UNIVERSITY OF BIRMINGHAM

Module Name:	**Physical Metallurgy (Titanium and Nickel Alloys)**
Module Code:	**04 21929**
Presenter(s):	**Professor Moataz Attallah, Dr Hector Basoalto**
Credit Rating:	**10**
Venue:	**School of Metallurgy & Materials, University of Birmingham**

Description:

This module looks at the applications of Nickel and Titanium alloys in aero-engines and the land-based gas turbine. The basic operation is first considered: thermodynamics, adiabatic heating in the compressor, efficiency and the need for high temperature resistant materials. For Nickel based alloys temperature resistance and oxidation resistance in Ni and Ni/Cr alloys are described. Other main topics covered are: developing high temperature strength through second-phase particles; slip in the A_3B system, involving disordering/re-ordering; the investment casting process; living with high gas temperatures and lifing issues with creep and fatigue; powder discs and the role of shot-peening. For Titanium alloys - phase diagrams and the main classifications of the alloys; Widmanstatten structures; higher strength alloys, and “burn resistant” alloys; defects in Ti alloys, and ways forward in Ti alloys, will be included. The potential for inter-metallics and MMCs will also be described.

Learning Outcomes:

By the end of the module the student will be able to:

- Define the operation of gas turbines and understand the functional requirements of the materials used for their construction;
- Describe the principles of alloy design for turbine blade and disc applications and critically assess the material strengthening and degradation mechanisms;
- Detail the principles of blade and disc fabrication, process developments for improved performance and integrity. Specify manufacturing processes;
- Perform calculations to determine the life of components made of nickel and titanium alloys.

Syllabus:

Nickel:

- The aero-engine/land-based gas turbine. Basic operation and thermodynamics: adiabatic heating in the compressor, efficiency (simplified Carnot cycle) need for high entry temperature in turbine; hence high-temperature resistant materials. Density considerations.
- Basic metallurgy of nickel-based superalloys.
- Developing high temperature strength through second-phase particles. Structure of gamma prime: alloying additions to control lattice parameter
- Evolution of γ' particles: driving forces, coarsening, calculation of volume fractions and application of heat treatments. .
- Mechanical properties and micromechanisms of nickel-based superalloys. Slip in the A_3B system. Disordering/re-ordering. Demonstration on (001) face of slip in [110] direction. Slip on (111) planes. Precipitation hardening.
- Principles of fatigue and crack growth in nickel-based superalloys.

Nickel-related references

1. "The Super-alloys – Fundamentals and Applications" Roger C Reed, Cambridge University Press, 2008.
2. Nabarro, Physics of creep, CRS Press, 1995
3. C. Sims, N. Stoloff and W.Hagel, Superalloys II: High temperature materials for aerospcae and industrial power, Wiley International (1986)
4. R.J. Mitchell, M.C. Hardy, M. Preuss and S. Tin, *Development of γ′ morphology in P/M rotor disc alloys during heat treatment*, ed. K.A.Green et al, TMS, Superalloys 2004.
5. Rolls-Royce, *Gas turbine technology: Introduction to a jet engine*, (2007)
6. H. B. Callen, *Thermodynamics and an introduction to Thermostatistics*, 2nd Ed, John Wiley and Sons, (1985)
7. Materials Science and Technology 2009, Vol. 25, No.2, pp.127-308 (Malcolm McLean Memorial Symposium) – 18 papers covering a wide range of topics.

Titanium:

- Titanium extractive metallurgy, production and applications.
- Physical Metallurgy of Ti-Alloys: Crystal structure of Ti, Deformation Modes, and Phase Transformations.
- Alloying elements and Alloy Classes: microstructure, processing and applications:
    - CP-α Ti-Alloys
    - Near-α Alloys
    - α+β Alloys
    - Near-β Alloys
    - β Alloys
- Thermomechanical Processing of Ti-Alloys
- Manufacturing process of Ti-Alloys:
    - Machining
    - Casting
    - Welding
    - Netshape manufacturing
- Advances in Titanium Alloys
    - Titanium-Aluminides
    - Shape Memory Alloys
    - Gum Metal and Superelastic Alloys
- Advanced in Extractive Metallurgy and Secondary Processing:
    - Extraction and Melting
    - Casting
    - Welding
    - Machining
    - Laser near net-shape
    - Superplastic Forming
- Applications: Automotive, Aerospace, and Biomedical
- Experimental characterisation of Ti-alloys
    - Quantitative Phase Analysis
    - In-Situ High Temperature Microscopy
    - Residual Stress Characterisation
    - Micro-mechanics
    - In-Situ High Temperature Diffraction
    - Synchrotron X-ray Tomography

Titanium-related references

1. Lutjering G, Williams JC. Titanium. Berlin: Springer-Verlag, 2007. pp. 8-11, 15-42, 79-137, 137-157, 161-167, 203-258, 259-336.
2. Welsch G, Boyer R, Collings EW. Materials Properties Handbook: Titanium Alloys. Ohio: ASM International, 1994.
3. Donachie-Jr MJ. Titanium: A Technical Guide. Metals Park, OH: ASM Inernational, 1998.
4. Leyens C, Peters M, editors. Titanium and Titanium Alloys: Fundamentals and Applications. Weinheim: WILEY-VCH Verlag GmbH & Co, 2003.

Titanium Characterisation
MM Attallah*, S Zabeen, RJ Cernik, and M Preuss: Comparative Determination of the α/β Phase Fraction in Ti-6246 using X-ray Diffraction and Electron Microscopy. Materials Characterization. 2009, vol. 60, no. 11, pp. 1248-1256.

Titanium Friction Welding
J Romero, MM Attallah*, M Preuss, M Karadge, PJ Withers, and SE Bray: Effect of the Forging Pressure on the Microstructure and Residual Stress Development in Ti-6Al-4V Linear Friction Welds. Acta Materialia. 2009, vol. 57, no. 10, pp. 5582–5592.
MM Attallah, M Preuss, C Boonchareon, A Steuwer, JE Daniels, DJ Hughes, C Dungey, GJ Baxter: Microstructural and Residual Stress Development due to Inertia Friction Welding of Ti-6246. Metallurgical and Materials Transactions A, 2012, vol. 43, no. 9, pp. 3149-3161.
Y Guo, Y-L Chiu, MM Attallah, H Li, SE Bray, and P Bowen: Characterization of Dissimilar Linear Friction Welds of α-β Titanium Alloys. Journal of Materials Engineering and Performance, 2012, vol. 21, no. 5, pp. 770-776.

Titanium Additive Manufacture
CL Qiu, N. J. Adkins, and MM Attallah*, Microstructure and Tensile Properties of Selectively Laser-Melted and HIPed Laser-Melted Ti-6Al-4V, Materials Science and Engineering A, In Press, 2013.

Titanium-based Shape Memory Alloys
T Haenschke, CL Davis, MM Attallah*: Influence of the Microstructural Inhomogeneities on the Martensite to Austenite Phase Transformation Temperatures in TiNiCu-based Shape Memory Alloys. Materials Chemistry and Physics, In Press, 2013.

Assessment:

Two hour open book examination and tutorial sheet during course presentation.