OxfordMaterials

Materials Science (MS)
Final Honours School
Core Lecture Course Synopses
2019-20

Department of Materials

Materials Science (MS)

Final Honours School

Core Lecture Course Synopses 2019-2020

General Paper 1: Structure & Transformation of Materials

Surfaces & Interfaces

1. Introduction:

    Why are we interested in interfaces?

    Interfacial free energy: Thermal grooving, triple junctions and wetting.

    Thermodynamic degrees of freedom and excess quantities at interfaces.

2. The Gibbs adsorption equation and interfacial segregation.

    Influence of segregation phenomena on materials properties.

3. The effect of interfacial curvature on equilibrium - the Gibbs-Thomson effect.

    Grain growth, Ostwald ripening.

4. Measurements of surface and interfacial energy.

5. Surfaces and interfaces involving solids.

    Anisotropy of surface and interfacial energy.

    Interfacial coherency and the shape of precipitates.

Background Reading

Reed-Hill, R. E., Abbaschian, R., **Physical Metallurgy Principles**, PWS Publishing
Company, Boston, "Chapter 6. Elements of Grain Boundarys" - Very good on grain
boundaries

Porter, D. A., Easterling, K. E., Sherif, M. Y., **Phase Transformations in Metals and
Alloys**, CRC Press, "Chapter 3. Crystal Interfaces and Microstructure" - Gentle
introductory text

Sutton, A.P., Balluffi, R. W., **Interfaces in Crystalline Materials**, Oxford University Press,
"Part II. Interfacial Thermodyamics" (including Chapters 5-7) - Formal and complete text,
particularly strong on thermodynamics

Top

Zangwill, A., **Physics at Surfaces**, Cambridge University Press, "Part 1.3 Crystal structure" and "Part 2.16 Epitaxy" - For those interested in surface crystallography and epitaxy

Phase Transformations & Diffusion

General principles

- Kinetics vs thermodynamics: role of interface energy.

- Progress of a reaction and the classification of transformations.

Diffusion

- Mechanisms of diffusion: activation energies and fast diffusion paths.

- Fick's 2nd law: specific solutions to time-dependent diffusion problems.

- Diffusion in substitutional alloys: Kirkendall effect.

- Darken's equations and interdiffusion coefficient: Matano analysis.

- Atomic mobilities and chemical potential gradients.

Interfacial structure and mobility

- Facetting, coherency, and the Jackson alpha factor model of S/L interfaces.

- Continuous and step growth mechanisms in S/L interfaces.

- Solid state interface mobility, glissile interfaces.

Nucleation

- Homogeneous and heterogeneous nucleation.

- Nucleation in the solid state: incubation, strain effects, transition phases and coherency loss.

- Widmanstätten precipitation

Rate laws and the Avrami equation

- Interface-controlled vs diffusion-controlled growth.

- Rate laws for different growth geometries and coarsening.

- The Avrami equation and growth exponents for different situations.

Alloy solidification

- Solute distributions, including the Scheil equation.

- Constitutional supercooling and interface stability.

- Macro- and micro-segregation in castings.

Coupled growth mechanisms

- Eutectic/eutectoid and cellular transformations.

'Diffusionless' transformations

- Ordering, recrystallisation, the massive transformation and martensite (basics only).

Required Reading

Porter, D. A., & Easterling, K. E., **Phase Transformations in Metals and Alloys**, especially chapters 2 to 5

Shewmon**, Diffusion in Solids**, The required reading Phase Transformations in Metals and Alloys Chapter 2 to 5 for Diffusion also contains main material for Phase Transformation part of the course.

Background Reading

Reed-Hill & Abbaschian, **Physical Metallurgy Principles**

Cahn, Haasen, **Physical Metallurgy**, chapters 8, 9 and 14

Martin, Doherty, (and Cantor), **The Stability of Microstructure in Metallic Systems**, especially chapters 1, 2 and 4

Woodruff, **The Solid-Liquid Interface**

Smallman R E and Ngan A H W, **Modern Physical Metallurgy**, Elsevier

7

2nd year MS
Prof S. Lozano-Perez
8 lectures

Corrosion & Protection

- Corrosion of metals: simple electrochemical theory, polarisation curves, activation and concentration polarisation; Evans diagrams.
- Passivity, pitting, localised corrosion.
- Common problems: galvanic corrosion, differential aeration, crevice corrosion.
- Corrosion prevention: cathodic protection, anodic protection, inhibitors.
- Paint: modes of protection, inhibitive and metallic pigments.
- Metal coatings: action, methods of application.
- Anodising of aluminium.
- Design and materials selection.

Background Reading

Jones, D. A., **Principles and prevention of corrosion**, Prentice Hall, especially chapters 2 to 4, 6, 7 and 12 to 14

West, J.M., **Basic corrosion and oxidation**, Ellis Horwood

Trethewey, K. R., & Chamberlain, J., **Corrosion for science and engineering**, Longman, mainly chapters 2 to 7 and 14 to 17

Gabe, D. A., **Principles of metal surface treatment and protection**, Pergamon

Ternary Phase Diagrams

1.　Gibbs triangle, isothermal sections, contour maps, vertical sections. Lever rule. Free energy curves.

2.　Three phase reactions. Eutectic. Peritectic. Criterion for determining type of reaction.

3.　Four phase reactions. Ternary eutectic. Quasi-peritectic. Ternary peritectic.

4.　Examples of engineering ternary diagrams.

Background Reading

West, D. R. F., **Ternary equilibrium diagrams**

Prince, A., **Alloy phase equilibria**

Porter, D. A., & Easterling, K. E., **Phase transformations in Metals and Alloys**,

Cottrell, A. H., **An introduction to metallurgy**

Smallman R E and Ngan A H W, **Modern Physical Metallurgy**, Elsevier, Chapter 2

Microstructure of Polymers

The main objectives of this course are to link chemistry and stereochemistry of polymers to their structure and bulk properties such as crystallinity and amorphicity. Model vinyl polymers exemplify these points. Physio-chemical properties such as solubility and melting are linked to formation and phase diagrams of polymer blends.

Molecular structures:

Essential terminology, examples of common synthetic polymers, molecular shape.

Configuration:

Tacticity, head-tail/head-head isomerism, geometric isomerism, copolymerisation.

Conformation:

Torsion angles, trans & gauche conformers, relationship to molecular structure.

Solubility and melting:

Flexibility of polymer molecules, the effect of flexibility on melting point and solubility, the effect of molecular weight on solubility, lattice models for polymer solubility and mixing, polymer blends, upper and lower critical solution temperatures, chemical and mechanical cross-links, hydrogen bonds.

Crystallinity:

Liquid crystallinity, lamellae, chain folding, spherulites, lamellar thickness, isothermal thickening, loss, T_m and T_g, degree of crystallinity, hierarchical structures.

Required Reading

Sperling, L. H., **Introduction to Physical Polymer Science**, Wiley-Interscience

Background Reading

Jones, R. A. L., **Soft Condensed Matter**, Oxford University Press

Powder Processing

Powder Production: Introduction. Advantages; economic aspects; chemical and electrolytic reactions; mechanical attrition; atomisation; heat flow and solidification in atomised powders; powder characteristics and microstructure.

Powder Compaction: Mixing and pressing; sintering and sintering mechanisms; sintering maps; post sinter operations; hot and cold isostatic pressing; injection moulding; designing with powder processed parts.

Powder based bulk products: Porous and non-porous bearings; filters; friction materials; structural parts; hard materials; electric and magnetic components; mechanical properties.

Alternative processes: Spray deposition, additive manufacture and other processes; advantages and disadvantages, future trends.

Background Reading
Thümmler, F., & Oberacker, R., **Introduction to Powder Metallurgy**, Institute of Materials
Jenkins, I., & Wood, J. V., **Powder Metallurgy - An Overview**, Institute of Materials
German, R. M., **Powder Metallurgy Science**, Metal Powder Industries Federation
chapters 3, 4, 6, 7, 8, 9 and 11
Swinkels, F. B. & Ashby, M. F., **A Second Report on Sintering Diagrams**, vol. 29, Acta. Met., p. 259.
http://www.epma.com

General Paper 2: Electronic Properties

Tensor Properties of Materials

1.   Basic principles

- Scalar and vector variables

- Tensor properties

- Crystal symmetry, Neumann's principle

- Transformation of vectors and tensors

- Representation surface, principal axes

2.   Second-rank tensors

- Electrical and thermal and conductivity

- Stress and strain

- Thermal expansion

- Electrical and magnetic susceptibility

- Optical properties of crystals

Required Reading

Nye, J. F., **Physical Properties of Crystals**, Oxford University Press

Lovett, D. R., **Tensor Properties of Crystals**, Adam Hilger, Chapter 1-6. Looks a bit old fashioned but covers everything you will need.

Background Reading

Kelly, Groves, & Kidd, **Crystallography and Crystal Defects**, Wiley, Chapter 1-3 Good introductory chapters with a more contemporary feel.

Wooster, A., **Tensors and Group Theory for the Physical Properties of Crystals**, Clarendon Press

Wooster, W. A., **Experimental Crystal Physics**, Clarendon Press

Kittel, C., **Introduction to Solid State Physics**, Wiley

Gay, P., **Crystal Optics**, Longmans

Guinier, A., **The Structure of Matter**, Arnold

GP2: Electronic Properties   Michaelmas Term

2nd year MS

Prof J.M. Smith

12 lectures

Quantum & Statistical Mechanics

1.   The need for a quantum description of matter.

2.   The postulates of quantum mechanics. The uncertainty principle as the cornerstone of quantum mechanics. Commutation relations.

3.   Schrodinger's equation. Particle in a 1-D box.

4.   Particle approaching an energy barrier, transmission and reflection.

5.   Summary of solutions for harmonic oscillator: relevance to thermal vibrations of matter.

6.   Schrodinger's equation in 3-D. Separation of variables. Particle in a 3-D box.

7.   Summary of quantum mechanical treatment of angular momentum and its relevance to the Periodic Table and directional bonding, relevance to the solutions of the hydrogen atom.

8.   Two particle states: fermions and bosons. The exclusion principle, and its supreme importance for atomic structure, the Periodic Table, and electrons in solids.

9.   Introduction to statistical mechanics. Its relation to thermodynamics, and statistical mechanics as the fundamental theory of macroscopic properties of materials in terms of their atomic constituents. $S = k \ln W$ and application to an ideal gas, $k = R/N$.

10.   Concentration of vacancies in a crystal.

11.   The Boltzmann distribution, the most fundamental of all in statistical mechanics.

12.   The derivation of the entropy in terms of probabilities that states are occupied.

13.   The partition function as the bridge between the microscopic world of quantum states and the macroscopic world of thermodynamics: $F = -kT \ln Z$.

14.   Two-state systems: paramagnetism with $s = \pm \frac{1}{2}$ as a function of temperature in a magnetic field. Two state systems in glasses – specific heat.

15.   Statement of Fermi-Dirac and Bose-Einstein statistics and how and when to use them. Qualitative explanation of their functional forms.

16. Einstein model of specific heat.
17. Free electron theory: particle in a box, k-space, Fermi sphere, Fermi energy, density of states.

Reading:

There is no one book that we will follow closely, so you are encouraged to dip into as many of those below as you can to develop an understanding of the topics. The 'required reading' consists of books that cover most - if not all - of the examinable topics with sufficient structure and detail to 'stand-alone'. 'Background reading' have some good explanations but should be used as 'primers' or 'further reading'.

Required Reading

Griffiths, D., **Introduction to Quantum Mechanics**, Pearson. An excellent book with good explanations and lots of problems to test you understanding!

Gasiorowicz, **Quantum Physics**, Wiley. Chapters 1-5, and bits of Chapters 6, 9-12, and 19). Comprehensive, clear and uncluttered; a very good read but watch out for the non-SI units.

Hayward, D., **Quantum Mechanics for Chemists**, Royal Society of Chemistry Publications, (Whole book, but only skim chapter 8). An excellent 'entry-level' introduction that covers most of the course well. One or two topics (such as 3-D Schrodinger equation) are a bit brief.

Bowley, & Sanchez, **Introductory Statistical Mechanics**, Oxford University Press, (Chapters 1-10). A very comprehensive and readable text book – highly recommended.

Glazer, M., & Wark, J., **Statistical Mechanics: a Survival Guide**, Oxford University Press, (Chapters 1-8). A very readable book that elegantly covers the basics.

Background Reading

Dicke, & Wittke, **Introduction to Quantum Mechanics**, Addison Wesley. Good on the theory (cuts no corners!) but feels quite old fashioned. Lots of textual explanations if you're suffering from algebra overload.

Blinder, S. M., **Introduction to Quantum Mechanics in Chemistry, Materials Science, and Biology**, Elsevier. Some good explanations, but moves quickly and (perhaps surprisingly given the title) doesn't pull any punches with the maths!

15

Feynman, Leighton, & Sands, **Lectures on Physics Vol III**, Addison Wesley. Some great – if non-standard – insights from perhaps the finest physics teacher of the past century.

McMahon, D., **Quantum Mechanics Demystified**, McGraw Hill. This book contains a lot of algebra and so might look daunting, but actually by doing things 'long hand' it is easier than many, and is good for building confidence. Not great for insight though – dives straight in! Recommend used sparingly.

Mandl, **Statistical Physics**, Wiley, (Chapters 1-6, 10). Takes a very 'thermodynamic' approach so may be hard going for some.

Sutton, A. P., **Electronic Structure of Materials**, Oxford University Press

GP2: Electronic Properties   Hilary Term

2nd year MS

Dr C.E. Patrick

8 lectures

Electronic Structure of Materials

1. Introduction: aims of course.
2. Free electron theory: one-, two- and three-dimensional densities of states, Fermi-Dirac distribution, electronic specific heat, electrical and thermal conductivity, Hall effect, thermionic and field emission.
3. Band theory - general principles: periodic lattices and Bloch's theorem, Brillouin zones and reciprocal lattice, Kronig-Penney model and band gaps, Nearly Free Electron (NFE) and Tight Binding (TB) limits.
4. Band Theory - NFE approximation: NFE secular equation, band structure and density of states of simple metals.
5. Band theory - TB approximation: TB secular equation, band structure of *sp*-valent semiconductors and *d*-valent transition metals, direct and indirect band gaps, electrons and holes, effective mass.

Required Reading

Kittel, **Introduction to Solid State Physics**, Wiley, Chapters 6, 7, 8

Ashcroft, & Mermin, **Solid State Physics**, Harcourt, Chapters 9, 10

Background Reading

Tanner, **Introduction to the Physics of Electrons in Solids**, Cambridge Univeristy Press, Chapters 2, 3, 4

Pettifor, **Bonding and Structure of Molecules and Solids**, Oxford University Press Chapters 3, 5, 6, 7

Cox, **The Electronic Structure and Chemistry of Solids**, Oxford University Press Chapter 3

Solymar, & Walsh**, Lectures on the Electrical Properties of Materials**, Oxford University Press, Chapter 6

Sutton, **Electronic Structure of Materials**, Oxford University Press, Chapter 7

Semiconductor Materials

1. Brief review of band diagrams, donor and acceptor levels, defect states.

2. Electron and hole statistics, carrier concentration, temperature dependence, intrinsic and extrinsic materials.

3. Current flow, drift, mobility, conductivity, Hall effect.

4. Excess carriers, diffusion, recombination, lifetime, diffusion length.

5. P-n junctions, band bending, depletion region, I-V characteristics.

6. Metal-semiconductor contacts, Schottky barrier, ohmic contacts.

Background Reading

Solymar, & Walsh, **Electrical Properties of Materials**, Clarendon Press

Sutton, A. P., **Electronic Structure of Materials**, Oxford University Press

Seymour, **Physical Electronics**, Pitman Paperbacks

Sze, S. M., **Physics of Semiconductor Devices**, Wiley

Top

Electrical & Optical Properties of Materials

Part 1. Electrical conductivity of materials with different types of bonding.
Metals, semiconductors and insulators; Ionic crystals: intrinsic & extrinsic vacancy density; energies of formation & activation; self-diffusion; ionic conductivity; superionic conductors; electron hopping conductivity. Superconductivity; metallic and ceramic superconductors.

Part 2. Dielectric Properties
Lorentz field, Clausius-Mossotti relation. Types of polarisation: electronic, ionic, orientation, space- charge. Static permittivities of gases, liquids and solids. Frequency dependent polarisation in non-polar and polar substances. Breakdown mechanisms.

Part 3. Piezo-, pyro- & ferro-electricity
Basics of phenomena. Piezoelectric materials. Ferroelectric phase transitions. Domains, hysteresis.

Part 4. Maxwells equations
Maxwell's equations & electromagnetic waves in 1D. Waves in free space, in insulating & conducting media. Impedance. The skin effect.

Part 5. Optical Properties
Reflection, refraction, absorption and propagation. Lens blooming & dielectric mirrors. Optic fibres. Some topics involving polarised light: liquid crystal displays.

Background Reading
Moulson, & Herbert, **Electroceramics**, Chapman & Hall
Solymar, & Walsh, **Lectures on the Electrical Properties of Materials**, Oxford University Press
Bleaney, & Bleaney, **Electricity & Magnetism**, Oxford University Press

Top

Kittel, **Introduction to Solid State Physics**, Wiley

Rose et al., **Structure & Properties of Materials** Vol.4, Wiley

Magnetic Properties of Materials

Part 1: Introduction to magnetism

Basic definitions. Magnetic moments of atoms.

Part 2: Types of magnetism

Classification of magnetic materials: diamagnetism, paramagnetism (Curie and Pauli), ferromagnetism, anti-ferromagnetism, ferrimagnetism. Theory of paramagnetism and ferromagnetism. Macroscopic properties of ferro- and ferr-magnetic materials, magnetisation curves, hysteresis. Magnetic domains.

Part 3: Measurements and applications of magnetic materials

Methods of measuring magnetic phenomena and observing domains. Soft and hard magnetic materials. Materials for special applications.

Background Reading

Spaldin, N., **Magnetic Materials Fundamentals and Applications**, CUP, 1st or 2nd edition both good

Solymar, & Walsh, **Electrical Properties of Materials**, OUP, Many editions: all good

Blundell, S., **Magnetism in Condensed Matter**, OUP

Kittel, C., **Introduction to Solid State Physics**, Wiley, Many editions: all good

General Paper 3: Mechanical Properties

Elastic Behaviour in Isotropic Materials

- Introduction.

- Stress-equations of equilibrium. Plane stress.

- Transforming stress (and strain) tensors, Mohr's circle revision.

- Strain.

- Hooke's law.

- Plane stress and plane strain problems. Compatibility equations. Airy stress function.

- Cylindrically symmetrical stress distributions and stresses around misfitting fibres. Stresses around holes under tensile forces; stress concentration factors.

- Spherically symmetrical stress distribution and stresses around misfitting spherical particles. Interaction between a dislocation and a particle.

Background Reading

Timoshenko, **Theory of Elasticity**, McGraw-Hill

Cottrell, **The Mechanical Properties of Matter**, Wiley

Sadd, **Elasticity Theory, Application and Numerics**, Elsevier

Top

GP3: Mechanical Properties   Michaelmas Term

2nd year MS

Prof. T.J. Marrow & Dr E.K.R. Tarleton

10 lectures

Microplasticity

1.   Dislocations

Elastic properties of dislocations. Stress field of screw and edge dislocations, strain energy, line tension, the force on a dislocation. Forces between dislocations. Image force. Dislocation sources and multiplication. Plastic strain due to dislocation movement.

Dislocations in f.c.c. materials: Perfect dislocations, Shockley partials and Frank partials and stacking faults. Sessile dislocations and locks.

Dislocations in b.c.c. metals, h.c.p. metals, superlattices, ionic, and covalent materials.

2.   Strengthening mechanisms

Intrinsic strength: bonding type

Solid solution effects: size effect and local modulus changes; interaction with dislocations, Cottrell atmospheres, yield point phenomena.

Precipitate and particle effects: interaction with dislocations, coherent, semi-coherent and incoherent particles, strong and weak obstacles.

Microstructural effects; grain boundaries and phase boundaries, Hall-Petch relation; dislocation pile-up.

Work hardening: interactions between dislocations, recovery mechanisms.

Ideal microstructures for strength.

Required Reading
Hull, D., & Bacon, D. J., **Introduction to Dislocations**, Elsevier, Electronic Resource, http://solo.bodleian.ox.ac.uk/primo-explore/fulldisplay?docid=oxfaleph000851708&context=L&vid=SOLO&search_scope=LSCOP_ALL&tab=local&lang=en_US

Background Reading

Kelly, A., & Groves, G. W., **Crystallography and Crystal Defects**, Wiley

http://solo.bodleian.ox.ac.uk/primo-explore/fulldisplay?docid=oxfaleph017541958&context=L&vid=SOLO&search_scope=LSCOP_ALL&isFrbr=true&tab=local&lang=en_US

A.P. Sutton, **Microplasticity: Lecture notes**, Materials Dept. Library

Martin, J. W., **Worked Examples in Strength of Metals and Alloys**, IoM

http://solo.bodleian.ox.ac.uk/primo-explore/fulldisplay?docid=oxfaleph010583434&context=L&vid=SOLO&search_scope=LSCOP_ALL&tab=local&lang=en_US

Whelan, M.J., **Worked Examples in Dislocations**, IoM

http://solo.bodleian.ox.ac.uk/primo-explore/fulldisplay?docid=oxfaleph010516489&context=L&vid=SOLO&search_scope=LSCOP_ALL&tab=local&lang=en_US

 Cahn, R.W., & Haasen, P., **Physical Metallurgy**, Elsevier, Electronic Resource,

http://solo.bodleian.ox.ac.uk/primo-explore/fulldisplay?docid=oxfaleph000851284&context=L&vid=SOLO&search_scope=LSCOP_ALL&tab=local&lang=en_US

Top

GP3: Mechanical Properties   Hilary Term

2nd year MS

Prof R.I. Todd

4 lectures

Creep

1. **Introduction to Creep**

   Time dependent deformation, creep curves, Andrade's law, regions of creep, importance of creep.

2. **Creep Mechanisms – background material**

   Dorn equation, Orowan equation, stress-directed diffusion.

3. **Creep by Movement of Lattice Dislocations**

   Harper-Dorn creep, power-law creep: work hardening versus recovery, Bailey-Orowan equation, pipe diffusion, power law breakdown.

4. **Diffusion Creep**

   Herring-Nabarro, Coble creep. Grain boundary sliding.

5. **Superplasticity**

   Micrograin superplasticity, superplastic forming in practice, SPF-DB.

6. **Deformation Mechanism Maps**

   Constant grain size, constant temperature.

7. **Creep Failure**

   Cavity nucleation, diffusional growth, plastic growth.

   Creep life prediction: Monkman-Grant, Larson-Miller parameter. Optimisation of creep life.

Background Reading

Nabarro, & de Villiers, **The Physics of Creep**

Evans, & Wilshire, **Introduction to Creep**

Frost, Ashby, **Deformation Mechanism Maps**

Evans & Wilshire, **Creep of Metals and Alloys**

Evans, **Mechanisms of creep fracture**

Poirier, **Creep of Crystals**

Cahn, & Haasen, eds., **Physical Metallurgy**, Chapters: 20 Creep and superplasticity, 21 Solid solutions (parts), 22 Multi phase alloys (parts)

Gittus, **Creep**

Gittus, **Cavities and Cracks in Creep and Fatigue**

Kassner, & Pérez-Prado, **Fundamentals of Creep in Metals and Alloys**

Dieter, **Mechanical Metallurgy**

Macroplasticity & Mechanical Working Processes

- **Macroplasticity**
  - Stress and Strain
  - Yield Criteria
  - Plastic Instability
  - Torsion
- **Metal working process**
  - Forging
  - Rolling
  - Extrusion
  - Wire-drawing
  - Thin sheet
- **Finite-element analysis** (largely non-examinable)
- **Effects on microstructure**

Background Reading

Dieter, G. E., **Mechanical Metallurgy**, McGraw-Hill

Hosford, W. E., & Caddell, R. M**, Metal forming: mechanics and metallurgy**, Cambridge Univeristy Press

Edwards, L., & Endean, M., **Manufacturing with Materials**, Butterworths

Top

Fracture

1. **Background.** Ideal strengths of materials in tension; real strengths of materials; brittle fracture.
2. **Griffith relation.** Generalising Griffith. Mechanical energy release rate, *G.*
3. **Linear Elastic Fracture mechanics.** LEFM, *K, Kc*, toughness measurement in brittle materials; non-elastic behaviour at the crack tip.
4. **Crack tip plasticity.** Irwin model for plastic zone; plane strain toughness testing, crack opening displacement (COD).
5. **Initiation of Fracture.** Surface damage; ductile-brittle transition (DBT); influence of particle dispersions, intergranular fracture.
6. **Ductile fracture.** Nucleation, growth and coalescence of cavities. Effects of particles.
7. **Fatigue failure;** Definitions; mechanical and microstructural characteristics, S-N curves; fatigue limit and endurance limit; high and low cycle fatigue, Basquin, Coffin-Manson, Goodman and Miner descriptions of fatigue life.
8. **Stages of fatigue;** crack initiation; crack growth; stress intensity factor range and the Paris law; use in life predictions; threshold stress intensity factor range; effect of environment and metallurgical variables on fatigue life; treatments to improve fatigue life.

Background Reading

Dieter, G. E., **Mechanical Metallurgy**, especially Chapters 7 onwards

Hertzberg, R. W., **Deformation and Fracture Mechanics of Engineering Materials**, Wiley

Ewalds, H. L., & Wanhill, R. J. H., **Fracture Mechanics**, Arnold

Knott, J. F., **Fundamentals of Fracture Mechanics**, Butterworths, especially Chapter 7

Knott, J. F., & Withey, P., **Fracture Mechanics – Worked Examples**, Institute of Materials

Lawn, B., **Fracture of Brittle Solids**, Lawn and Wilshaw, especially Chapters 1 and 2

Lawn, B., **Fracture of Brittle Solids**, Cambridge Univeristy Press, especially Chapters 1 and 2

Green, D.J., **An Introduction to the Mechanical Properties of Ceramics**, Cambridge Univeristy Press, especially Chapter 8

Honeycombe, R. W. K., **The Plastic Deformation of Metals**, Arnold, especially Chapters 7 and 13-15

Martin, J. W., **Micromechanisms in Particle-Hardened Alloys**, Cambridge Univeristy Press, especially Chapter 3

Suresh, S., **Fatigue of Materials**, Cambridge University Press

GP3: Mechanical Properties   Hilary Term

2nd year MS

Prof H.E. Assender

4 Lectures

Mechanical Properties of Polymers

Introduction to polymer deformation. Plastic deformation. Glassy behaviour. Rubbery behaviour.

Introduction to rubber elasticity. Entropic effects. Applications of rubbers.

Linear viscoelasticity. Creep. Stress relaxation. Spring and dashpot models. The standard linear solid. Time-temperature superposition.

Plastic deformation of thermoplastics. Yielding in polymers.

Temperature. Dependence of viscoelasticity and yielding on temperature. The ductile-brittle transition. Yield and necking.

Fracture. Fracture toughness in polymers. Crazing and rubber toughening.

Comparison of mechanical properties of metals and polymers.

Required Reading

McCrum, N. G., Buckley, C. P., & Bucknall, C. B., **Principles of Polymer Engineering**, Oxford University Press, Chapters 3, 4 & 5

Ward, I. M., & Sweeney, J., **An Introduction to the Mechanical Properties of Solid Polymers**, Wiley, Chapters 3, 4, 6, 9, 11, 12

Background Reading

Sperling, L. H., **Introduction to Physical Polymer Science**, Wiley, Chapters 8, 9, 10 & 11

Billmeyer, F. W., **Textbook of Polymer Science**, Wiley, Chapter 11

Kumar, A., & Gupta, R. K., **Fundamentals of Polymer Engineering**, CRC Press Chapter 10 & 12

Mechanical Properties of Composites

Stiffening due to fibres:

- rule of mixtures (Voigt and Reuss averages) – revision.
- elastic shear lag model for short fibres (results only, not full derivation), stress transfer length, efficiency factor.

Elastic behaviour of composite sheets:

- orthotropic plates, reduced compliance tensor, stress & strain transforms.
- off axis properties, compliance transforms.

Strength of composites:

- longitudinal, transverse & shear strength of long fibre composites.
- longitudinal strength of short fibre composites.

Fracture of composites:

- toughening mechanisms.
- work of fracture for fibre pull-out.

Background Reading

Polymers and Composites 1st year lecture notes

Mechanics of Composite Materials MATTER project, interactive CD, available on Materials Teaching Labs Network

Hull, D., & Clyne, T. W., **Introduction to Composite Materials**, Cambridge University Press

Derby, B., Hills, D. A., & Ruiz, C., **Materials for Engineering**, Longman, Chapter 8

Matthews, F. L., & Rawlings, R.R., **Composite Materials: Engineering and Science**, Chapman & Hall

Harris, B., **Engineering Composite Materials**, Institute of Materials

General Paper 4: Engineering Applications of Materials

GP4: Engineering Applications of Materials   Michaelmas Term
2nd year MS
Dr N.P. Young
8 lectures

Microstructural Characterisation of Materials

- The course covers practical techniques for the characterisation of the microstructures of materials, concentrating on various methods of microscopy.

- Introduction – what are microstructures? Modes of magnification. Field ion microscopy and the atom probe.

- Components of the conventional microscope. Optical microscopes and TEMs. Factors limiting resolution in optical and electron microscopy.

- Some special topics in optical microscopy: Polarised light, Phase contrast, Interference microscopy.

- Diffraction in the transmission electron microscope. Selected area diffraction patterns.

- Imaging in the transmission electron microscope. Contrast mechanisms. Diffraction contrast to image defects.

- Scanning electron microscopy. Performance and resolution in secondary electron and backscattered electron modes.

- Scanning transmission electron microscopy: annular dark-field imaging and electron energy-loss spectroscopy.

- X-ray microanalysis in the electron microscope. Energy-dispersive and wavelength-dispersive spectrometry.

- Scanning tunnelling microscopy and atomic force microscopy.

Background Reading

Gifkins, R.C., **Optical Microscopy of Metals**, Pitman Paperbacks, See section 32 of Materials departmental library

Modin, H., & Modin, S., **Metallurgical Microscopy**, Butterworths

Longhurst, R.S., **Geometrical & Physical Optics**, Longmans

Francon, M., **Progress in Microscopy**, Pergamon

Tolansky, S., **An Introduction to Interferometry**, Longmans

Williams, D .B. & Carter, C.B., **Transmission Electron Microscopy**, Plenum Press

Goodhew, P.J., & Humphreys, F.J., **Electron Microscopy and Analysis**, Taylor & Francis

Kay, D.H., ed., **Techniques for Electron Microscopy**, Blackwell

Thomas, G., & Goringe, M. J., **Transmission Electron Microscopy of Materials**, Wiley

Thornton, P.R., **Scanning Electron Microscopy**, Chapman & Hall

Andrews, K. W., **Interpretation of Electron Diffraction Patterns**, Adam Hilger

Edington, J. W., **Practical Electron Microscopy in Materials Science**, MacMillan

Bonnell, D.A., **Scanning Tunneling Microscopy**, VCH

Williams, D.B., et al., **Images of Materials**, Oxford University Press

Semiconductor Devices

1. Diode Devices: Rectifiers, varactors, fast switching, tunnel diode.
2. Bipolar Transistors: Operation (including amplification and switching), graded base devices, heterojunction bipolar transistors.
3. Field Effect Transistors: MOSFETs, MESFETs, HEMTs.
4. Microwave Devices: Transferred electron oscillators.
5. Optical devices: Photodetectors, solar cells, light emitting diodes, lasers, electrooptic modulators, fibre optics.

Background Reading

Streetman, B.G., **Solid State Electronic Devices**, Prentice Hall. How the devices work

Yang, E.S., **Fundamentals of Semiconductor Devices**, McGraw-Hill. How the devices work

Sze, S. M., **Physics of Semiconductor Devices**, Wiley. How the devices work

Grovenor, C. R. M., **Microelectronic Materials**, Adam Hilger. How the devices are processed

Sze, S. M., **VLSI Technology**, McGraw-Hill. How the devices are processed

Engineering Alloys

Intrinsic and secondary properties: basic engineering alloy requirements and the factors controlling hardness, strength, plasticity, etc.

The metals: their structure, properties, abundance and cost.

Steel making: Basic oxygen furnace, electric arc furnace, secondary steel-making, continuous casting, control of C, Si, Mn, P and S.

Plain carbon steels: Fe-C phase diagram; ferrite-pearlite steels; heat treatment, microstructure, properties, use; isothermal and continuous cooling transformations; martensitic and bainitic steels.

Alloy steels: alloy effects; transformation kinetics and mechanisms and use; tool, maraging and other special steels.

Stainless steels: classes, microstructures, properties and use;

Cast irons: types, effect of casting parameters, properties and use.

Aluminium alloys: cast and wrought alloys; precipitation hardening; non-heat treatable alloys; uses and limitations; aerospace alloys; composites.

Titanium alloys: α and β alloys; alloy additions; heat treatment, microstructure, properties and use; composites.

Nickel alloys: cast alloys and wrought alloys; alloying effects; directional solidification and single crystal alloys; microstructure, properties and use; thermal barrier coatings.

Magnesium alloys: alloys; microstructure; properties and use.

Background Reading

Reed-Hill, R.E., & Abbaschian, R., **Physical Metallurgy Principles**, Chapters 18-20

Higgins, R.A., **Engineering Metallurgy**, Chapters 7, and 11 -18

Llewellyn, D. T., Steels, **Metallurgy and Applications**, Chapters 2, 3 & 4

Honeycombe, R. W. K., & Bhadeshia, H. K. D. H., Steels, **Microstructure and Properties**, Chapters 3-6

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Polmear, I.J., **Light Alloys**, Chapters 2, 3, 5 & 6

Reed, R.C., **The Superalloys: Fundamentals and Applications**, Chapters 2, 3 & 4

Leyens, C., & Peters, M., eds., **Titanium and Titanium alloys: Fundamentals and Applications**, Chapters 1, 2, 8, 10 & 11

Kainer, K.U., ed., **Magnesium: Alloys and Technology**, Chapters 1, 2, 5 & 7

Ghosh, A., **Secondary Steelmaking: Principles and Applications**, Chapters 1, 5, 6 & 7

Top

GP4: Engineering Applications of Materials   Trinity Term

2nd year MS

Prof J.T. Czernuszka

8 lectures

Ceramics & Glasses

1. Definitions: Ceramics, glasses and cements. Typical properties and applications.

2. Lattice defects: aliovalent and isovalent substitutions. Balanced and unbalanced Frenkel and Schottky defects.

3. Engineering ceramics: Methods of manufacture. Powder production, compaction and sintering; residual porosity; liquid phase sintering, hot-pressing, *in situ* methods. Properties and examples.

4. Traditional ceramics: whiteware, clay products, refractories. Properties and examples.

5. Glasses: Definitions, compositions; devitrification, glass-ceramics.

6. Room temperature formation. Cements and concrete: Portland cement, composition, manufacture, additives and hydration; macro-defect free cement.

7. Partially stabilised zirconias – the 'ceramic steel'.

Background Reading

Kingery, W. I., Bowen, H. K., & Uhlmann, D. R, **Introduction to Ceramics**, Wiley

Davidge, R. W., **Mechanical Behaviour of Ceramics**, Cambridge University Press

Richerson, D. W., **Modern Ceramic Engineering**, Dekker

McMillan, P. W., **Glass Ceramics**, Academic Press

Lawn, B. R., **Fracture of Brittle Solids**, Cambridge University Press

Taylor, H. F.W., **Cement Chemistry**, Academic Press

Bye, G. C., **Portland Cement, Composition, Production and Properties**, Pergamon

Doremus, R. H., **Glass Science**, Wiley

Mann, E. S., Webb, J., & Williams R. J. P**., Biomineralization**, VCH

Engineering Applications of Polymers

General Application of Polymer Materials. Advantages and disadvantages of polymeric materials. Range of properties. Materials selection. Biodegradability and recyclability. Polymers and the environment.

Processing routes. Control of anisotropy. Melt vs. solution processing. Major processing routes: extrusion, injection moulding, vacuum forming, spin coating, printing, colloids.

Extreme anisotropy: Fibres**.** Melt spinning. Extended chain crystals. Extensional flow. Gel drawing. Colloids. Spin coating.

Additives.

Electrical conductivity in polymers. Polymers as insulators. Composite conductivity. Ionic conductivity. The conjugated chain. Conduction mechanisms. Applications.

Other conjugated polymer systems. NLO behaviour.

Required Reading

McCrum, N. G., Buckley, C. P., & Bucknall, C. B., **Principles of Polymer Engineering**, Oxford University Press   Chapters 7 & 8
Geoghegan, M., & Hadziioannou, G., **Polymer Electronics**, Oxford University Press Chapters 2, 5, 8, 10

Top

Background Reading

Sperling, L. H., **Introduction to Physical Polymer Science**, Wiley, Sections 4.4 & 14.7-8

Ashby, M. F., **Materials Selection in Mechanical Design**, Butterworth-Heinemann

Billmeyer, F. W., Textbook of Polymer Science, Wiley, Chapter 17

Chilton, J. A., & Goosey, M. T., eds., **Special Polymers for Electronics and Optoelectronics**, Chapman & Hall

Margolis, J. M., **Conductive Polymers and Plastics**, Chapman & Hall

Cowie, J .M .G. and Arrighi, V., **Polymers: Chemistry and Physics of Modern Materials**, CRC Press, Chapter 16

Salaneck, W.R., Strafstrom, S. & Bredas, J.-L., **Conjugated polymer surfaces and interfaces: electronic and chemical structure of interfaces for polymer light emitting devices**, Cambridge University Press

Kumar, A., & Gupta, R. K., **Fundamentals of Polymer Engineering**, Marcel Dekker Chapter 15

Other Lectures

2nd year MS

Prof S.C. Benjamin

8 lectures

Maths - Partial Differential Equations & Fourier Series

Fourier Series

1. Background revision on the nature of periodic functions.
2. Introducing the notion of composing a general period function from a sum of elementary functions; Fourier's theorem.
3. Special cases of Fourier series; examples including the square and triangular waves.
4. Exploring Fourier Series with MATLAB.
5. Fourier series for functions with periods other than 2π. Integration and differentiation of Fourier series.
6. Approximating periodic functions by finite sums of trigonometric functions.
7. Complex form of Fourier series.

Introduction to the Fourier Transform

8. Fourier transforms as a generalisation of Fourier series.
9. Applications of Fourier transforms, and exploration with MATLAB.

Partial differential equations

10. Revision of core concepts for differential equations.
    ### Diffusion equation
11. Derivation of the diffusion equation.
12. Solution of the diffusion equation for
     - Simplified initial condition (sinusoidal distribution of density)
     - Realising initial conditions (block-like initial distribution)

     The latter introducing the notion of *separation of variables*.
13. Introduction to the problem of a semi-infinite volume;

     derivation of the complimentary error function by similarity transformation.
    ### Wave equation for a taut string
43

14. Derivation of the wave equation; static and travelling waves.

15. Analysing the frequency composition of a plucked string.

Background Reading

Bolton, W., **Fourier Series**. A gentle introduction to Fourier series. There is a copy in the RSL, and St Edmund Hall has one in its library. This book doesn't cover all the topics in the lecture course, however.

Brown, J., & Churchill, R., **Fourier Series and Boundary Value Problems**, comprehensive book. We'll mainly be concerned with the material in the first four chapters.

Kreyszig, E., **Advanced Engineering Mathematics**, Wiley, Chapters 10 and 11 cover Fourier series and PDEs

Mathematical Methods for Physics and Engineering, RHB Chapter 10 covers Fourier Series, and chapters 16 and 17 cover PDEs

www.mathworks.com. There are also excellent resources online, both for Fourier series / transformation, and for PDEs. Tutorials in MATLAB can also be found, on the www.mathworks.com site and elsewhere