Subject Name: Advanced Thermodynamics and Kinetics

Syllabus: Thermodynamics: First law, Second law, Entropy, Heat engine, Cyclic process, Entropy criteria for equilibrium, Combination of 1st and 2nd laws; Maxwell's Relation, Gibb's-Helmholtz equation, Thermal expansivity and compressibility; Third law: Hess law, Kirchhoff's law; Phase Equilibria: Clausius–Clapeyron equation, solid-liquid/vapor-condensed phase equilibria, Fugacity; Solution Thermodynamics: Raoult's law, Henry law, Gibb's–Duhem equation, Configurational entropy, Regular solution, Excess function, Thermodynamics of point defects; Free energy: Evaluation of phase diagram, Gibb's phase rule, Lever rule; Thermodynamics of Metallurgical Reaction: Ellingham diagram, Predominance area diagram;
Kinetics: Laws of kinetics, Theory of reaction rates, Grain growth kinetics, Precipitate nucleation and growth kinetics, Concept and modelling of diffusion controlled growth.

Textbooks/Reference Books

- David R. Gaskell, Introduction to thermodynamics of materials
- C.H.P. Lupis, Chemical thermodynamics of materials
- G.S. Upadhyaya and R.K.Dube, Problems in metallurgical thermodynamics and kinetics

Subject Name: Principles of Metallurgical Engineering

Syllabus: Introduction: Solid Engineering Materials- their classification and characteristic properties. Structure of solids: crystal systems/lattices, crystal structure, crystallographic planes and directions, interstitial sites, crystalline metals and alloys. Microstructures and metallography; Amorphous or glassy state; Solidification of pure metal: homogeneous and heterogeneous nucleation processes, cooling curve, the concept of supercooling, microstructure of pure metals and alloys. Defects in solids: point, line, planar, and volume defects. Diffusion in solids: Atomic model, Fick's laws and applications. Diffusion coefficient. Fundamentals of plastic deformation of metals, deformation by slip and twin, plastic deformation in polycrystalline metals, the concept of cold working, preferred orientation; Annealing: recovery, recrystallization and grain growth; hot working; Concept of formation of alloys: Types of alloys, solid solutions, factors affecting solid solubility, order-disorder transformation; Binary phase diagrams: isomorphous, eutectic, peritectic, eutectoid, and peritectoid systems, the effect of non-equilibrium cooling: coring and homogenization; Ironcementite phase diagram: Construction and interpretation of Fe-Fe3C and Fe-Graphite diagrams. Microstructure, and properties of different alloys in steel and cast iron, types of cast iron, their microstructures, and typical uses; Heat treatment: T-T-T and C-C-T diagrams, the concept of heat treatments of steel: annealing, normalizing, hardening and tempering; microstructural effects brought about by these processes and their influence on mechanical properties. Effect of common alloying elements in steel, the concept of hardenability, factors affecting it; Common alloy steels, stainless steel, tool steel, high-speed steel, high strength low alloy steel, micro-alloyed steel, specifications of steels; Physical metallurgy of common non-ferrous alloys: Cu-,Al- and Ni-based alloys. Microstructures and heat treatment of common alloys of these systems.

Textbooks/Reference Books

- William D. Callister, Jr. Materials Science and Engineering, Wiley India (P) Ltd.
- V. Raghavan, Materials Science, and Engineering: A First Course 5 th Ed., Prentice Hall of India, New Delhi (2000)
- Sidney H. Avner, Introduction to Physical Metallurgy, Tata McGraw-Hill.
- Butterworth-Heinemann, Michael Ashby, Hugh Shercliff, and David Cebon, Materials Engineering, Science, Processing and Design

Subject Name: Principles of Materials Engineering Introduction

Syllabus: Solid Engineering Materials- their classification and characteristic properties. Structure of solids: crystal systems/lattices, crystal structure, crystallographic planes and directions, interstitial sites, crystalline metals and alloys, ceramics, semiconductors and polymers, amorphous or glassy state Defects in solids: point, line, planar and volume defects Diffusion in solids: Atomic model, Fick's laws and applications. Diffusion coefficient. Concept of formation of alloys: Types of alloys, solid solutions,

factors affecting solid solubility, order-disorder transformation; Binary phase diagrams: isomorphous, eutectic, peritectic, eutectoid and peritectoid systems. Properties of materials: Fundamentals of functionalities, and common tests conducted to evaluate important engineering properties such as electrical, dielectric, chemical, magnetic, semi/superconducting, optical, and thermal properties in engineering materials. Engineering materials: Structure, properties and application of common engineering metals and alloys, ceramics and polymers especially in functional applications.

Textbooks/Reference Books

- William D. Callister, Jr. Materials Science and Engineering, Wiley India (P) Ltd.
- V. Raghavan, Materials Science, and Engineering: A First Course 5 th Ed., Prentice Hall of India, New Delhi (2000)
- L.L. Hench and J. K. West, Principles of Electronic Ceramics, John Wiley and Sons Ltd, New York, 1990
- M. W. Barsoum, Fundamentals of Ceramics, CRC Press, 2000

Subject Name: Mechanical Behaviour of Materials

Syllabus: Elasticity basics: Stress and strain tensors, tensor transformations, Mohr's circle representation of stress and strain, constitutive equations. Origin of stresses in thin films: thermo-elastic mismatch between film and substrate, lattice mismatch in hetero-epitaxial films, recrystallization, phase transformation, incorporation of atoms and chemical reactions. Application of the above for designing structures with low stresses. Experimental techniques for measuring stresses/strains in thin films: Substrate curvature; Stoney's equation, methods for curvature measurement and X-ray diffraction. Measurement of mechanical properties of thin films - nanoindentation, bulge test, 4-point bend test, and micro-tensile test. Models for high stresses, strain-hardening rates and Bauschinger effect in thin films, influence of grain size, film thickness and interfaces.

Textbooks/Reference Books

- Marc André Meyers, Krishan Kumar Chawla, Cambridge,*Mechanical Behavior of Materials*

Subject Name: Advanced Physical Metallurgy

Syllabus: Microstructure & Properties: solidification and solidification structures, interfaces, crystallographic texture, residual stress, structure-property relations. Plasticity and work-hardening: fundamentals, stress-strain behavior, fracture, creep & deformation mechanisms. Recovery, recrystallization, grain growth. Phase transformation: thermodynamic basics, nucleation and growth, spinodal decomposition, martensitic transformations.

Textbooks/Reference Books

- R. E. Smallman PhD and A.H.W. Ngan, Physical Metallurgy and Advanced Materials, Seventh Edition

Subject Name: Powder Materials & Processing

Syllabus: Introduction: development of powder metallurgy, scope of powder metallurgy, characterization of metal powders, physical properties-particle size and shape determination, technological properties-apparent density, flow rate etc. and chemical properties, particle interaction and control; Powder manufacturing: powder mixing and blending, dry and colloidal processing, reduction, electrolysis, and atomization processes, shaping techniques such as compacting, injection molding; Compaction and sintering: die compaction and other consolidation techniques, sintering, sintering with liquid phase; Powder metallurgy products: bearing, filters, friction parts, hard metals, refractory metals, contact materials, magnetic materials, structural parts, and dispersion strengthened materials.

Textbooks/Reference Books

Glaus G. Goetzel, TREATISE ON POWDER METALLURGY in three volumes

- Volume 1: Technology of Metal Powders and Their Products
- Volume II: Applied and Physical Powder Metallurgy
- Volume III: Classified and Annotated Bibliography

Subject Name: Materials Processing

Syllabus: Solidification processing: Plane front solidification, cellular solidification, cellular-dendritic transition, Theories of regular and irregular eutectic growth, Rheocasting, Thixocasting, casting of composites; Powder processing: preparation of metallic, ceramic and composite powders; Sintering and full density processing; Metal forming processes: Deformation theories, Applications in rolling, forging, extrusion, machining; Processing of new materials: nanomaterials and biomaterial; Joining of materials: Fundamentals of liquid and solid state joining, friction stir welding, joining of similar and dissimilar materials; Processing of minerals, particulate materials; characterization of particles; crushing, grinding and classification; minerals separation using gravity techniques, electrical and magnetic methods, froth flotation, de-watering using thickening, filtration and drying operations; effluent processing and tailings disposal; Processing of ceramics: Crystal Systems, Amorphous Systems - Glass, Phase Equilibria, Sintering of ceramics, Microstructure of Ceramics, Mechanical Properties, Thermal Properties, Optical Properties, Electrical and Magnetic Properties, Chemical Properties Traditional Ceramic Raw Materials, Non-Traditional and Special Ceramic Raw Materials, Glass ceramics, Bio implants, Advanced ceramics; Material processing from solid waste from metal industry and thermal power plants.

Textbooks/Reference Books

- Porter, Easterling and Sherif, *Phase Transformation in metals and alloys*
- Randall M. German, *Powder Metallurgy & Particulate Materials Processing*
- WD Kingery, HK Bowen, DR Uhlmann, *Introduction to ceramics*
- B.A. Wills and T. Napier-Munn, *Wills' Mineral Processing Technology*
- E.G. Kelly and D.J. Spottiswood, *Introduction to Mineral Processing*

Subject Name: Materials Characterization

- **Syllabus:** Importance of characterization studies in materials science – applications in industry and research; Review of materials science fundamentals; Mechanical waves and Ultrasonic testing; Principles of image formation and optical aberrations; Sample preparation techniques for optical and scanning electron microscopy; Optical metallographic - phase contrast, Nomarski contrast techniques; Scanning electron microscopy: beam-sample interaction, Interaction volume concept, WDS, EDS, EPMA techniques and their application; X-ray diffraction – application in macro-texture, crystal structure and residual stress determination; Atomic absorption spectroscopy; Optical emission spectroscopy; X-ray fluorescence spectroscopy; Electron energy loss spectroscopy; Gas chromatography –application in dissolved gas analysis; Differential scanning calorimetry; Thermo gravimetric analysis; Surface analysis methods: AES, XPS; Transmission electron microscopy: sample preparation, bright field and dark field imaging, Kikuchi line formation and selected area diffraction analysis; Orientation imaging microscopy: sample preparation, application in micro-texture, phase, residual stress and grain size determination; Mass spectrometry.

Textbooks/Reference Books

- J. Goldstein, D.E. Newbury, D.C. Joy, C.E.Lyman,P.Echlin,E. Lifshin, L. Sawyer, J.R. M L Sawyer, J R Michael, *Scanning Electron Microscopy and X-ray Microanalysis*.
- ASM Handbooks Online
- David B. Williams, C.Barry Carter, *Transmission Electron Microscopy: A Textbook for Materials Science (4 Vol. Set)*.
- G. Hohne, W.F. Hemminger, H. –j Flammersheim, *Differential Scanning Calorimetry*.
- O. Engler, V. Randle, *Introduction to Texture Analysis: Macrotexture, Microtexture, and Orientation Mapping*.
- B.D. Cullity, C.R. Stock, *Elements of X-Ray Diffraction*

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Subject Name: Phase Transformation in Materials

Syllabus: Diffusion and thermodynamics of surfaces and interfaces, Irreversible thermodynamics, Kinetics of phase transformations, Salient features of solid-solid and solid-liquid phase transformations, Ingot, Continuous cast and fusion weld microstructure, Defects during solidification, Diffusional transformations in steel, Precipitation phenomena in age hardened alloys, Order-disorder transformation, Martensitic transformations.

Textbooks/Reference Books

- D. A. Porter and K. E. Easterling, *Thermodynamics of solids, R.A. Swalin,Phase transformations in metals and alloys*.
- P. G. Shewmon, *Diffusion in solids*.
- R. E. Reed-Hill, *Physical metallurgy principles*.
- R. w. Cahn and P Haasen, *Physical Metallurgy (4th Ed.)*
- M. P. Allen, D. J. Tildesley, *Computer Simulation of Liquids*.
- J. M. Haile, *Molecular Dynamics Simulation: Elementary Method.*

Subject Name: Functional Oxides: Structure and Properties

Syllabus: Introduction: Importance of oxides in functional applications, Revision of basic crystallography: point group and space group.
Structure: Concepts of ionic bonding, Grouping of ions and structure rules, Radius ratio concept, Structure of crystalline oxides, Case studies, Demonstration of open-source software package(s) for geometric construction of oxide structures and determination of structural parameters.
Defect Reactions and Defect Equilibria: Different types of defects in oxides, Rules for defect reaction, Kröger-Vink notations, Conditions of equilibrium, Thermodynamics, Conditions of stoichiometry.
Electrical conductivity and Conducting oxides: Laws of diffusion,Lattice, grain boundary and surface diffusion, Theory of ionic conductivity, Solid electrolytes and fast ion conductors, Concepts of Thermoelectric effect.
Linear and non-linear dielectric oxides: Theory of linear dielectrics, circuit description, Dielectric constant and polarization, Dipolar polarization theory, Crystallographic consideration towards non-linear dielectric behavior. Concepts of piezo and ferroelectricity, Case studies.
Magnetic Oxides: Basic Theory, Types of magnetism, Exchange interactions, Case studies, Coupling of electrical and magnetic orders in oxides.

Textbooks/Reference Books

- L.L. Hench and J. K. West, Principles of Electronic Ceramics, John Wiley and Sons Ltd, New York, 1990.
- W. D. Kingery, H. K. Bowen (Author), Donald R. Uhlmann, Introduction to Ceramics, Wiley-Interscience; 2nd edition, 1976
- M. W. Barsoum, Fundamentals of Ceramics, CRC Press, 2002
- Per Kofstad, Non-stoichiometry, Diffusion and Electrical Conductivity in Binary Metal Oxides, Wiley-Interscience, 1972
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Subject Name: Advanced Composite

Syllabus: Synthesis of composites, reinforcements, matrices; Metal Matrix Composites (MMCs), Ceramic
Matrix Composites (CMCs), Special High Temperature High performance Carbon-Carbon composites; Processing issues in Metal Matrix Composites and Ceramic Matrix Composites, Solidification, Particulate technology, Sol gel, Chemical Vapour Deposition (CVD) and Physical Vapour Deposition (PVD) routes of manufacturing composites; Physico-chemical aspects of interfaces in composites; Nan composites.

Textbooks/Reference Books

- Krishan Kumar Chawla, *Composite Materials: Science and Engineering*.
- Krishan Kumar Chawla, *Ceramic Matrix Composites*.

Subject Name: Corrosion Science & Engineering

Syllabus: Importance of corrosion, corrosion rates evaluation, thermodynamics of corrosion; electrochemical mechanisms: Electrode potentials and corrosion tendency, polarization, mixed potential theory, Evan's corrosion diagrams, potential-pH diagrams; Different forms of corrosion including microscopic and macroscopic forms. High temperature corrosion: Oxidation laws, selective oxidation, internal oxidation and catastrophic oxidation. Corrosion testing: design principles of corrosion evaluation of materials, accelerated corrosion tests, common experimental techniques for corrosion rate measurements including electrochemical methods. Different forms of corrosion and their control *viz.*, uniform corrosion, galvanic corrosion, selective leaching, crevice corrosion, fill form corrosion, pitting corrosion, inter-granular corrosion, erosion corrosion, fretting damage, stress corrosion cracking, corrosion fatigue, hydrogen embrittlement and microbes induced corrosion. Elementary treatment of corrosion testing procedures, inhibitors and corrosion of steels. Corrosion protection methods -studies on electroplating, cathodic and anodic protection, protecting coatings, coatings for prevention of high temperature oxidation etc. Some case studies of real life corrosion.

Textbooks/Reference Books

- M.G. Fontana, McGraw Hill, Singapore, 1987, *Corrosion Engineering*.
- Edward Arnold, London, 1983.A.S. Khanna, *Introduction to Oxidation of Metals*.
- Zaki Ahmed, Butterworth-Heinemann Publication, *Principles of Corrosion Engineering and Corrosion Control.*

Subject Name: Mineral Beneficiation

- **Syllabus:** Principles of mineral beneficiation, Mineralogy, Colloids and material chemistry Sampling methodology, Working principles and equipment design for: primary crushers, secondary crushers, grinding, froth flotation, magnetic separation, electrical separation, Electro and Hydro-Metallurgy processes, Bio-mineral processing, Discrete element method simulations.

  Textbooks/Reference Books
  - A. Ghosh, H. S. Ray, *New Age International,Principles of Extractive Metallurgy*.
  - H.S Ray, R Shridhar, K.P Abraham , *East-West Private Ltd,Extraction of Non-Ferrous Metals.*
  - Barry A. Wills, Elsevier and Butterwoth – Heineman, *Wills' Mineral Processing Technology, Seventh Edition: An Introduction to the Practical Aspects of OreTreatment and Mineral Recovery*.

Subject Name: Ceramic Materials

Syllabus: Introduction, Ceramic Materials: structure, microscructure and polymorphism, synthesis of ceramics, ceramic forming processes, silicate and non-silicate ceramics, structural, functional (electronic, optical) and bio-ceramics, nano-ceramics, Properties and Applications of Ceramics: refractory materials, properties of refractories, fracture of refractories, corrosion of refractories, different refractory lines, alumina-silica brick, magnesia refractories, silica brick, doloma refractories, carbonaceous refractories, spinel-containing refractories, glass tank blocks, ceramic wool preparation and properties, carbide and nitride based refractories, refractory coatings, refractory castables, unshaped refractory products, surface chemistry as a tool for the development of advanced refractory castables, thermo-mechanical considerations for refractory linings, refractory

applications in refineries and circulating fluid bed reactors, heating wall refractories, damage and causes of failure, testing of refractory materials, refractory lining design and manufacture.

Textbooks/Reference Books

- W. D. Kingery, H. K. Bowen, Donald R. Uhlmann, *Introduction to Ceramics*, 2nd Edition.

Subject Name: Extractive Metallurgy

- **Syllabus:** Thermodynamics and kinetics of metallurgical reactions, heat transfer and fluid flow, Methods of extraction and refining of metals – pyrometallurgy, hydrometallurgy and electrometallurgy; Extraction of non-ferrous metals such as – U, Th, Cu, Zn, Au, Ag, Al, Pb, etc; Extractive metallurgy of rare earths; Iron making, blast furnace, blast furnace slag, various zones in blast furnace, controlling of various elements like P, Si, Mn, S, in hot metal, alternative routes of iron making processes *i.e.* solid state reduction, steel making principles, furnaces, modern steel making process, control of various elements in steel by refining the hot metal, slag property, stainless steel making, Ferro-alloy; Green extraction processes; Current research developments in extraction processes.

  Textbooks/Reference Books
  - A. Ghosh, H. S. Ray, *New Age International,Principles of Extractive Metallurgy*.
  - H.S Ray, R Shridhar, K.P Abraham , *East-West Private Ltd, Extraction of Non-Ferrous Metals*.
  - A. Ghosh, A. Chatterjee, *PHI Learning Ltd.,Iron making and Steel Making; Theory and Practice*.
  - E.G. Kelly and D.J. Spottiswood, *Introduction to Mineral Processing*

Subject Name: Transport Phenomena

Syllabus: Heat, mass and momentum balance, laminar, turbulent flow, concept of boundary layer, friction factor, heat and mass transfer coefficients and dimensionless correlations; Process modeling: governing equations, boundary conditions, and some case studies of some important metallurgical system: packed and fluidized bed, moving boundary problems with melting, solidifications and reactions, solid-gas reactions. Modeling of electrochemical processes. Numerical methods applied in transport modeling: control volume method for solving partial differential equations. Numerical solutions of some metallurgical processes: extraction processes, iron making, steel making gas stirred ladle, filling ladle, fusion welding, cored wire injection, soaking pits, continuous casting etc.

Textbooks/Reference Books

- R. Byron Bird, Warren E. Stewart, Edwin N. Lightfoot. *Wiley International edition,Transport Phenomena.*
- D. R. Poirier, G. H. Geiger, Wiley, *Transport Phenomena in Materials Processing*.
- Julian Szekely, Academic Press, *University of Michigan,Fluid flow phenomena in metals processing.*

Subject Name: Solidification of metals and alloys

Syllabus: Introduction to solidification in metal casting and other important processes; Heat flow in solidification, shrinkage during solidification; Modes of solidification: plane front solidification, dendritic solidification, cellular solidification; Solidification of single phase alloys, directional solidification, faceted and non-faceted growth and its implications in microstructure formation,

crystal growth; Nucleation and interface kinetics: Homogeneous nucleation, heterogeneous nucleation, lateral growth, continuous growth, instability at the solid/liquid interface; Defects in cast products: segregation, inclusions etc; Special casting techniques: investment casting, rheocasting and thixocasting, squeeze casting, high and low pressure die casting, continuous casting; Cast metal matrix composites (MMCs) and Cast metal matrix nanocomposites (MMNCs): processes and applications

Textbooks/Reference Books

- M. C. Flemings: Solidification processing, McGraw-Hill, 1974.
- Metals Handbook, Casting , vol. 15, 10th Edition, ASM International, Materials Park, Ohio, USA, 2008.
- D.A. Porter, K. E. Easterling, "Phase Transformation in Metals and Alloys", 3rd Edition, CRC Press, 2009.

Subject Name: Electrochemical Methods in metallurgy

Syllabus: Overview of electrode processes; nature of electrode-electrolyte interface and electrode double layer theory; cell potential and mixed potential; electrode kinetics; Arrhenius equation and potential energy surfaces; Types of overvoltage; Effect of electrode potential on electrode kinetics; Tafel relation as a special case of Butler-Volmer Equation;
Potential step methods; Chronoamperometry; polarography and pulse voltametry; galvanostatic and controlled current methods; hydrodynamic methods; mass transfer by migration and diffusion; impedance spectroscopy; adsorption and double layer theory; scanning probe methods; couple characterization; case studies.

Textbooks/Reference Books

- Bard, A. J., & Faulkner, L. R., Electrochemical methods: fundamentals and applications, Vol.25, 2nd Edn.,Wiley and Sons, 2013.
- Pletcher, D., & Walsh, F. C., Industrial electrochemistry, Springer, 1990.