Materials engineering syllabus

Materials engineering examinations

Group A - Examinations (six of seven required)

21-Mat-A1 Thermodynamics

Phase relationships and phase rule. First, second and third laws of thermodynamics, enthalpy and heat balances, entropy, free energy, and chemical equilibrium. Solution chemistry and solution models, chemical potential, relationships between phase diagrams and thermodynamic properties. Thermochemical analyses of materials processes.

Textbooks (most recent edition is recommended):

- D.R. Gaskell: Introduction to Metallurgical Thermodynamics, CRC Press
- R. De Hoff: Thermodynamics in Materials Science, CRC Press

21-Mat-A2 Materials Transport Phenomena

Transport equations for momentum, heat and mass transfer. Understanding of transport phenomena in materials processes, e.g., transfer in casting processes, fluid flow in piping networks, mass diffusion in doping of semiconductors. Boundary conditions describing process/transport phenomena. Interphase transport: gas-solid, gas-liquid, liquid-liquid, and liquid-solid applied to materials systems. Materials processing operations: mixed flow, plug flow, residence time. Radiation heat transfer: black and grey body, emissivity and view factors. Development of relevant mathematical models.

Textbooks (most recent edition is recommended):

- D.R. Gaskell: An Introduction to Transport Phenomena in Materials Engineering, Prentice-Hall

Supplementary:

- A. Powell IV: Transport Phenomena in Materials Engineering, MIT Open Courseware. http://ocw.mit.edu/courses/materials-science-and-engineering/3-185-transportphenomena-inmaterials-engineering-fall-2003/

21-Mat-A3 Structure and Characterization of Materials

Characteristics of crystal structures for steel and metallic, ceramic, and polymeric structures. Uses and limitations of elemental analysis (i.e., EDS, XPS, XRD) and standard materials characterization techniques, i.e., optical and electron microscopy (SEM) and thermal analysis (i.e., DTA, DSC, TGA) to determine or analyze crystal structure, microstructure, and surface morphology.

Textbooks (most recent edition is recommended):

- D.D. Brandon and W.D. Kaplan: Microstructural Characterization of Materials, Wiley
- Y. Leng: Materials Characterization: Introduction to Microscopic and Spectroscopic Techniques, Wiley-VCH
- ASM Handbook Committee: Metals Handbook, Volume 10: Materials Characterization, ASM International
- J.F. Shackelford: Introduction to Materials Science for Engineers, MacMillan Publishing Company

21-Mat-A4 Deformation Behaviour and Properties of Materials

Elastic and plastic deformation. Strengthening mechanisms in materials including dislocation interactions, slip and twinning in crystalline solids, polymer crosslinking and degree of crystallinity. Fracture mechanisms.

Introductory fracture mechanics. High temperature (creep) deformation. Cyclic stresses and fatigue crack propagation. Thermal properties. Electronic properties.

Textbooks (most recent edition is recommended):

- T.H. Courtney: Mechanical Behaviour of Materials, Waveland Press
- G. Dieter: Mechanical Metallurgy, McGraw-Hill
- W.D. Callister and D.G. Rethwisch: Materials Science and Engineering: An Introduction, Wiley
- R.W. Hertzberg: Deformation and Fracture Mechanics of Engineering Materials, John Wiley & Sons

21-Mat-A5 Phase Transformations and Thermal Treatment

Binary phase diagrams. Annealing and heat treatment techniques for stress relief, recovery, recrystallization, grain growth, and precipitation hardening. Crystallization kinetics, diffusion, and nucleation and growth phenomena in metals. Amorphous materials, glass transition temperature, Tg. Time-temperature-transformation (TTT) diagrams.

Textbooks (most recent edition is recommended):

- M.Y.A. Sherif, D.A. Porter and K.E. Easterling: Phase Transformations in Metals and Alloys, CRC Press
- W.D. Callister and D.G. Rethwisch: Materials Science and Engineering: An Introduction, Wiley

21-Mat-A6 Materials Selection and Design for Materials Processing

The process of materials selection for different design criteria and constraints. The importance of shape and processing variables. Use of materials indices and materials selection charts. Sustainable materials selection and design. Materials life cycle assessment, including end-of-life potential.

Textbooks (most recent edition is recommended):

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

21-Mat-A7 Environmental Degradation of Materials

Fundamental aspects of environmental degradation of metals (corrosion), ceramics, and polymers, with an emphasis on aqueous environments. Topics include: Basic corrosion theory. Electrochemical corrosion theory. Stress assisted corrosion. Protective coatings. Corrosion inhibitors. Cathodic and anodic protection.

Textbooks (most recent edition is recommended):

- M. Kutz: Handbook of Environmental Degradation of Materials, Elsevier
- W.D. Callister and D.G. Rethwisch: Materials Science and Engineering: An Introduction, Wiley
- S.A. Bradford: Corrosion Control, CASTI
- R.W. Revie and H.H. Uhlig: Corrosion and Corrosion Control: An Introduction to Corrosion Science and Engineering, Wiley

Group B - Optional examinations (four required)

21-Mat-B1 Hydrometallurgy and Electrometallurgy

Unit processes of hydrometallurgy: acid, alkaline and pressure leaching. Thermodynamic and kinetic aspects. Pourbaix diagrams. Purification of leach liquors by ion exchange, solvent extraction and selective precipitation operations. Solid-liquid separation techniques. Principles of electrometallurgy. Recovery of metal values by cementation, electrowinning and refining from aqueous solutions. Electrolyte preparation, cell potential, effect of additives. Hydrogen precipitation methods. Application of processes for the recovery of copper, nickel, zinc, cobalt, gold and uranium.

Textbooks (most recent edition is recommended):

- M.L. Free: Hydrometallurgy: Fundamentals and Applications, TMS

21-Mat-B2 Pyrometallurgy

Principles of mineral processing: comminution, physical separation techniques, flotation, dewatering. Pyrometallurgical operations including roasting, smelting, converting, and refining. Refractory design and selection. Process analysis based on flow sheets, heat and mass balances. Environmental impact of processing operations.

Textbooks (most recent edition is recommended):

- R.E. Reed-Hill, Abbaschian, R. and Abbaschian, L.: Physical Metallurgy Principles, Cengage Learning

21-Mat-B3 Ironmaking and Steelmaking

Thermodynamics and kinetics of iron and steelmaking reactions. Theory and practice of ironmaking including direct reduction processes. Primary steel refining. Ladle metallurgy including desulfurization, deoxidation, inert gas and vacuum treatment. Secondary refining processes including AOD, VAD, and VOD. Continuous casting. Chemical properties of fluxes, slags and refractories. Analysis of new and emerging steelmaking technologies including new processes for reduced energy consumption and pollution.

Textbooks (most recent edition is recommended):

- B. Deo and R. Boom: Fundamentals of Steelmaking Metallurgy, Prentice-Hall
- E.T. Turdogan: Fundamentals of Steelmaking, Woodhead Publishing Ltd

21-Mat-B4 Physical and Extractive Metallurgy of Non-Ferrous Metal and Alloys

Properties, structure and processing of non-ferrous metals and alloys: Aluminum, Copper, Titanium, Nickel, Cobalt, Magnesium and Zinc. The application of principles of thermodynamics, kinetics, and transport phenomena to the extraction and refining of nonferrous metals using pyrometallurgical processes. Production of copper, nickel, lead, and zinc from sulphides. Converting and flash smelting operations. Production of aluminum and magnesium using fused salt electrolysis. Reduction cell operation. Production of refractory metals by chlorination and purification. Recent developments in non-ferrous pyrometallurgy. Environmental impact.

Textbooks (most recent edition is recommended):

- C.B. Gill: Non-Ferrous Extractive Metallurgy, John Wiley and Sons
- W.F. Smith: Structure and Properties of Engineering Alloys, McGraw-Hill
- ASM Handbook Committee: Metals Handbook for Non-Ferrous Alloys, Properties and Selection: Nonferrous Alloys and Special-Purpose Materials, Volume 2, ASM International

21-Mat-B5 Physical Metallurgy and Fabrication of Iron and Steel

Properties, structure and processing of iron-carbon alloys (Fe-C system and transformation of austenite to ferrite, cementite and/or martensite) including plain carbon steels, alloyed steels, stainless steels, tool steels, and cast irons. Heat treatment (annealing and normalizing, cold working and process annealing, tempering, austempering and martempering). Surface hardening and modification. Casting methods (ingot, continuous, sand, die, investment casting). Hot working (hot rolling, extrusion, and forging). Bending and sheet metal operations (roll bending and forming, shearing operations, stretch forming and drawing, and hydroforming). Welding (arc welding, friction stir welding, and laser welding).

Textbooks (most recent edition is recommended):

- E.P. DeGarmo, J.T. Black, and R.A. Kohser: Materials and Processes in Manufacturing, Wiley
- W.F. Smith: Structure and Properties of Engineering Alloys, McGraw-Hill

Supplementary:

- ASM Handbook Committee: Metals Handbook Volume 4 – Heat Treating, ASM International
- ASM Handbook Committee: Metals Handbook Volume 1 – Properties and Selection: Iron, Steels and High Performance Alloys, ASM International

21-Mat-B6 Ceramic Materials

Bonding in ceramics. Ceramic structures. Effect of chemical forces and structure on physical properties. Defects in ceramics. Diffusion and electrical conductivity. Phase equilibria. Sintering and grain growth. Mechanical properties: fast fracture, creep, slow crack growth and fatigue. Thermal stresses and thermal properties. Dielectric properties.

Textbooks (most recent edition is recommended):

- W.D. Kingery, H.K. Bowen, and D.R. Uhlmann: Introduction to Ceramics, Wiley

21-Mat-B7 Structure and Properties of Polymers

Chain architecture: chain dimensions, Gaussian segment density distribution, polymer conformation. Molar mass determination: osmometry, light scattering, gel permeation chromatography, capillary viscometry. Polymer phase equilibria: solvent quality, polymer blending. Polymer structure/transitions: melting and glass transition temperatures, free volume. Crystallization: crystal structure, fractional crystallinity. Mechanical properties: testing methods, compliance, viscoelasticity, dynamic testing, time- temperature superposition, rubber elasticity. Polymer flow properties: viscosity, rheology, shear thinning, analysis of flow fields. Polymer processing techniques.

Textbooks (most recent edition is recommended):

- R.J. Young, and P.A. Lovell: Introduction to Polymers, CRC Press
- Alfred Rudin: The Elements of Polymer Science and Engineering, Academic Press

21-Mat-B8 Electrical, Optical, and Magnetic Materials and Devices

Free electron theory, band theory: energy levels in solids, effective mass, Fermi-Dirac statistics. Semiconductors: effective mass, doping, activation, P-n junctions, field-effect transistors, and solar cells. Dielectrics and polarization: dielectric materials, index of refraction, light-matter interactions, dielectric breakdown, piezoelectricity, ferroelectricity and pyroelectricity. Magnetism: field intensity, permeability, exchange interaction, saturation magnetization, magnetic domains and anisotropy, hysteresis loop. Superconductivity: Meissner effect, superconducting materials, critical field and current density, BCS theory.

Textbooks (most recent edition is recommended):

- L. Solyman and D. Walsh: Electrical Properties of Materials, Oxford University Press
- J. Livingston: Electronic Properties of Engineering Materials, Wiley

21-Mat-B9 Modeling and Simulation of Materials Processing

Mathematical and physical modelling of processes employed in the production of materials; standard techniques of numerical analysis and their application to materials systems. The application of models to analyze, design and optimize materials production and/or usage.

Textbooks (most recent edition is recommended):

- C.I. Pruncu and J. Jiang, Modeling and Optimization in Manufacturing: Toward Greener Production by Integrating Computer Simulation, Wiley
- S. Alavi, Molecular Simulations: Fundamentals and Practice, Wiley

21-Mat-B10 Properties and Processing of Micro- and Nanomaterials

Traditional microfabrication processes: lithography (photolithography, ebeam lithography), etching (wet vs. dry, isotropic vs. anisotropic), physical deposition (ebeam and sputtering), chemical deposition (CVD, PECVD, ALD), electrodeposition, oxidation, diffusion, ion implantation. Techniques: Lift-off, self-alignment, epitaxy. Yield and metrology.

Textbooks (most recent edition is recommended):

- J.D. Plummer, M.D. Deal, and P.B. Griffin: Silicon VLSI Technology: Fundamentals, Practice, and Modeling, Prentice-Hall

21-Mat-B11 Composite Materials

Metals, polymers, ceramics, glass as matrix and fillers for various materials properties (PMC, CMC, MMC). Fabrication techniques considering particle and fiber reinforcement. Isostress and isostrain loading. Continuous, random, aligned, critical length, orientation of fillers. Failure modes and mechanisms and use in thermal, mechanical, optical, electrical, high-temperature applications.

Textbooks (most recent edition is recommended):

- K. K. Chawla: Composite Materials, Springer-Verlag
- W. D. Callister and D.G. Rethwisch: Materials Science and Engineering: An Introduction, Wiley