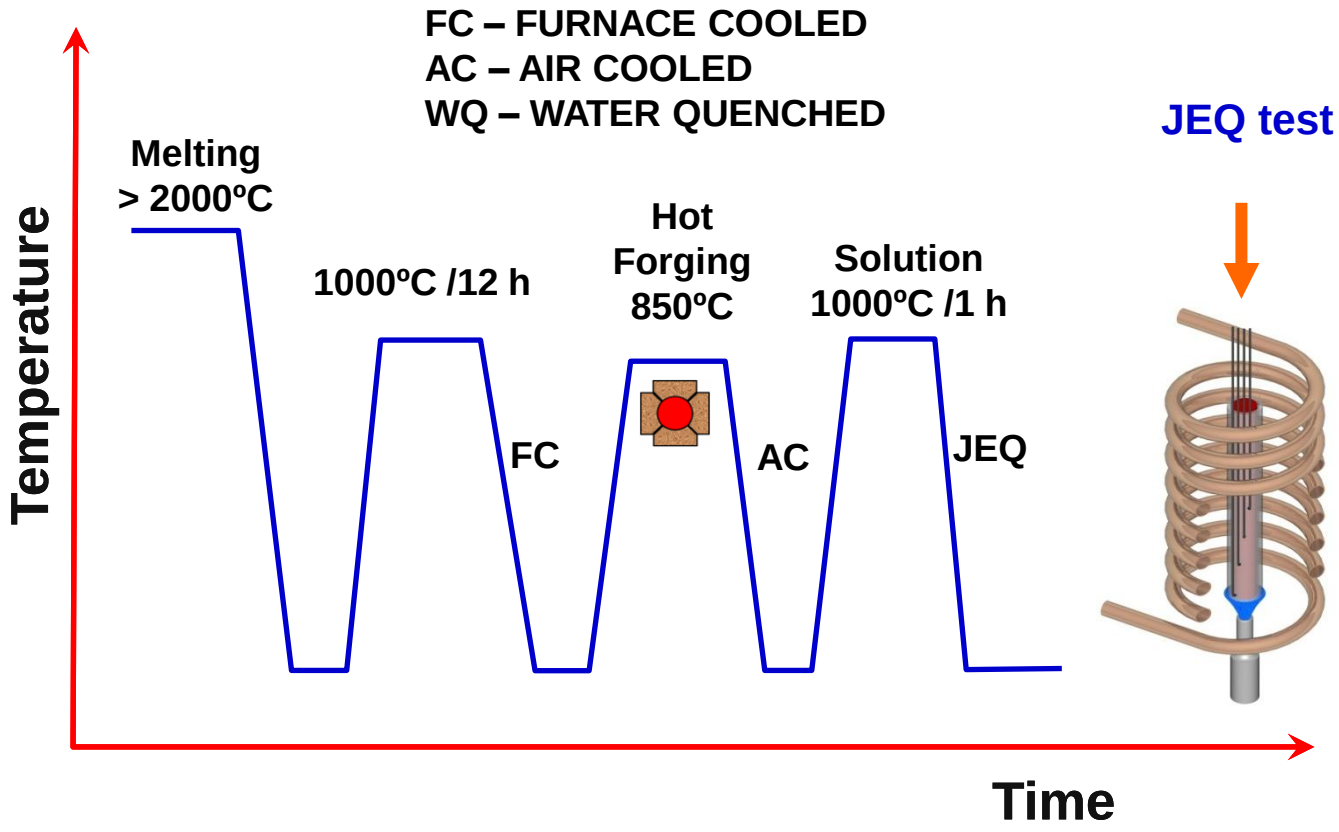




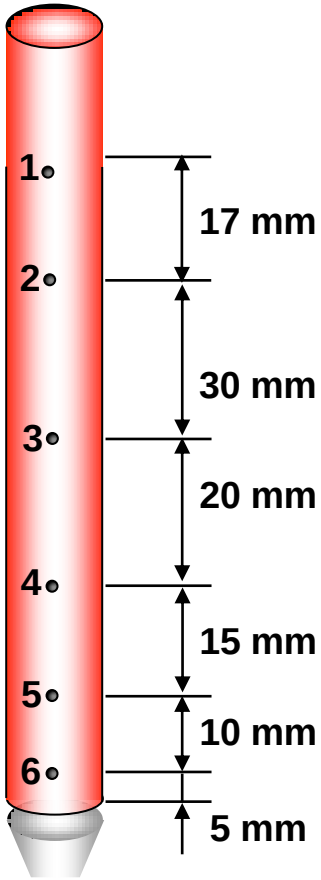
Alloy Composition

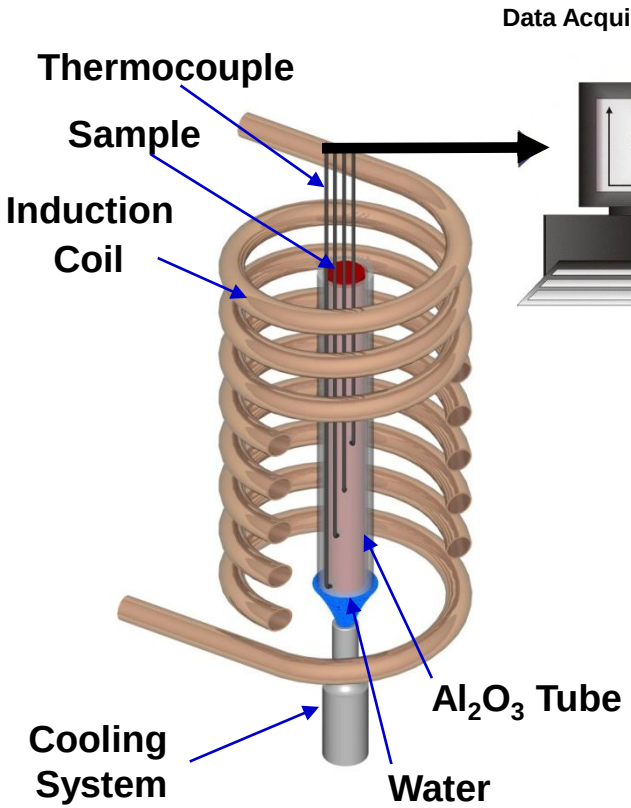
Nominal (wt.%)	Measured (wt.%)
Ti-7.1 Cu	Ti-7.6Cu

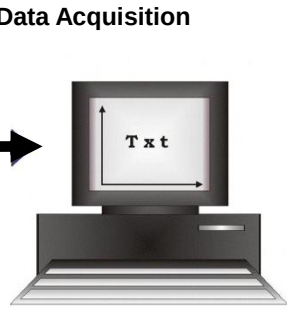
JEQ Experiment

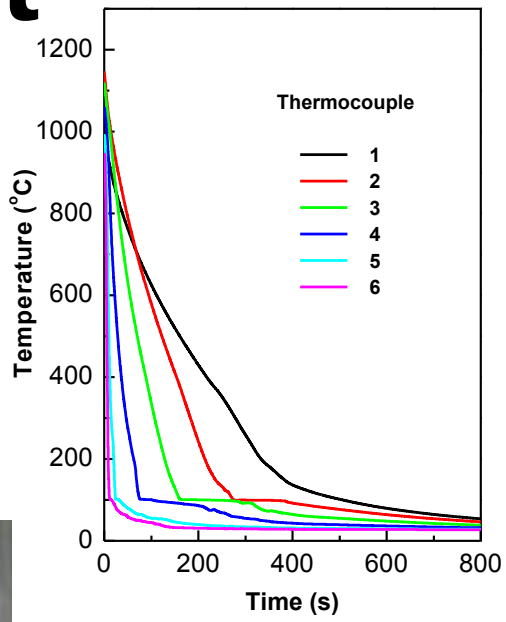


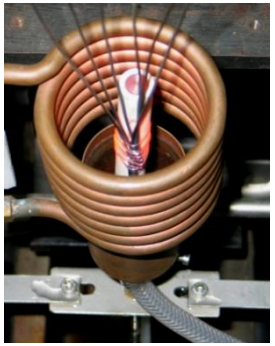
JEQ Experiment







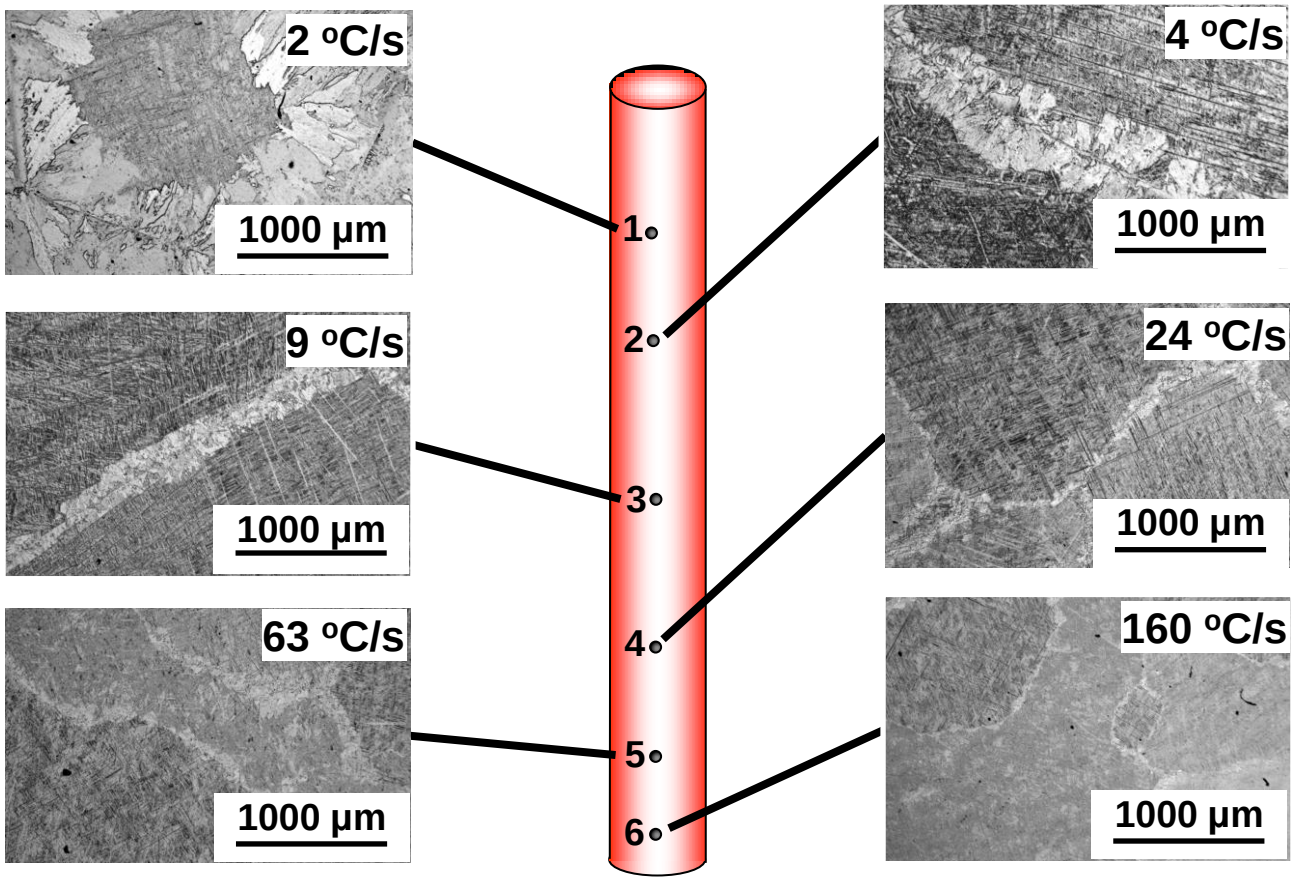




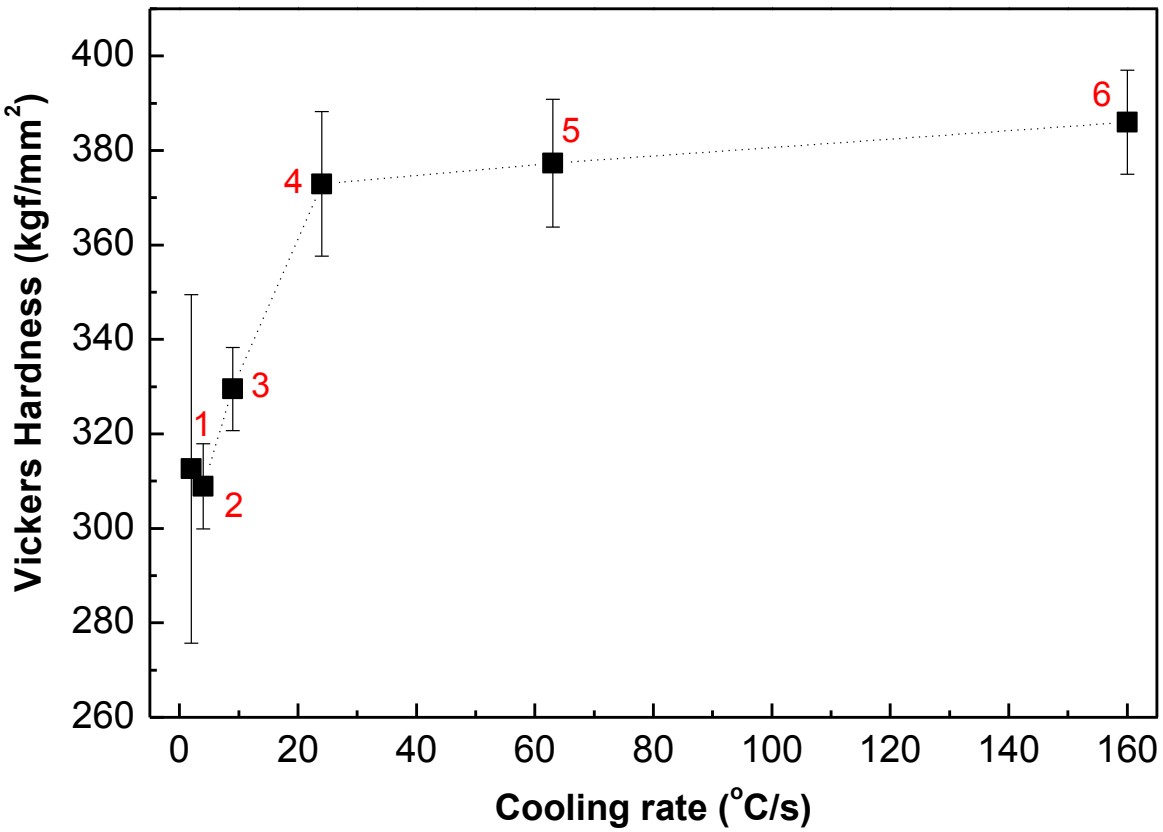
Sample Characterization

- **Samples were characterized using:**
  - **SEM, FEI FEG Nova NanoSEM 230, operating at 20 to 30 keV**
  - **TEM, FEI Tecnai F20-FEG instrument operating at 200 kV**
  - **3DAP tomography were prepared using the dual-beam FIB instrument**

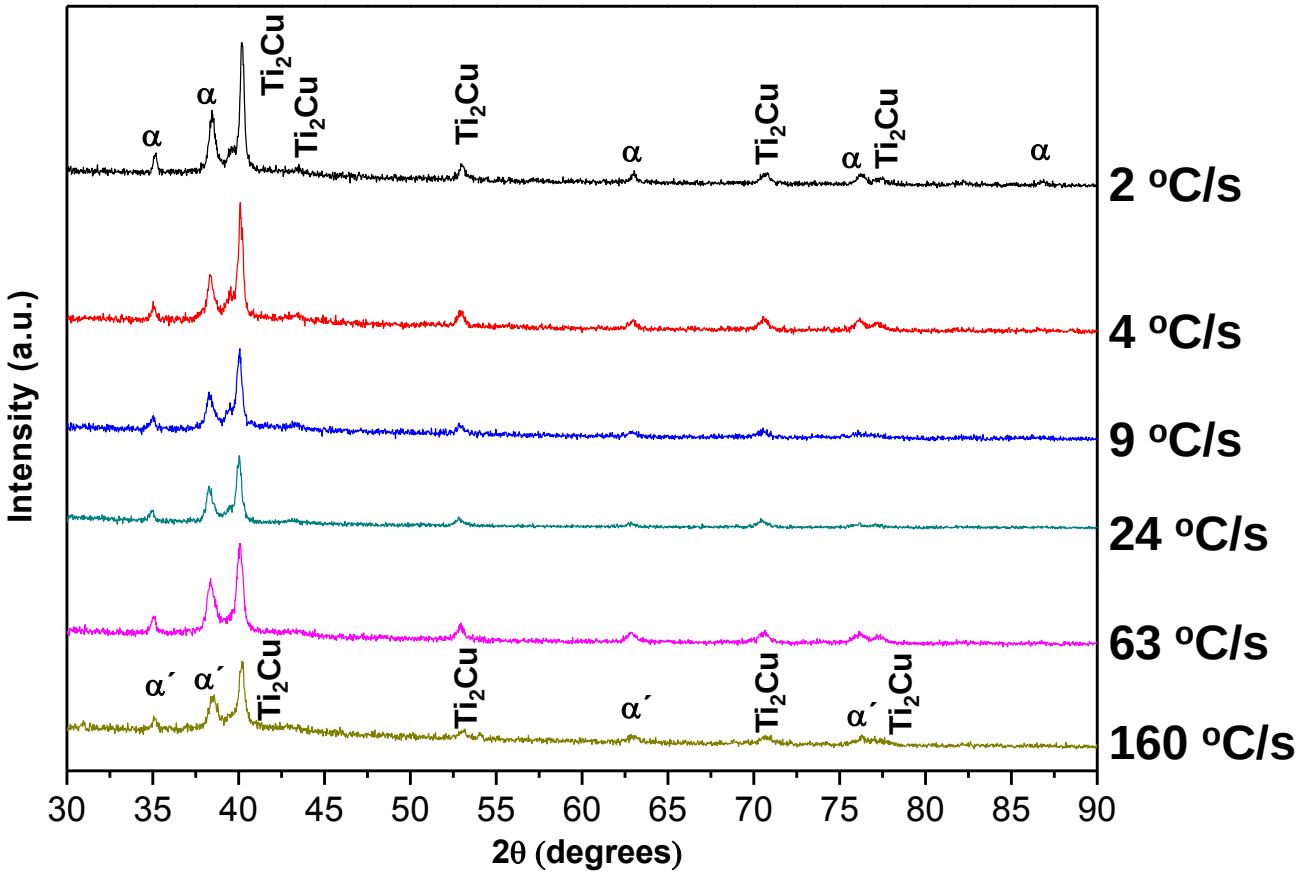
JEQ Microstructures



JEQ Hardness



JEQ XRD Patterns

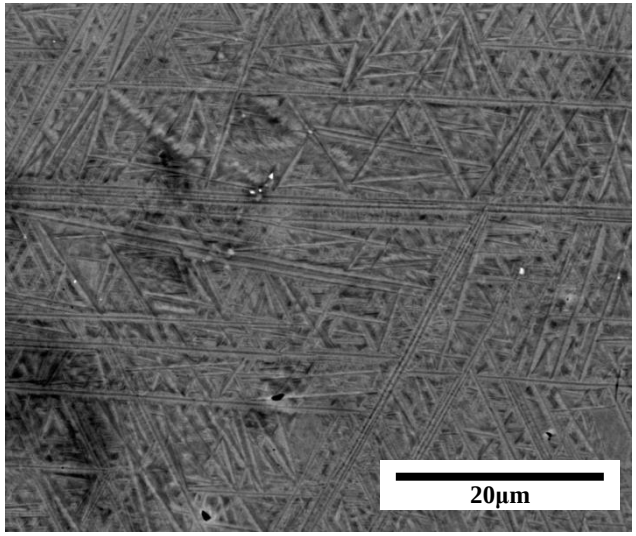


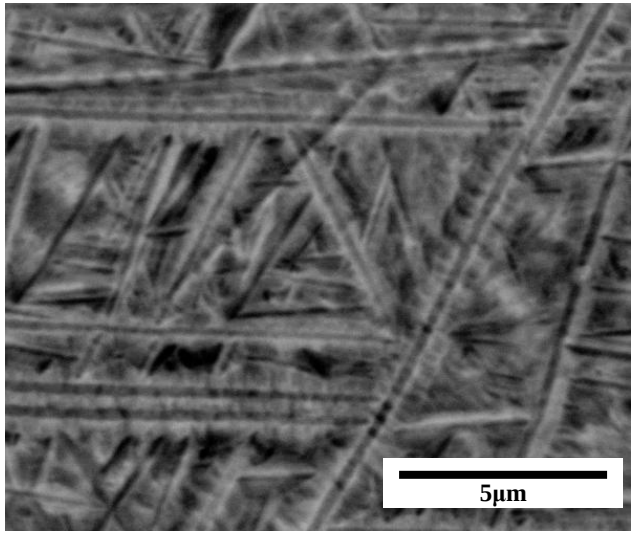
SEM, TEM and 3DAP

- **Samples processed in the modified Jominy End Quench Test apparatus were cut into several pieces.**
- **Three of them were selected to be analyzed by SEM, TEM and 3DAP.**
- **These samples were submitted to cooling rates of 160 K/s, 9 K/s and 2 K/s, respectively.**

Cooling Rate: 160 K/s

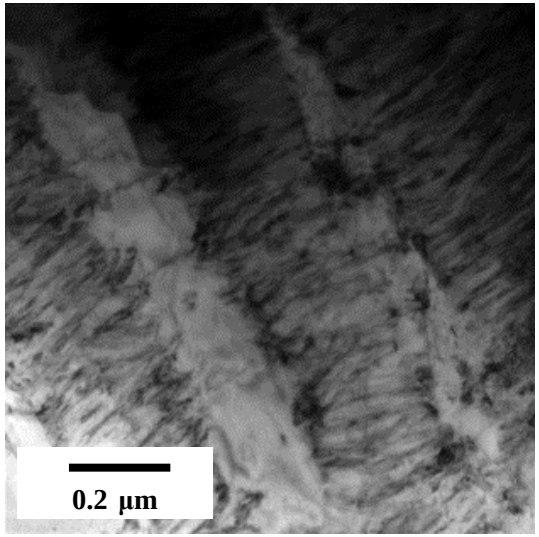
- **Long plates well dispersed in the microstructure**
- **High magnification images suggest martensite formation**
- **Similarities among α phase and hexagonal martensite do not allow to confirm martensitic transformation**

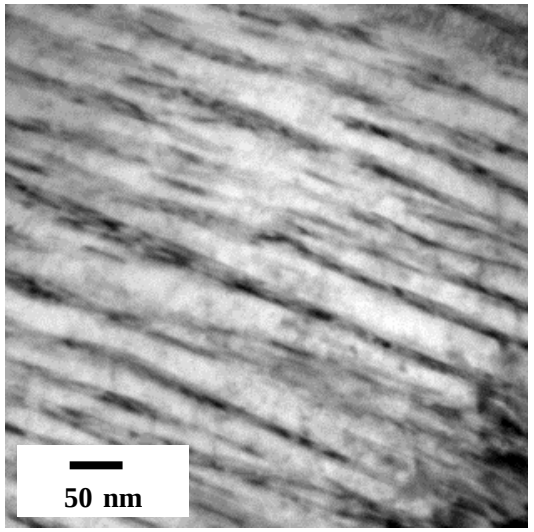




Cooling Rate: 160 K/s

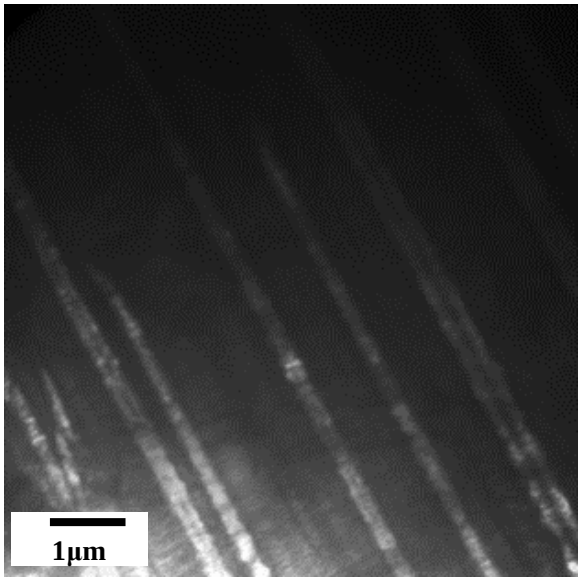
- **Lamellar structure coexisting with martensite plates**
- **Higher magnification shows details of lamellar structure**
- **Primary plates and secondary plates**

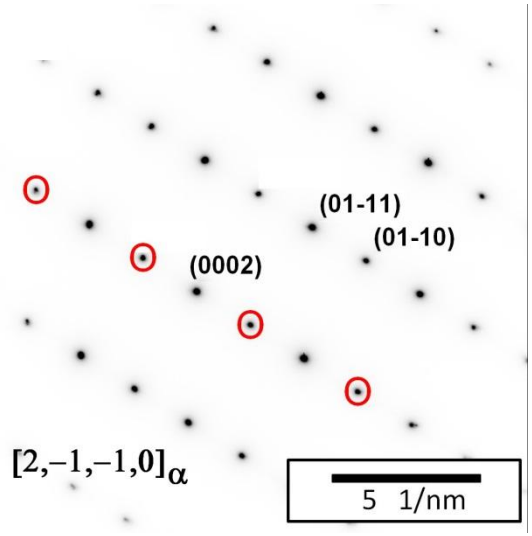




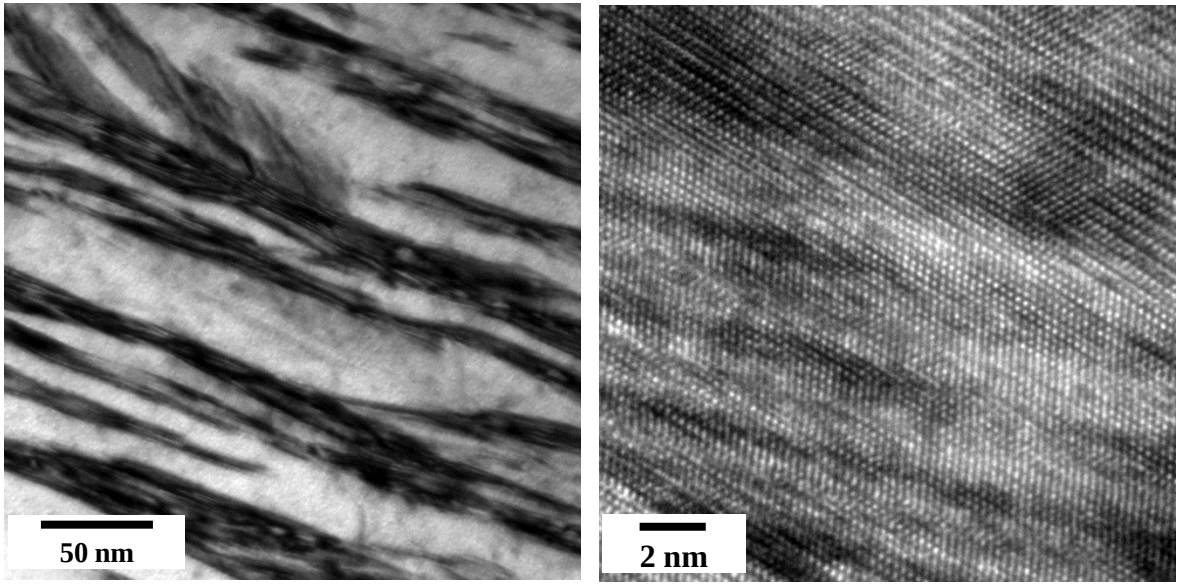
Cooling Rate: 160 K/s

- TEM image showing parallel primary plates
- SADP of [2-1-10] zone axis of the martensite plates
- Plates were identified as α/α’



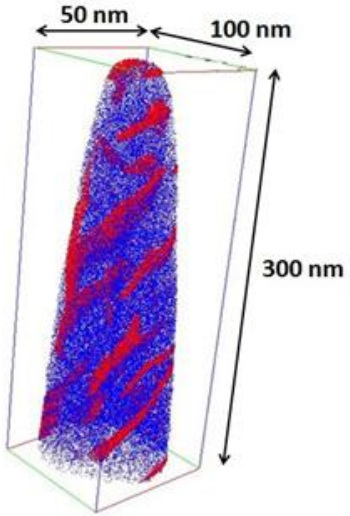


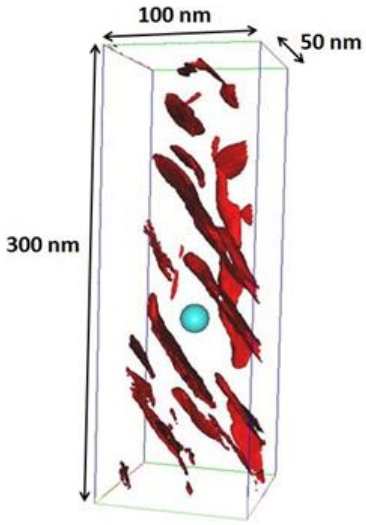
Cooling Rate: 160 K/s

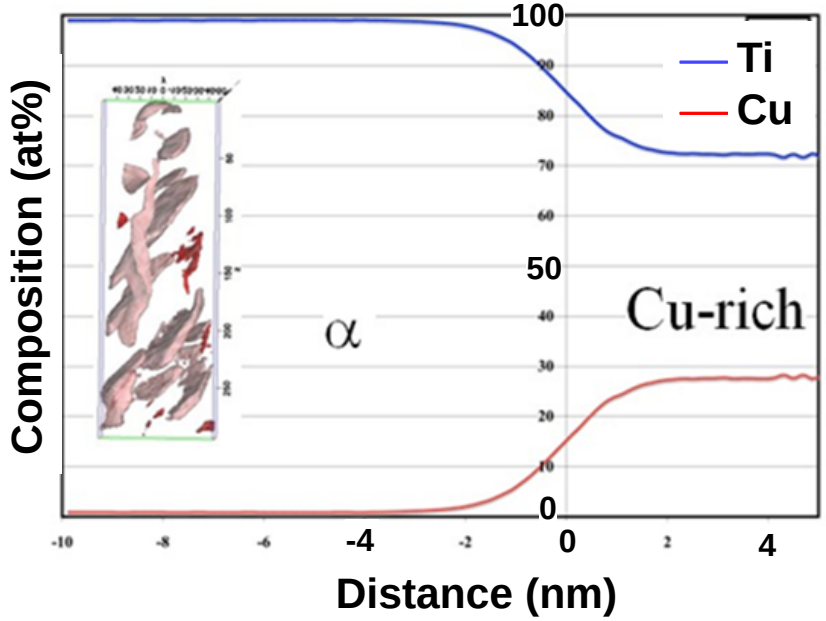


Cooling Rate: 160 K/s

- **Cu rich phase = 27.3 at. pct Cu**
- **Ti rich phase = 0.9 at. pct Cu**

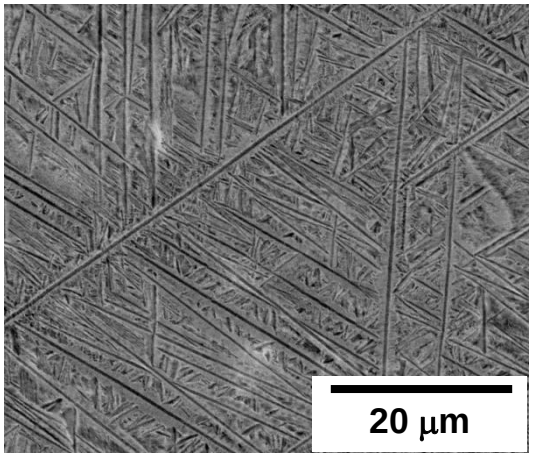


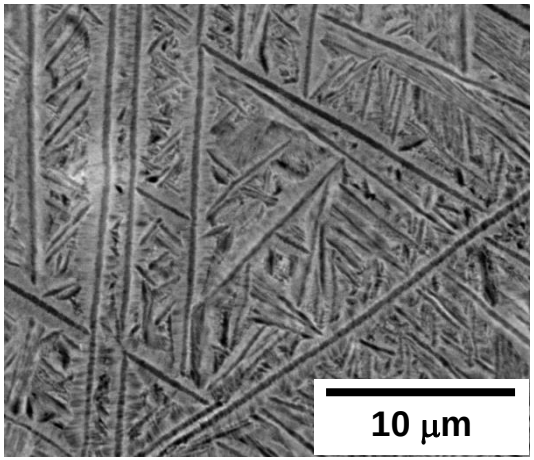


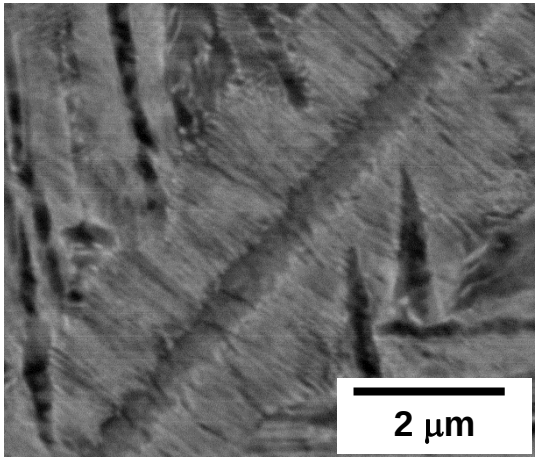


Cooling Rate: 9 K/s

- **Acicular martensitic structure formed by α/α' and Ti_2Cu**
- **Fine lamellar structure composed by α/α' and Ti_2Cu**
- **As cooling rate was reduced, number martensite plates also decreased**

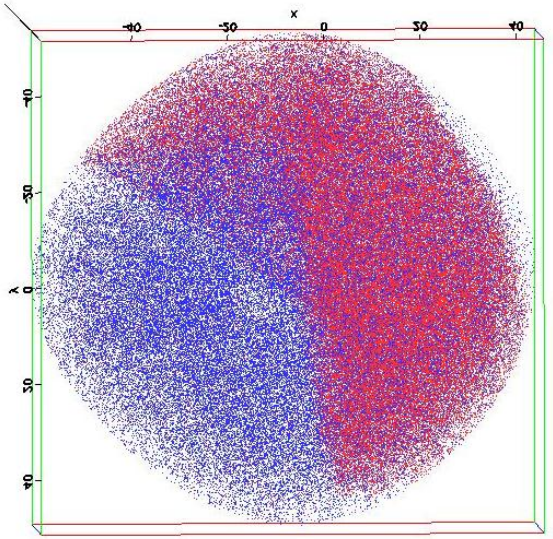


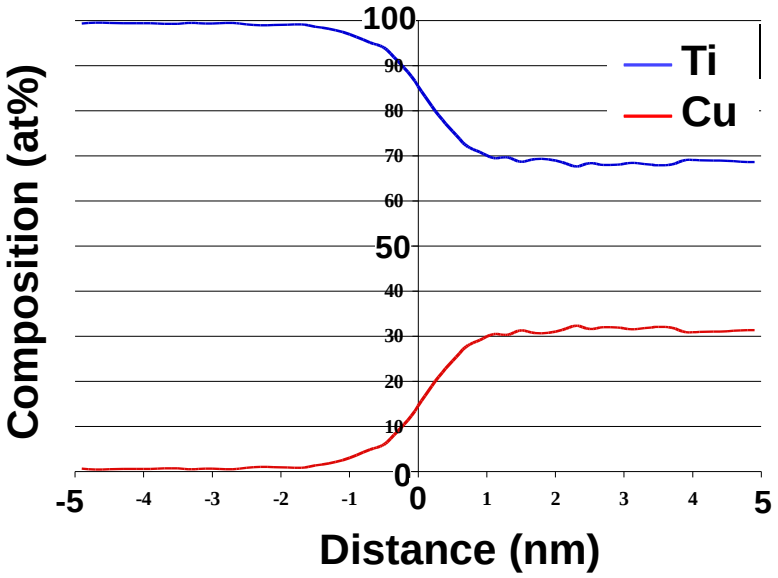




Cooling Rate: 9 K/s

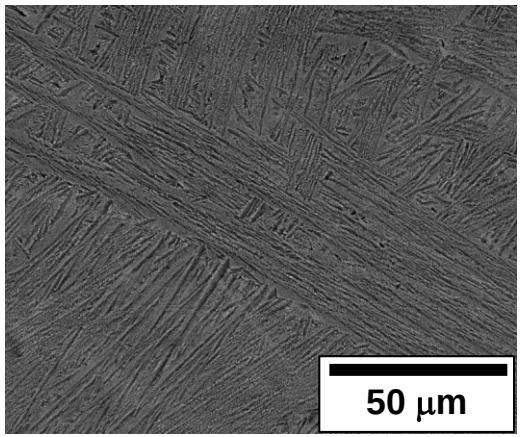
- **Cu rich phase = 30.5 at. pct Cu**
- **Ti rich phase = 0.6 at. pct Cu**

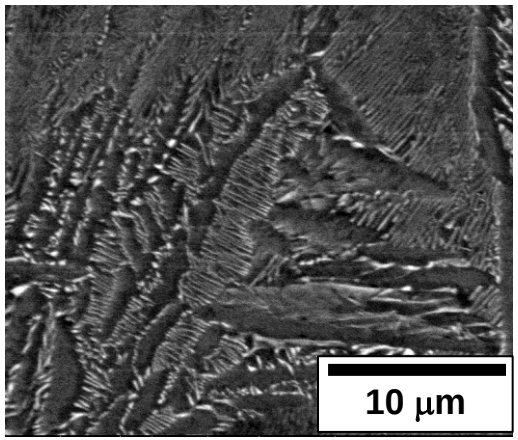


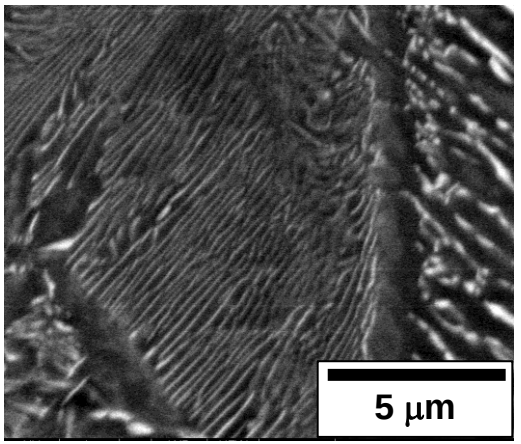


Cooling Rate: 2 K/s

- **Low magnification image shows acicular microstructure**
- **High magnification image reveals perlitic colonies**
- **low cooling rate results in eutectoid growth at a temperature not far below the eutectoid temperature with large lamellar spacing, 0.2 μm**

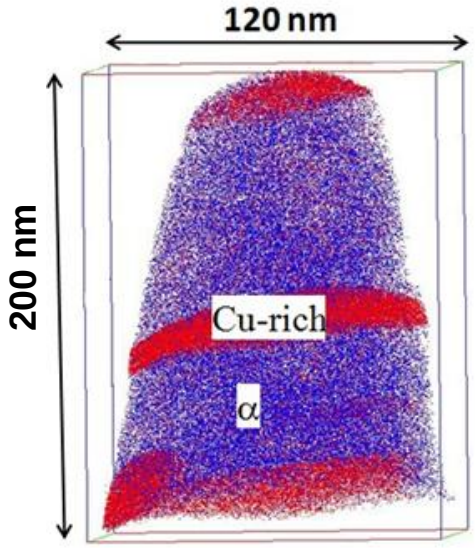


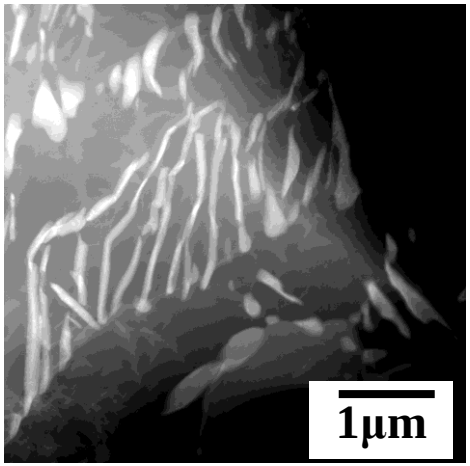


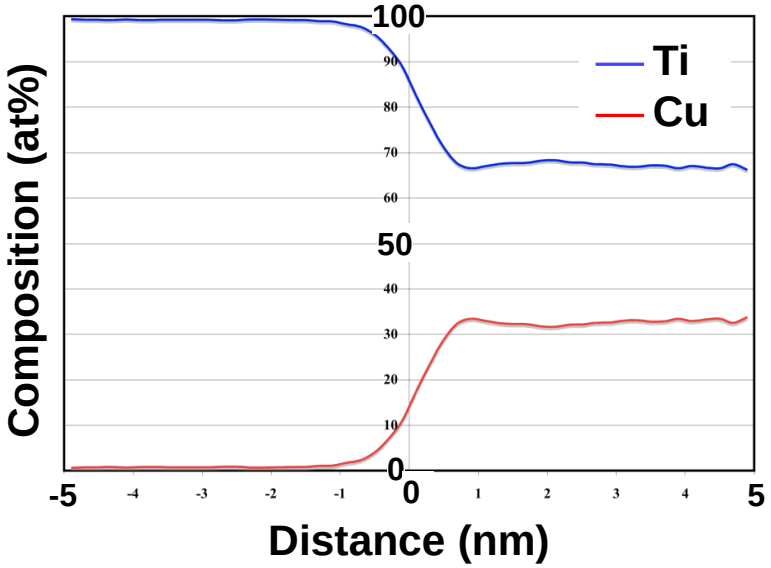


Cooling Rate: 2 K/s

- Lamellar perlitic structure formed by αTi and Ti_2Cu
- Cu rich phase = 34.1 at. pct Cu
- Ti rich phase = 0.9 at. pct Cu







Conclusions

- **Ti-Cu samples cooled at 160 K/s showed primary martensite plates combined with secondary martensite plates;**
- **High magnification TEM images suggested formation of very fine lamellar structures composed by Cu rich and Ti rich phases;**
- **Composition of each phase were far from their respective equilibrium composition;**
- **Composition of each eutectoid phase approximated to the equilibrium compositions with the decreasing in cooling rate;**
- **The 3DAP results show that the composition changes at the interface of phases in perlitic structure could be either rather gradual for high cooling rates or more abrupt if intensity of quenching decreases;**
- **No matter the cooling rate applied, no evidences of β phase stabilization were found.**