University of Campinas, Brazil

Effects of Aging Heat Treatment on the Microstructure of Ti-Nb and Ti-Nb-Sn Alloys Employed as Biomaterials

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Mediterranean Conference on Innovative Materials and Applications

15 – 17 March 2011

Beirut - Lebanon

University of Campinas, Brazil

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Outline

- Introduction
  - Orthopedic Implants
  - Total Hip Replacement Requiriments
  - Bone Elastic Deformation
  - Ti Alloys Phase Transformations
- Objectives
- Experiments
- Results
  - DSC
  - High Temperature X-Ray Diffraction
  - Aging Heat Treatment and Mechanical Behavior
  - Cold Forged Femoral Stem
- Conclusions

Introduction

- **Concept of implanting materials in the human body is not new**
  - **Ancient Egypt**

    mummified foot with an artificial wooden toe

  - **Ancient Egypt**

    dental implant

    in mummies

  - **Ancient mediterranean civilization**

    dental bridge

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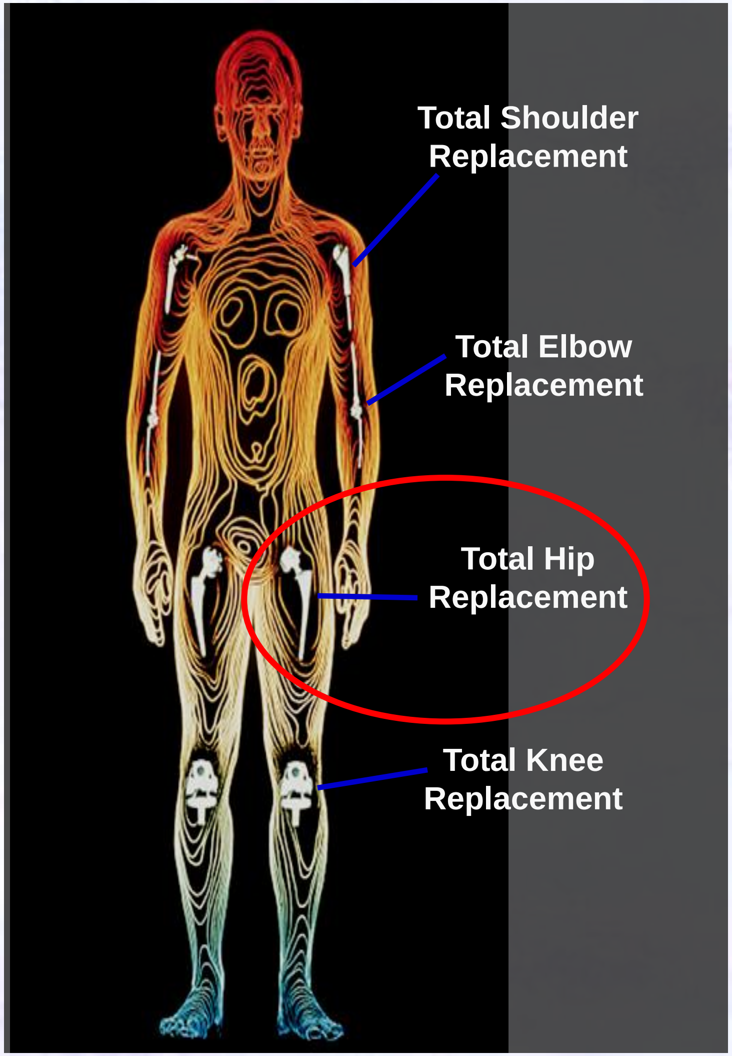
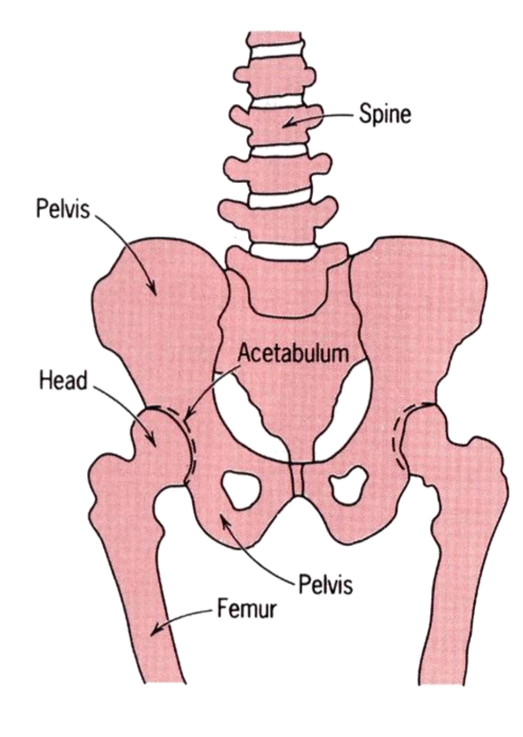
Total Joint Replacement

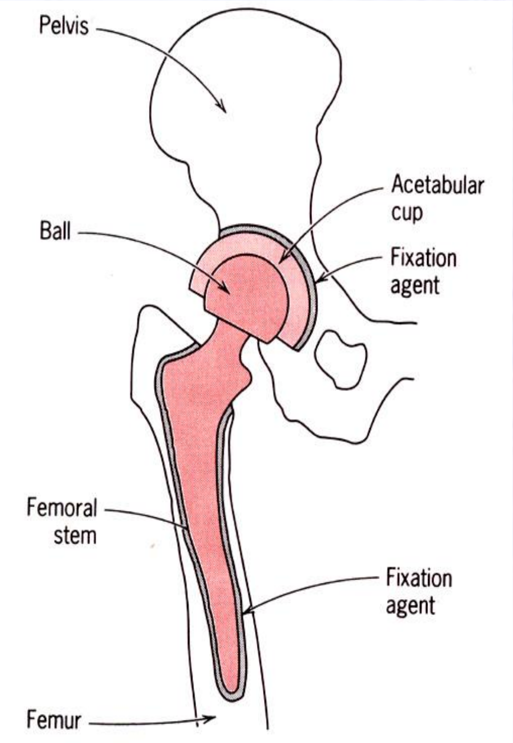
- **TJR is a surgical procedure in which certain parts of a damaged joint, are removed and replaced with a plastic or metal device called a prosthesis**
- **Prosthesis is designed to enable the artificial joint to move just like a healthy joint**



Total Hip Replacement



Hip joints and adjacent skeletal components



Total hip replacement

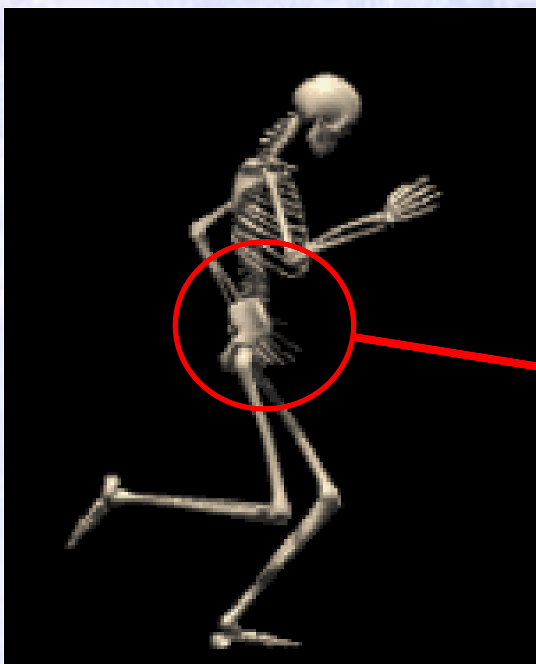
Implant after surgery

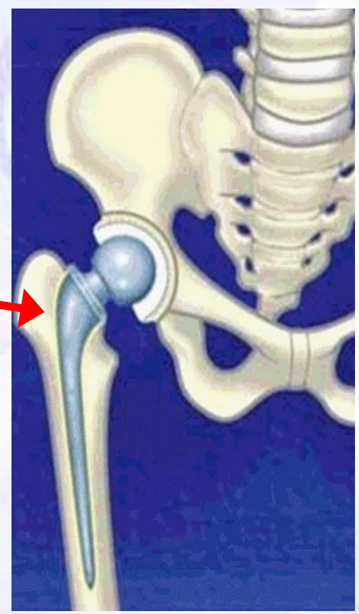
Total Hip Replacement

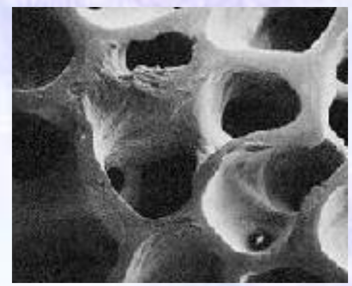
Adapted from Orlin & Cohen Orthopedic Group

Bone Elastic Deformation

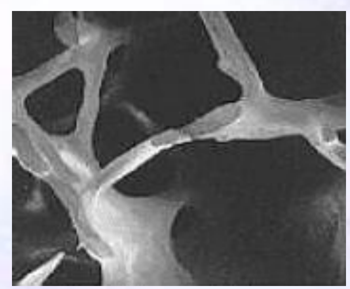
- Implant material must simulate bone elastic behavior
- Wolff's Law: Bone modifies its internal architecture and external shape as a result of mechanical stress
- Insufficient load transfer from the implant to the bone causes bone mass loss and osteoporosis







Healthy bone

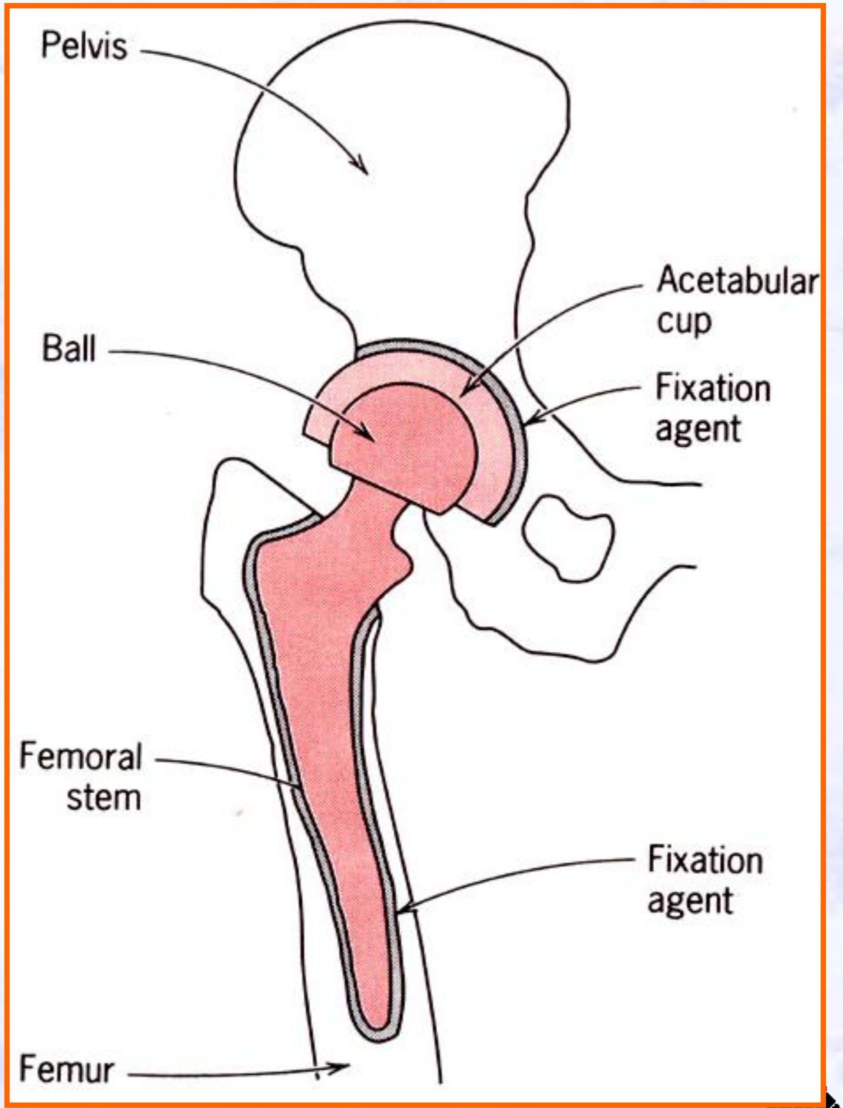


Bone with osteoporosis

Bone fracture

Total Hip Replacement Requirements

- Femoral Stem Requirements
- High mechanical strength
- Low prices
- High biocompatibility
- High corrosion resistance
- Low elastic modulus
  - E_{bone}: 10 - 30 GPa
  - $E_{stainless\ steel}$: 200 GPa
  - $E_{Ti-6Al-4V}$: 106 GPa
- "Necessary development of low elastic modulus Ti Alloys"



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Objectives

- To discuss phase transformations in β Ti-Nb-Sn alloys:
  - α phase precipitation during aging heat treatment of metastable microstructures
  - Correlation between microstructure and mechanical behavior
  - Application of phase transformations knowledge in Ti-based femoral stem manufacturing

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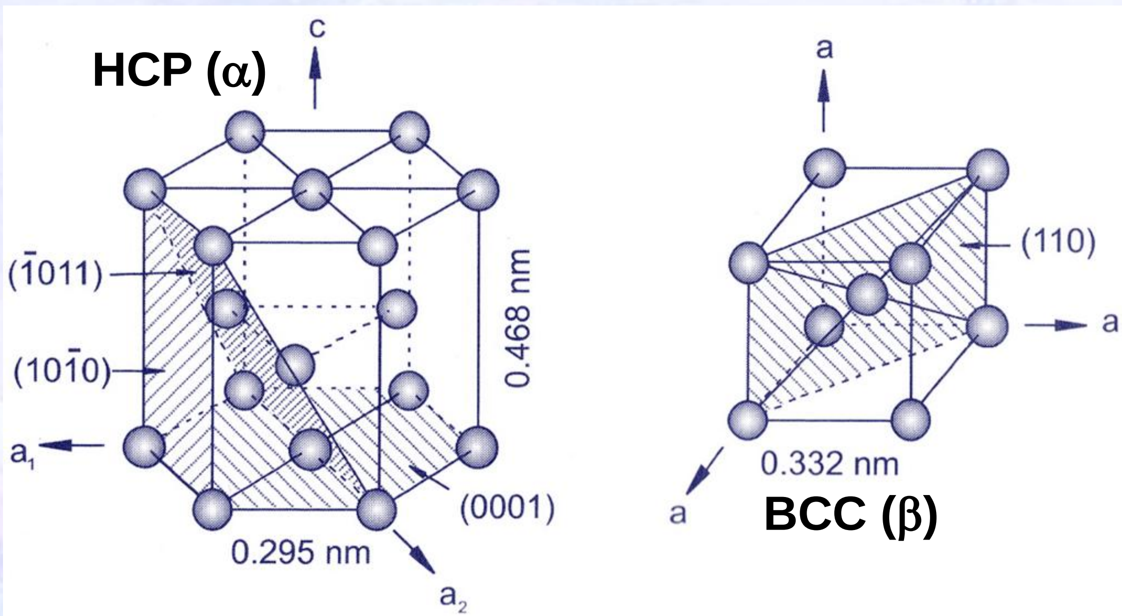
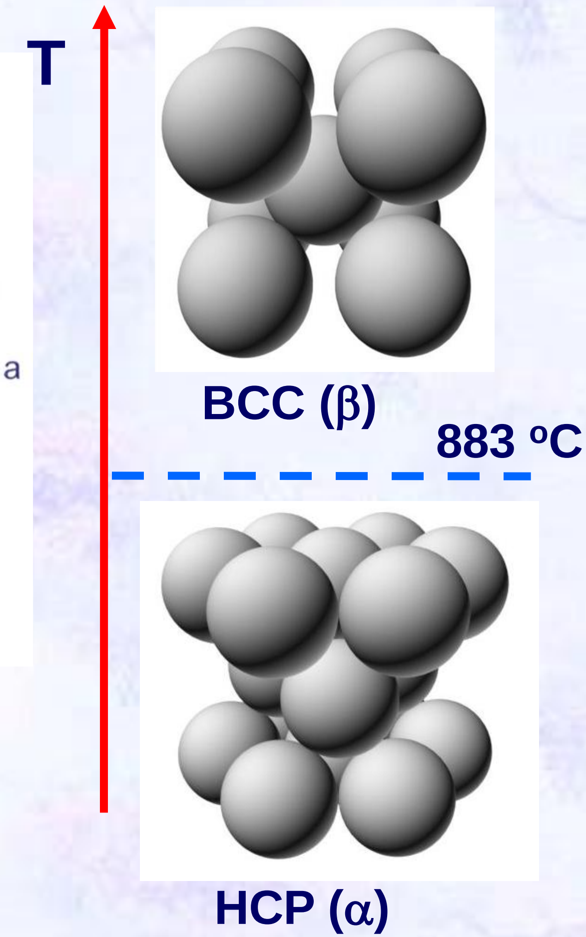
Titanium Metallurgy

- **Titanium shows two allotropic forms: HCP and BCC**



- **Addition of alloying elements may change the phase stability and hence, the microstructure and mechanical behavior**



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β Titanium Alloy

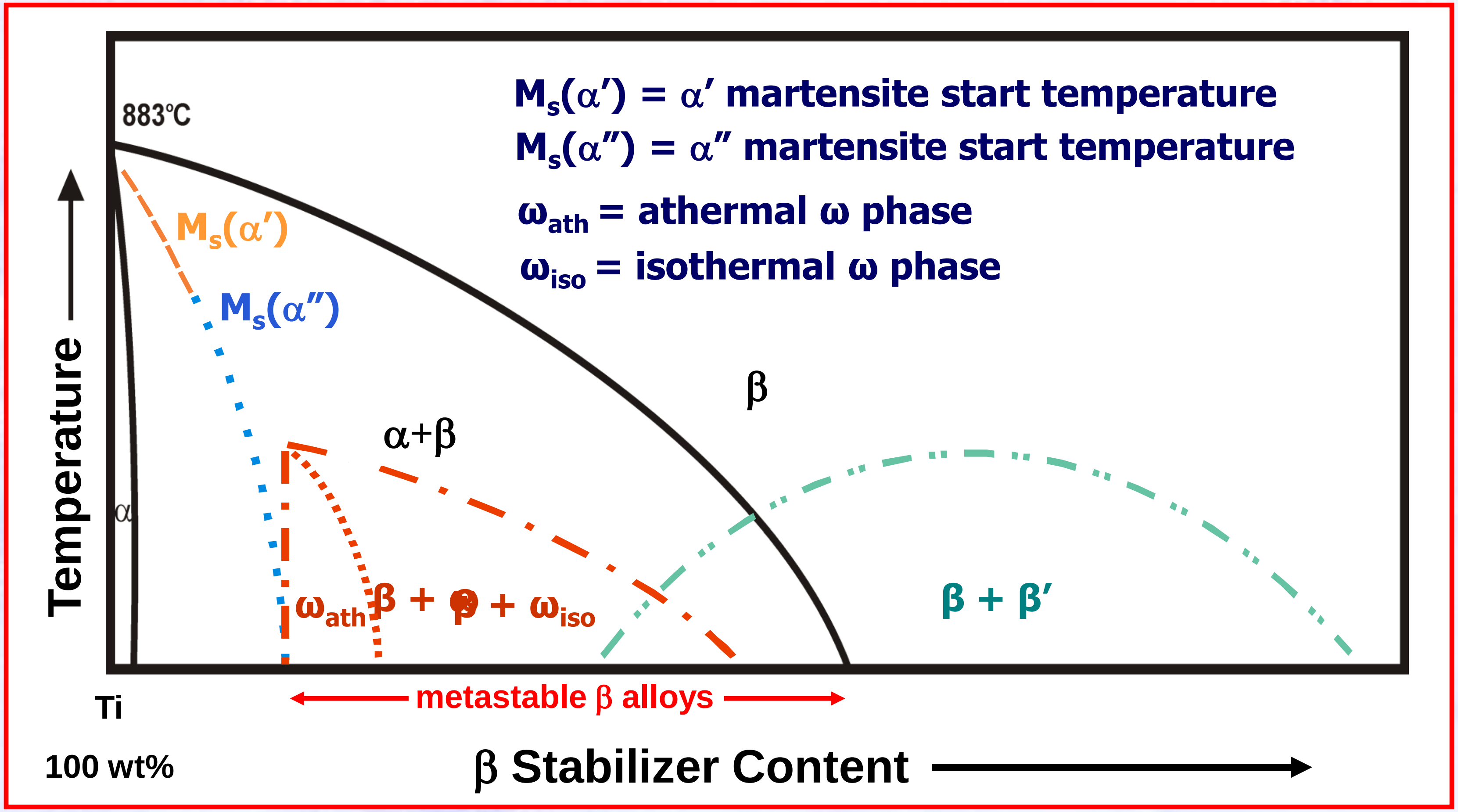
β Ti alloys

β Stabilizer elements:
Cr, Nb, V, Ta, Mo

- **HIGH STRENGTH-TO-DENSITY RATIO**
- **LOW ELASTIC MODULUS**
- **HIGH STRENGTH**
- **HIGH TOUGHNESS**
- **BIOCOMPATIBILITY**
- **EASY TO HEAT TREAT**
- **EXCELLENT CORROSION RESISTANCE**
- **LOW FORGING TEMPERATURE**

Ti Alloys Phase Transformations

CHEMICAL COMPOSITION AND HEAT TREATMENTS → MECHANICAL PROPERTIES OF Ti ALLOYS



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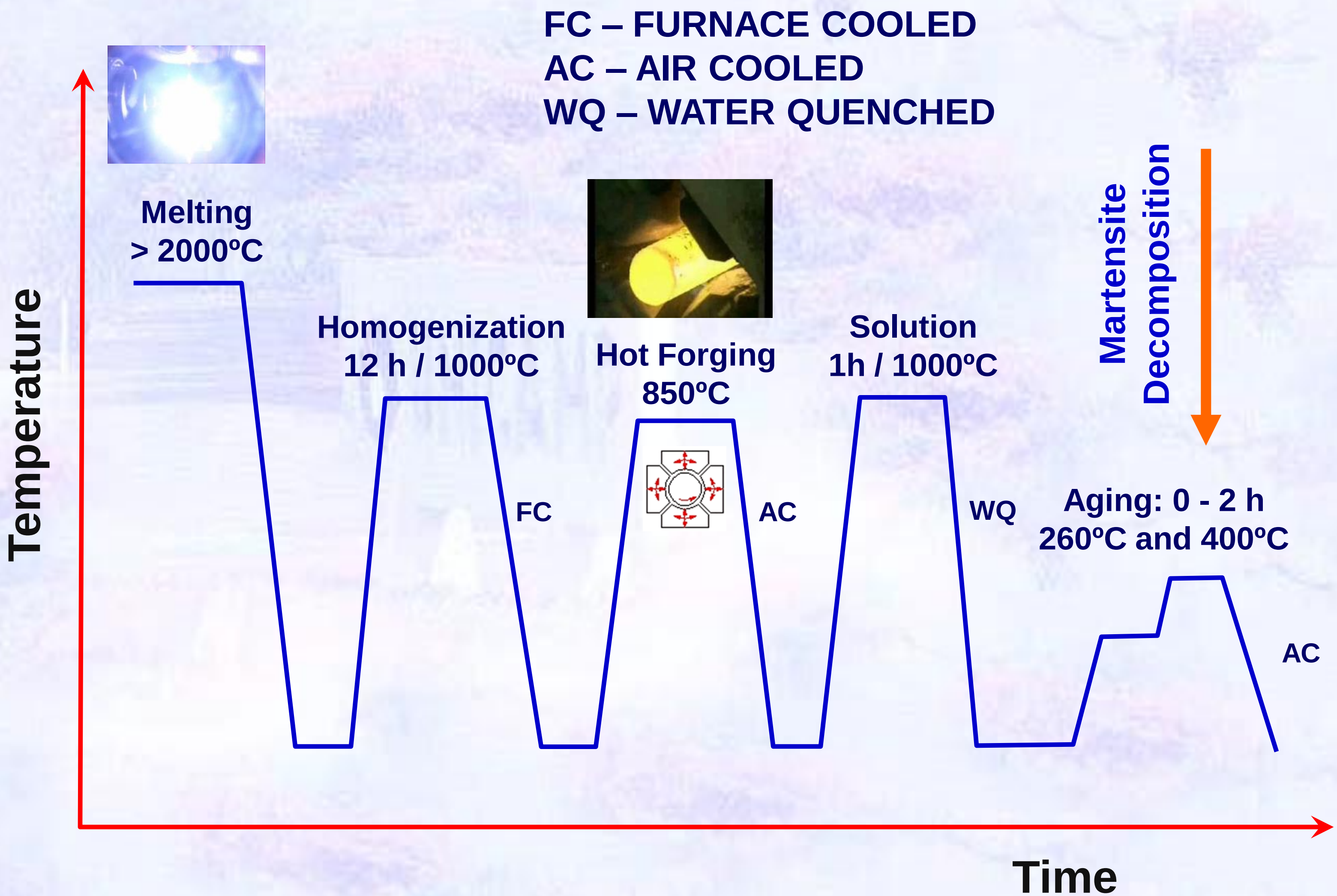
Processing Route

Alloy Compositions: Ti-30Nb and Ti-30Nb-2Sn (wt. %)



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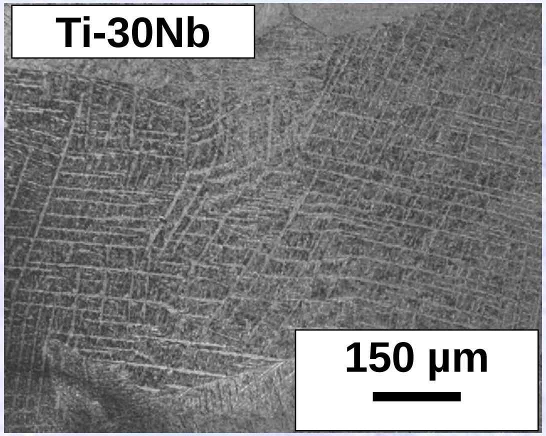
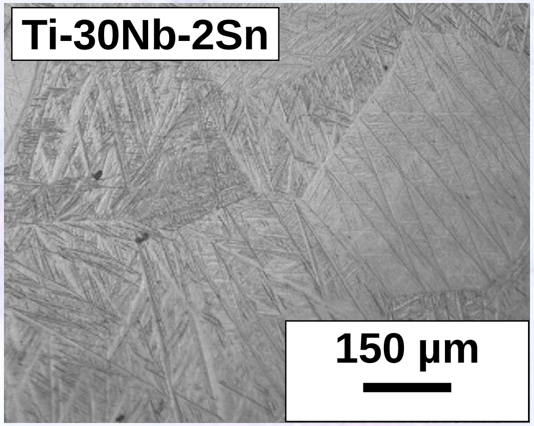
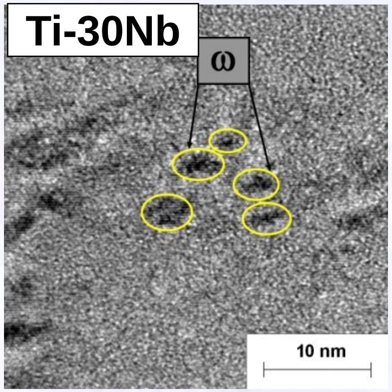
Effect of Sn on α" Amount

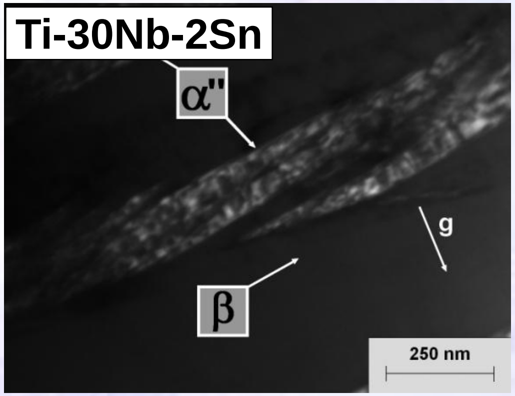
Effect of Sn addition on the amount of martensite
Water Quenched Samples





Microstructure = orthorhombic martensite (α") and β phase.





Small amount of nanometric precipitates of ω in Ti-30Nb.

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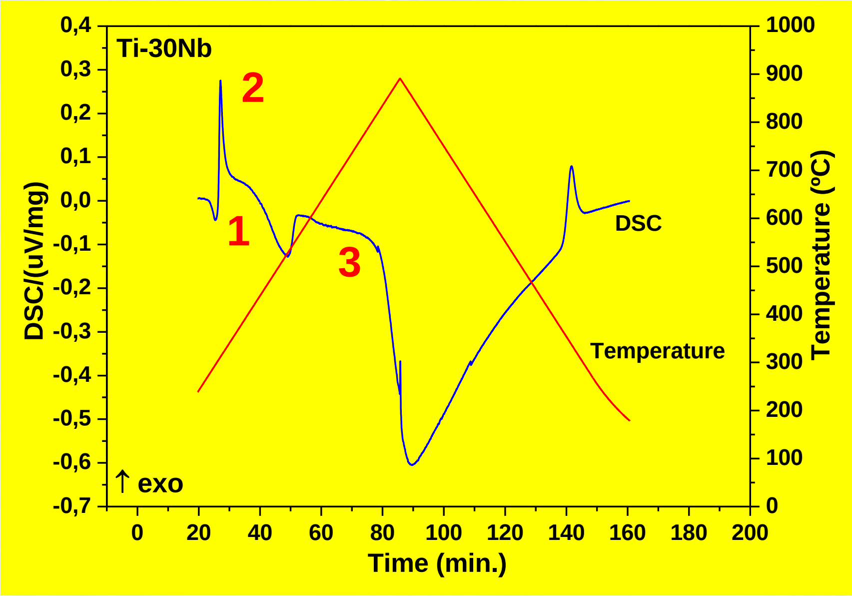
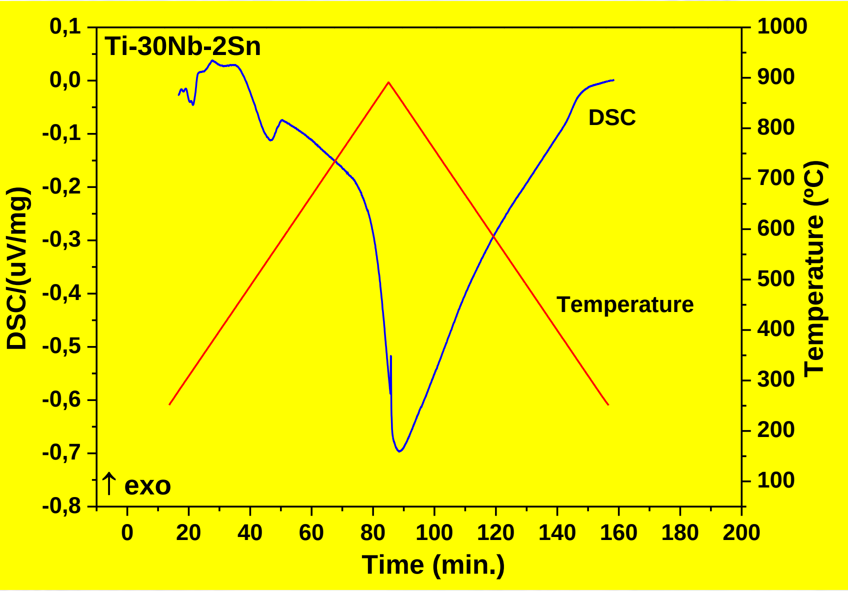
Martensite Decomposition

Thermal Analysis – DSC

- WQ Ti-30Nb and Ti-30Nb-2Sn samples with α" and β phases
- Peak 1: reverse transformation α"→ β
- Precipitation of ω in β matrix (end of peak 1)
- Peak 2: nucleation of α - "ω act as substrates"
- Peak 3: β transus





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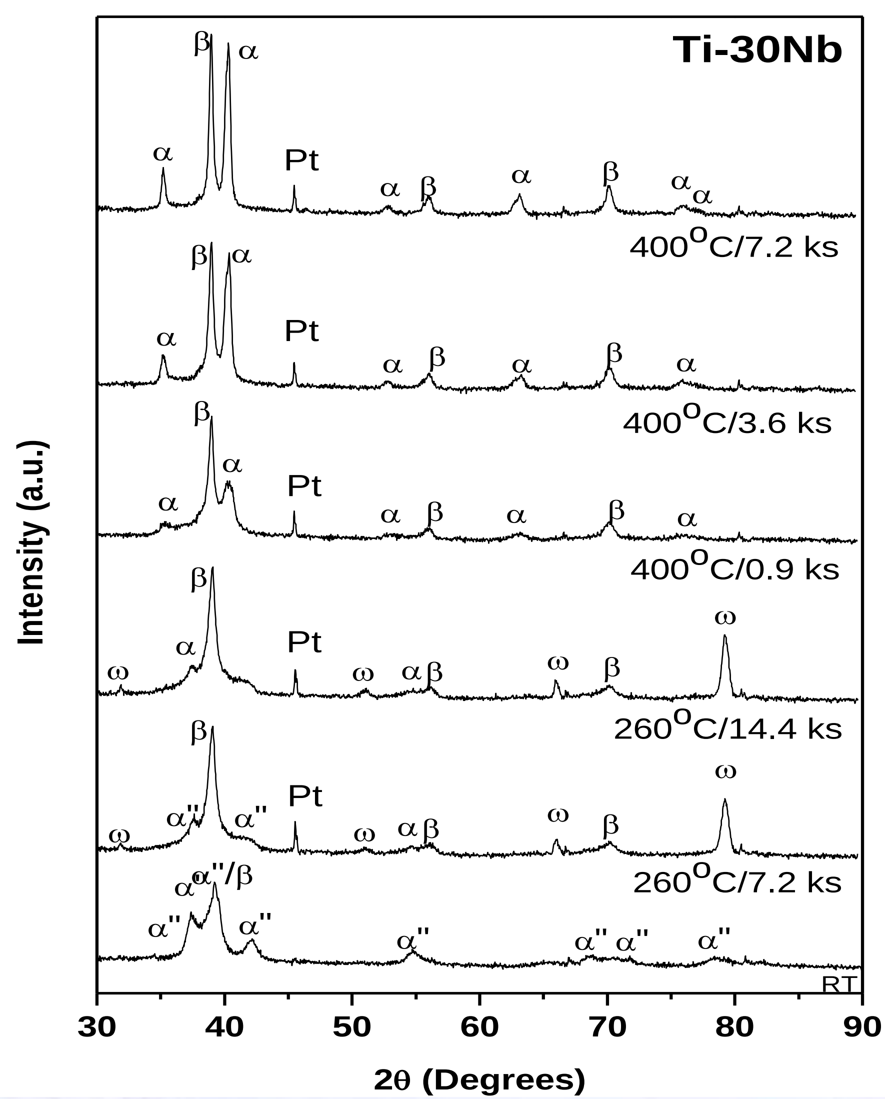
Martensite Decomposition: Ti-30Nb

High Temperature X-Ray Diffraction

- Martensite decomposition occurred with the aging time
- Reverse transformation of α” into β phase also took place
- Precipitation of α and ω phases is visible by high temperature XRD



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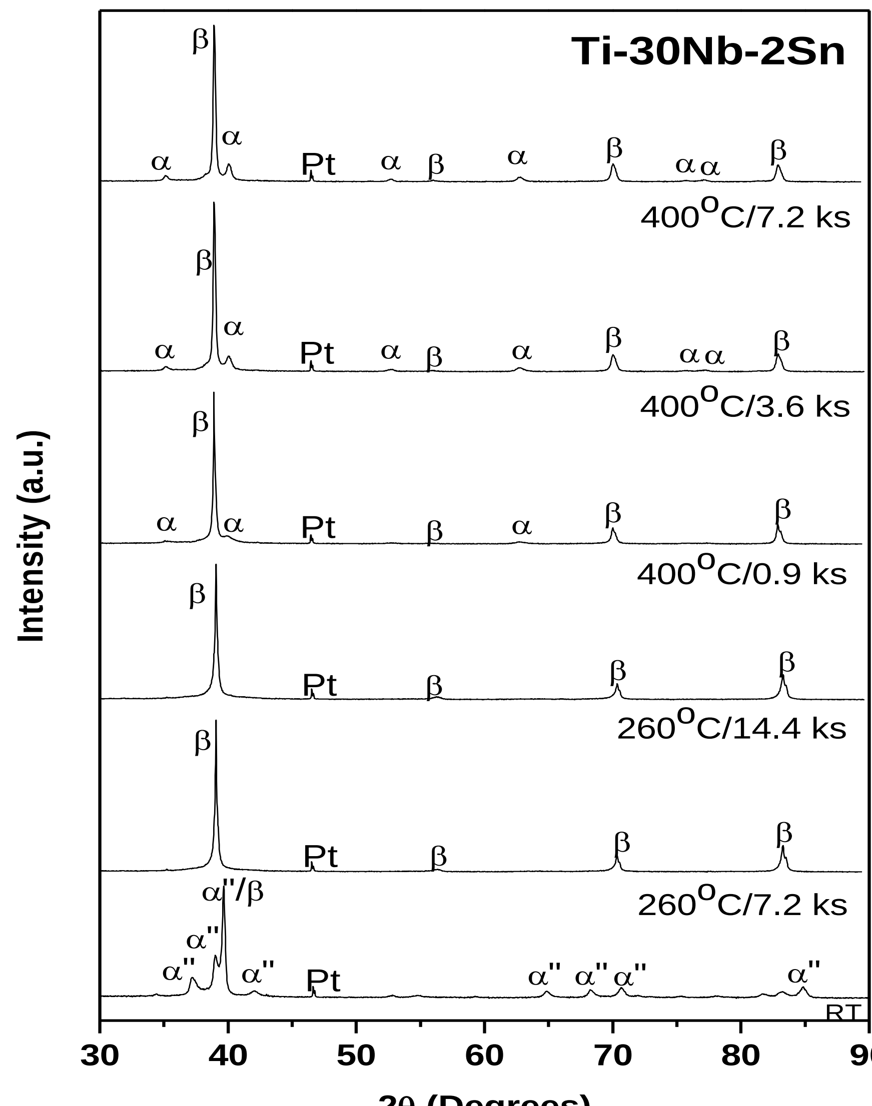
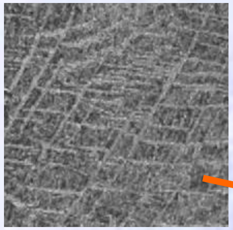
Martensite Decomposition: Ti-30Nb-2Sn

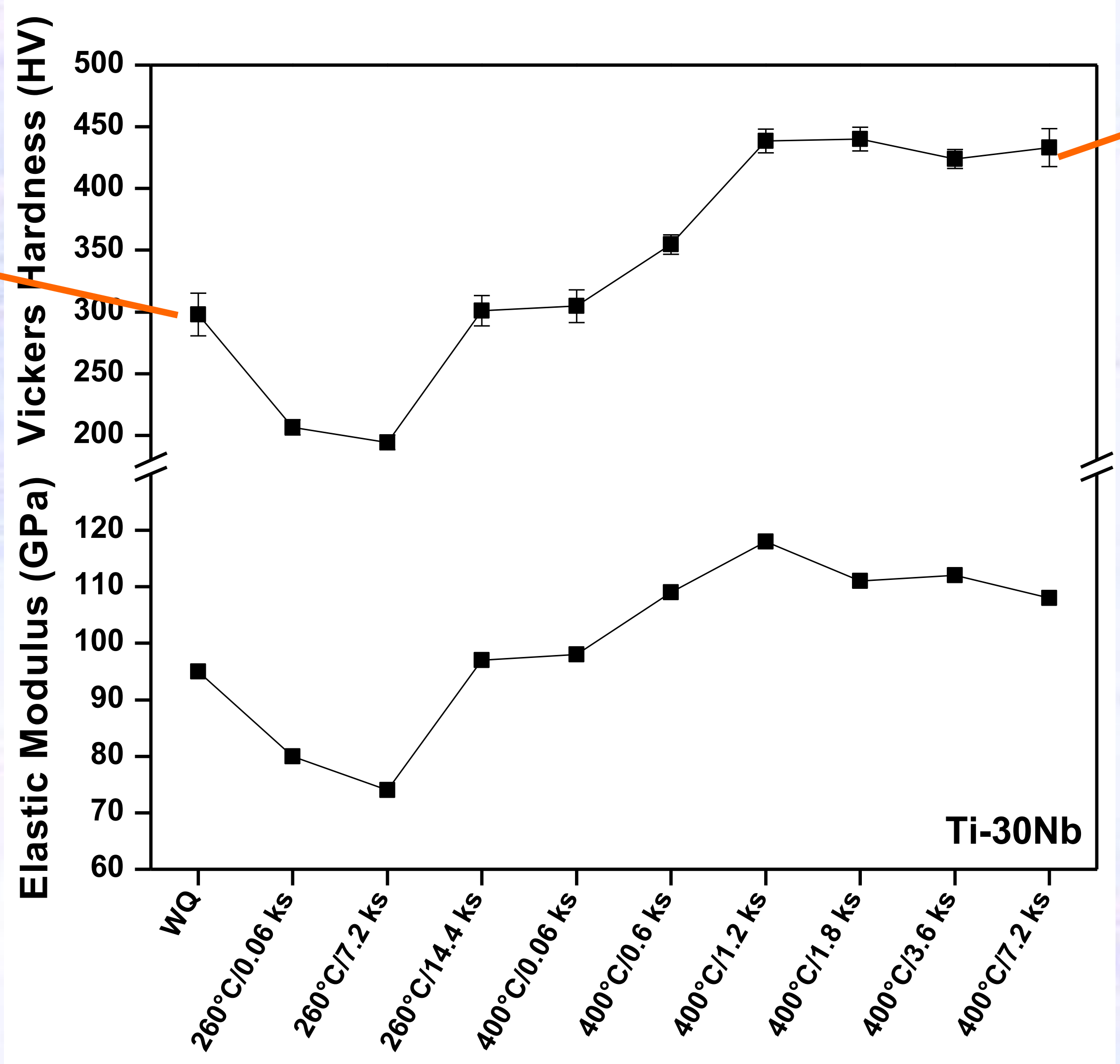
High Temperature X-Ray Diffraction

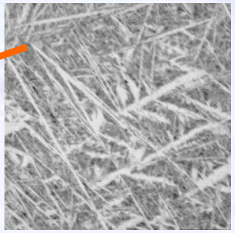
- **Martensite decomposition occurred with the aging time**
- **Reverse transformation of α” into β phase also took place**
- **No precipitation of ω phase is observed by high temperature XRD**



Mechanical Behavior: Ti-30Nb







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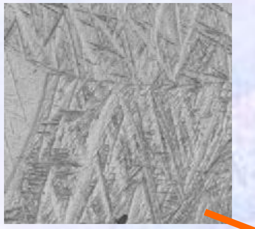
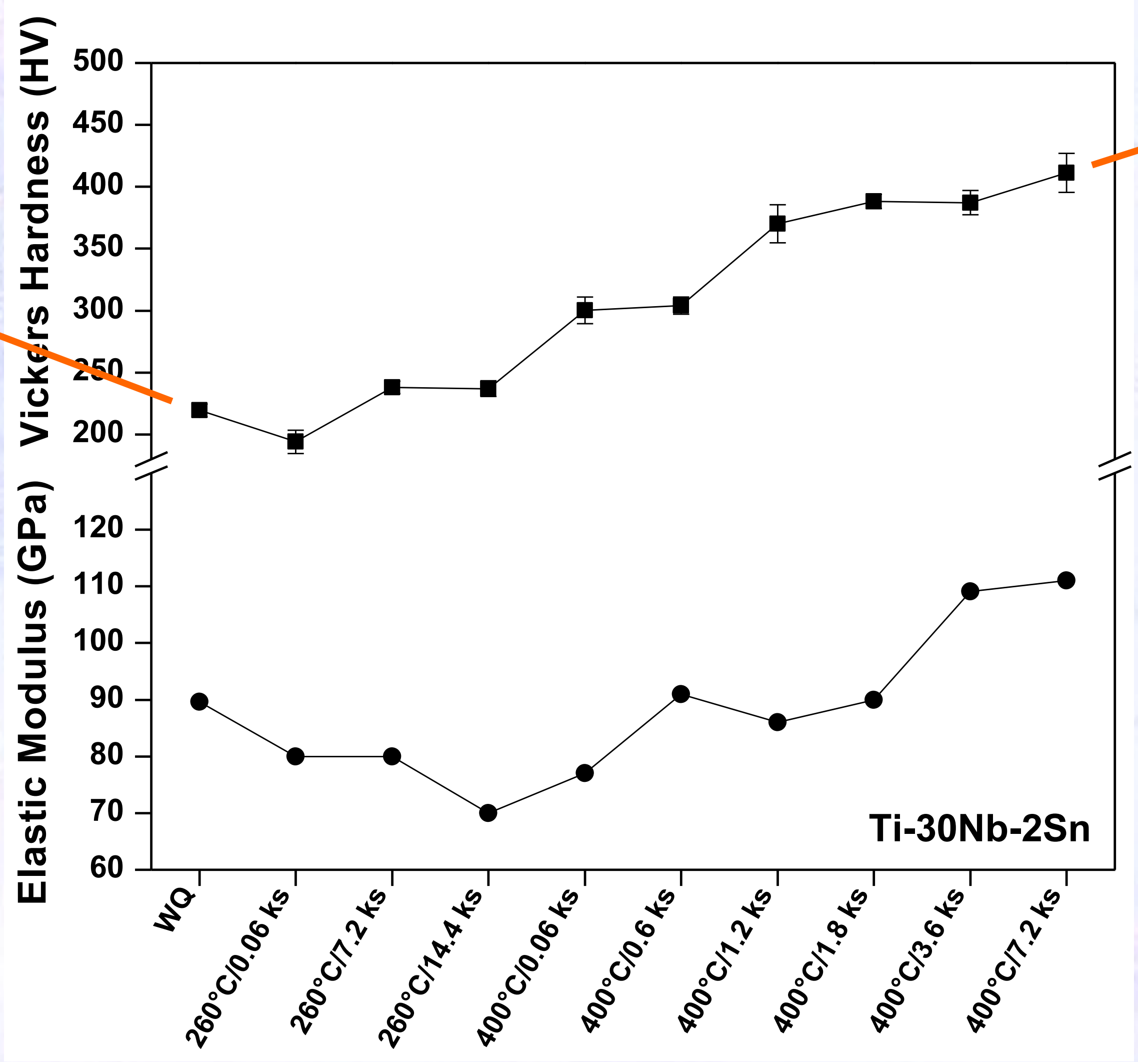
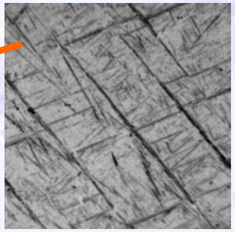
Mechanical Behavior: Ti-30Nb-2Sn







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Tensile Test: Mechanical Properties

Effect of aging on mechanical behavior

Alloy Condition	Phases (XRD)	σ_{UTS} (MPa)	Elong (%)	E (GPa)	Hardness (VH)
Ti-30Nb	$\alpha''+\beta+\omega$	332 ± 21	30 ± 7	74	299 ± 6
Ti-30Nb Aged	$\beta+\alpha+\omega$	826 ± 24	0.8 ± 0.1	105	430 ± 10
Ti-30Nb-2Sn	$\alpha''+\beta$	300 ± 32	36 ± 4.0	67	219 ± 5
Ti-30Nb-2Sn Aged	$\beta+\alpha+\omega$**	800 ± 22	3.0 ± 0.2	85	390 ± 15

ω - very small amount**

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Cold Forging

Cold Forged Femoral Stem using Ti-30Nb-2Sn alloy

Conclusions

- Microstructure of WQ Ti-30Nb and Ti-30Nb-2Sn was formed by β and α'' phase and the amount of α'' decreases with increase of Sn;
- Aging caused α'' decomposition and precipitation of β, ω and α phases;
- Results suggest that Sn may act as a suppressor of ω precipitation, which allows the control of microstructure features and hence, mechanical properties
- WQ Ti-Nb-Sn sample showed yield strength near 300 MPa, which makes easier cold forging process, whose aged sample value increased up to 800 MPa
- Aged Ti-Nb-Sn alloy showed elastic modulus of 85 GPa
- These final values are very suitable in terms of orthopedic biomaterial applications

Questions??