Biju Patnaik University of Technology, Orissa
Rourkela

Syllabus
of
M.Tech

in

METALLURGICAL ENGINEERING

(Specialization: Metallurgical and Materials Engineering)

From 2014 -2015 Academic Session

BIJU PATNAIK UNIVERSITY OF TECHNOLOGY, ORISSA, ROURKELA

Course Structure & Syllabus for M.Tech Programme in Metallurgical and Materials Engineering (from 2014-15 academic session)

1st SEMESTER				2nd SEMESTER			
	THEORY	*Contact Hours*			*THEORY*	*Contact Hours*	
Code	*Subject*	*L-T-P*	*Credits*	*Code*	*Subject*	*L-T-P*	*Credits*
	Professional Core				**Professional Core**		
MMPC101	Physical Metallurgy	3-1-0	4	MMPC201	Characterization of Materials	3-1-0	4
MMPC102	Metallurgical Thermodynamics and Kinetics	3-1-0	4	MMPC202	Process Metallurgy	3-1-0	4
MMPC103	Mechanical Behaviour of Materials	3-1-0	4				
	Professional Elective-I (Any one)	3-0-0	3		**Professional Elective-III (Any one)**	3-0-0	3
MMPE101	Solid State Phase Transformations			MMPE201	Mineral Engineering		
MMPE102	Solidification of Metals and Alloys			MMPE202	Fuels, Furnaces & Refractories		
MMPE103	Transport Phenomena in Metallurgy			MMPE203	Ferrous Metallurgy		
				MMPE204	Powder Metallurgy		
	Professional Elective-II (Any one)	3-0-0	3		**Professional Electives-IV (Any one)**	3-0-0	3
MMPE104	Failure of Materials			MMPE205	Non Ferrous Metallurgy		
MMPE105	Mechanical working of Materials			MMPE206	Alternative Routes of Iron Making		
MMPE106	Joining of Materials			MMPE207	Ferro Alloys Technology		
MMPE107	Physics of Materials			MMPE208	Biomaterials		
					Professional Electives-V (Any one)	3-0-0	3
				MMPE209	Advanced Casting Processes		
				MMPE210	Composite Materials		
				MMPE211	Nano Materials		
				MMPE212	Engineering Materials		
		Credits (Theory)	**18**			**Credits (Theory)**	**17**
	PRACTICALS/ SESSIONALS				***PRACTICALS/ SESSIONALS***		
MMPR101	Physical Metallurgy and Materials Testing Lab	0-0-6	4	MMPR201	Materials Processing and Process Metallurgy Lab	0-0-6	4
MMPT101	Pre-thesis work and Seminar	0-0-3	2	MMPT201	Pre-thesis work and Seminar	0-0-3	2
				MMCV201	Comprehensive Viva-Voce -I	0-0-3	2
		Credits (Practicals / Sessionals}	**6**			**Credits (Practicals / Sessionals)**	**8**
		TOTAL SEMESTER CREDITS	**24**			**TOTAL SEMESTER CREDITS**	**25**
		TOTAL CUMULATIVE CREDITS	**24**			**TOTAL CUMULATIVE CREDITS**	**49**

3rd SEMESTER				4th SEMESTER			
	THEORY	***Contact Hours***			***THEORY***	***Contact Hours***	
Code	***Subject***	***L-T-P***	***Credits***	***Code***	***Subject***	***L-T-P***	***Credits***
MMOE	**Open Elective (Any One)**	3-0-0	3				
1.	Degradation of Materials						
2.	Tribology of Materials						
3.	Surface Engineering						
4.	Modelling and Computer Application in Metallurgy						
5.	Secondary Steel Making						
	Credits (Theory)		**03**		**Credits (Theory)**		**00**
	PRACTICALS/ SESSIONALS				***PRACTICALS/ SESSIONALS***		
MMPT301	Thesis Part-I		14	MMPT401	Thesis Part-II		20
				MMCV401	Technical Seminar	0-0-3	2
				MMCV402	Comprehensive Viva-Voce-II	0-0-3	2
	Credits (Practicals / Sessionals}		**14**		**Credits (Practicals / Sessionals)**		**24**
	TOTAL SEMESTER CREDITS		**17**		**TOTAL SEMESTER CREDITS**		**24**
	TOTAL CUMULATIVE CREDITS		**66**		**TOTAL CUMULATIVE CREDITS**		**90**

1^{st} Semester
Professional Core

Physical Metallurgy (3-1-0) Credits: 04

Module-1 (14 Hours)

Crystallography: Crystalline and amorphous structures, Elements of crystal symmetry, symmetry elements and axes, two, three, four and six fold symmetry, review of atomic bonding in materials, , common crystal systems, crystal structure of metals , representation of planes and directions in crystals, atomic packing in crystals, calculation of packing density, voids in common crystal structures and imperfection in crystals.
Metallography: Metallurgical microscope, Specimen preparation, Techniques for microscopic observation. High temperature microscopy, Quantitative metallographic.

Module-II (14 Hours)

Thermodynamics of phase change: Equilibrium, phase stability, evolution of phase diagrams, chemical potential gradient, Atomic model of diffusion, solid solution, Theories of alloying, Hume-Rothery rules, Single component systems, P-T diagrams, Allotropy. Free energy- composition diagram, Binary equilibrium diagrams (Isomorphous, eutectic, eutectoid, monotectic, peritectic, peritectoid, Syntectic systems), Gibbs phase rule, Tie line, Lever rule. Common alloy systems (Pb-Sn, Cu-Zn, Al-Si etc) Ternary system: Ternary phase diagrams, representation, isothermal and vertical sections, Ternary isomorphous and eutectic systems, Tie lines, Two phase, Three phase and four phase equilibrium, Gibb's triangle representation.

Module-III (14 Hours)

Fe-C system: Effects of alloying elements, Formation of Austenite, Decomposition of Austenite, Pearlitic, Bainitic and Martensitic phase transformations, TTT and CCT diagrams, Hardenability, Critical diameter, Jominy end quench Test, Tempering of steel, Temper brittleness, Thermomechanical Treatment, Ausforming, Maraging steels, Processing- structure property relationship in multiphase alloys (steels and cast irons), Rapid solidification processing, Metallic Glasses, Single crystal processing. Nano crystalline materials.

Books for reference:

1. Reedhill R.E., Physical Metallurgy Principles, Affiliated East West Press.
2. R.W.Cahn and Peter Haasen, Physical Metallurgy.
3. Avner S.H., Introduction to Physical Metallurgy, Tata McGraw Hill.
4. Porter D.A. & Easterling K.E., Phase Transformations in Metals and Alloys.
5. Kakani S.L. and Kakani A., Materials Science, New Age International.
6. Clarke & Varney, Introduction to Physical Metallurgy.

Metallurgical Thermodynamics and Kinetics of Materials (3-1-0) Credits: 04

Module-I (14 Hours)

General principles: first and second law, mathematical formalism for the thermodynamic description of closed systems with constant composition. Mathematical formalism for the thermodynamic description of systems with variable composition. The chemical potential. Partial properties. -- Relation between integral and partial molar properties. Chemical potential of ideal gases (pure and mixtures) and non-ideal gases (pure and mixtures). Chemical potential of pure liquids and solids and of components in liquid and solid solutions. The activity concept.Standard states and activities. Ideal solutions and non-ideal solutions. Activity coefficients. Properties of solutions. Simple solution models.

Module-II (14 Hours)

Introductory concepts of statistical thermodynamics. The regular solution model.Phase stability and phase diagrams Reaction equilibrium, oxidation and reduction, Ellingham diagrams.Thermodynamics vs. kinetics, homogeneous and heterogeneous reactions; Chemical Reaction Control-rate equation, reaction rate constant, reaction order, non-elementary reactions; Basic concepts of reaction steps, rate of reactions, Order of reaction, Determination of order of reactions. Arrhenius equation in reaction kinetics, Mechanism of reaction and rate controlling steps, Activated complex and its thermodynamic and kinetic aspects, Effect of concentration and temperature on reaction kinetics. Kinetics of heterogeneous reactions.

Module-III (14 Hours)

Solid State Diffusion -Fick's Law, mechanism of diffusion, uphill diffusion, Kirkendall effect, steady and transient diffusion;External Mass Transfer -fluid flow and its relevance to mass transfer, general mass transport equation, concept of mass transfer coefficient, models of mass transfer -film theory and Higbie's penetration theory; Internal Mass Transfer-Ordinary and Knudsen diffusion, Mass transfer with reaction; Adsorption –physical adsorption vs. chemisorption, adsorption isotherms; Langmuir, BET, adsorption as the rate limiting step; gasification of C by CO2, dissolution of N2 in molten steel, porous solids, specific surface area and pore size distribution;

Applications in extractive metallurgy, e.g. iron and steel making, copper making

Applications in physical metallurgy, e.g. solid phase transformations and equilibria in metallic alloys, cemented carbides etc

Books for reference:

1. Gaskell D.R., Metallurgical Thermodynamics.
2. Darken and Gurry, Physical Chemistry of Metals
3. Ragone, David V. *Thermodynamics of Materials*. Vol. 1. New York, NY: Wiley,
4. Porter, David A., and K. E. Easterling. *Phase Transformations in Metals and Alloys*. 2nd ed. New York, NY: Chapman & Hall,
5. Balluffi, Robert W., Samuel M. Allen, and W. Craig Carter. *Kinetics of Materials.* Hoboken, NJ: J. Wiley & Sons,

Mechanical Behaviour of Materials (3-1-0) Credits: 04

Module-I (14 Hours)

Introduction: Theory of elasticity and plasticity, Generilised Hooke`s law, stress-strain relationship.

Mechanism and crystallography of slip and twinning. Plastic response of materials-a continuum approach: classification of stress-strain curves, yield criteria.Concept of critical resolved shear stress. Deformation of single crystals and polycrystals. Hall –Petch relationship. Role of grain boundaries in deformation, strengthening mechanisms.

Dislocation Theory: Elements of dislocation theory, movement of dislocation, elastic properties of dislocation, intersection of dislocation, dislocation reactions in different crystal structures, origin and multiplication of dislocations.

Module- II (14 Hours)

Fracture: Mode and mechanism of fracture, Griffith`s theory, Ductile to brittle transition.Transition temperature phenomena, Factors affecting transition temperature, Fracture mechanism, strain energy release rate, stress intensity factor, plane strain fracture toughness.

Fatique :Fatigue testing methods and machines. Stress controlled and strain controlled fatigue. Analysis of cyclic stress –strain data. Mechanism of fatigue crack, nucleation and propagation.

Creep: Generation and analysis of creep and rupture data. Dislocation and diffusion mechanisms of creep. Grain boundary sliding and migration. Deformation mechanism maps. Effect of metallurgical and test variation on creep and fracture. Superplasticity.Parametric methods for prediction of long time properties.

Module- III (14 Hours)

Tension test- Engineering & true stress-strain curves, evaluation of tensile properties, Tensile instability, Effect of strain-rate & temperature on flow properties.
Hardness tests- Brinell, Rockwell, Vickers, Meyer, Knoop, etc., relationship with flow curve.
Compression Test- Comparison with tension, phenomenon of buckling & barreling.
Bend Test- Pure bending & flexure formula.
Impact Test- Notched bar impact tests, transition Temperature & metallurgical factors affecting it.

Books for reference:

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

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

3. Meyers M. A. and Chawla K. K., Mechanical Behaviour of Materials.

4. Courtney T.H., Mechanical Behaviour of Materials.

Professional Elective-I (Any one)

Solid State Phase Transformations (3-0-0) Credits: 03

Module I (14 Hours)

Introduction: Thermodynamics of phase equilibrium and phase changes; Definition, utility, order and classification of phase transformations.

Diffusion: Definition of Fick's law on steady and non-steady state diffusion and their solutions; Mechanism of diffusion in solids; Chemical diffusion and Darken's equation; Kirkendall effect; Effect of pressure and temperature on diffusivity.

Nucleation and growth: Formation of nucleus; Homogeneous and Heterogeneous nucleation; Mechanism and kinetics of thermally activated growth; Interface and diffusion control growth regimes.

Phase equilibrium and phase diagrams: Important phase changes in unary and binary systems; Types and interpretation of phase diagram; Utility of phase diagrams, Lever rule; important phase diagrams in metallic and ceramic systems; Free energy Composition diagrams; Ternary phase diagrams; Isomorphous and eutectic Systems.

Module II (12 Hours)

Solid state diffusive transformation: Classification of solid-solid transformations; Nucleation in solids; Precipitate growth; Age hardening; Spinodal decomposition; Precipitate coarsening. Order-disorder change, polymorphic change. Recrystallization, grain growth. Eutectoid transformation. Application of solid state precipitation. Pearlitic and bainitic transformations in steel; Zone refining, crystal growth, crystallography, stabilization,. Annihilation of point imperfections, , eutectoidal reaction, cellular reaction. Strengtheming mechanisms, massive decomposition. Martensite and martensitic changes in ferrous materials.

Module III (12 Hours)

Review of Iron-carbon alloy system: Iron-cementite and iron-graphite phase diagrams, cooling of hypo-eutectoid, eutectoid and hyper-eutectoid steels, hypo-eutectic, eutectic and hyper-eutectic cast irons, nucleation and growth of pearlite.

Heat treatment of steels: TTT and CCT diagrams, conventional heat treatment processes – annealing, normalizing, hardening and tempering. Hardenability, role of alloying elements in steels. Surface hardening and chemical treatment in steels. Thermo-mechanical treatment of steels; High temperature and low temperature Thermo-Mechanical treatment. Heat treatment of some Cu, Al and Ti based alloys.

Books for reference:

1. Porter D. A. and Easterling K. E., Phase Transformations in Metals and Alloys, CRC Press.
2. Sharma R. C., Phase Transformations in Materials.
3. Raghavan, Solid State Phase Transformations, PHI.
4. Thelning K E, Steel and its Heat treatment, Butterworth.
5. Rajan and Sharma, Heat Treatment, PHI.
6. Principles of Heat Treatment of Steels, ASM
7. Reed-Hill R. E., Physical Metallurgy Principles, East West Press.

8. Christian J.W., Theory of Transformations in Metals and Alloys, Pergamon Press.

Solidification of Metals and Alloys (3-0-0) Credits: 03

Module I (12 Hours)

Thermodynamics of solidification: Nucleation and growth; Pure metal solidification: Gibbs- Thomson effect; Alloy Solidification: Mathematical Analysis of redistribution of solute during solidification. Constitutional undercooling, Mullins-Sekerka instability, Heat flow and heat evolution, shrinkage during cooling and solidification

Module II (12 Hours)

Nucleation and interface kinetics: Homogeneous nucleation, heterogeneous nucleation, grain refining, lateral growth, continuous growth, instability at the solid/liquid interface.

Solidification microstructure: Solidification of single phase alloys, directional solidification, crystal growth etc. Cells, dendrites, solidification of polyphase alloys, eutectic and peritectic solidification, growth of graphite in cast iron, segregation in castings, inclusions in castings etc.

Module III (12 Hours)

Melting practice

Melting practice and special precautions for steels, alloy steels, cast irons, aluminium alloys, copper alloys and magnesium alloys, safety considerations, fluxing, degassing and inoculation. Modelling of solidification; Case studies.

Books for reference:

1. Campbell J., Casting, Butterworth - Haneman, London.
2. Flemings M.C., Solidification Processing, McGraw Hill.
3. Hein R.W., Loper C. R. & Rosenthal P.C, Principles of Metal Casting, T.M.H.
4. Taylor H.F., Flemming M.C. & Wulff, Foundry Engineering, Wiley Eastern.
5. Beeley P.R., Foundry Technology, Butterworth, London.

Transport Phenomena in Metallurgy (3-0-0) Credits: 03

Module I (12 Hours)

Momentum transfer fundamentals: properties of fluids, types of fluid flow, viscosity of liquid and gases, laminar flow, momentum balance general momentum equation(GME) and its application in flow of falling film, flow through a circular tube, flow between the parallel plates, application of Navier Stokes Equations, turbulent flow: friction factors, flow past submerged bodies, flow through packed bed of solids, fluidized beds, energy balanced application in fluid flow: conservation of energy, flow through valves and fitting, flow from ladles.

Module II (12 Hours)

Energy transport fundamentals: fouriers laws and thermal conductivity of liquids gases, solids and bulk materials, heat transfer and general energy equation and its application in heat transfer with convention and conduction in solids, examples of solidification in sand molds and metal molds, continuous casting, radiation heat transfer, black and grey body radiation, radiations from gases, its application to furnace enclosures and thermal behavior of metallurgical packed bed reactors.

Module III (12 Hours)

Mass transfer fundamentals: molar density of mixture, mole fraction, molar flux, total molar fluxes, diffusion mechanisms in solids, Fick's first law and second law of diffusion, diffusion coefficient and inter diffusion coefficient, mass fraction, mass average velocity, general mass transport equation(GMT), application of (GMT): mass transfer through a near stagnant medium, mass transfer through a near stagnant medium with chemical reaction, examples such vaporization of Zn in molten copper , Silicon growth by chemical vapour deposition, loss of liquid Mn by passes of argon gases. Convective mass transfer: forced convection and natural convection, Navier Stokes Equations, application in mass transfer in laminar film flow, mass transfer in porous solids.

Books for reference:

1. Geiger G.H. and Poirier D.R., Transport phenomena in metallurgy, addison-wesley publishing company.
2. Bird R.B.., Stewart W.E..and Lightfoot E.N., Transport phenomena. addison-wesley publishing company.

Professional Elective-II (Any one)

Failure of Materials (3-0-0) Credits: 03

Module I (12 Hours)
Introduction Types and cause of failure of materials.

Fracture failures:

Stress intensity factor, stress analysis of cracks, Derivation of the relationship between strain energy release rate and stress intensity factor. Crack- tip plastic zone, Dugdales's plastic strip model.

Plane stress versus plane strain, Crack opening displacement, Plain strain fracture toughness K_{IC} testing, fracture toughness determination with elastic plastic analysis (J_{IC}).

Module II (12 Hours)

Fatigue failures:
(i) Stress Life Approach, S-N Curve, Factors affecting fatigue under this approach.
(ii) Strain Life Approach: Low cycle fatigue, Coffin-Manson equation, Strain Life equation. Nubers Approach.
(ii) Fatigue crack propagation: Paris law, Fatigue life estimation, Factors affecting fatigue crack growth rate.

Module III (12 Hours)
Creep failures:
Creep & Stress rupture tests, Mechanism of creep deformation, Deformation mechanism Maps, Development of creep resistant alloys, Prediction of long time properties.

Stress corrosion cracking, K_{iscc} determination, Corrosion fatigue, Temper embrittlement, Hydrogen embrittlement, SEM fractography of ductile (Dimple), brittle (cleavage), and Fatigue fractured surface.

Books for reference:

1. Dieter G. E., Mechanical Metallurgy, McGraw-Hill Company.
2. Hertzberg R.W., Deformation and Fracture Mechanics of Engineering Materials, John Wiley.
3. Broek D., Elementary Fracture Mechanics, Martinus Nijho Publisher.
4. Failure Analysis & Prevention (Vol. - X), Metal Hand Book, ASM Publication.
5. Meyers M. A. and Chawla K. K., Mechanical Behaviour of Materials.
6. Courtney T.H., Mechanical Behaviour of Materials.
7. Suresh S., Fatigue of Materials by, Cambridge University Press.
8. Colangelo V. J., Heiser F. A., Analysis of Metallurgical Failures, Wiley.

Mechanical Working of Materials (3-0-0) Credits: 03

Module I **(14 Hours)**

Classification of forming processes.
Fundamentals of metal working – Flow curve for materials ,Effect of temperature, strain rate, metallurgical structure, workability and residual stress. Yielding theories, processing maps. Friction in metal working, Lubrication.
Rolling - Classification & processes, load, torque, power, variables controlling process, forward slip. Fundamentals of roll pass design, mill type. Rolling practice, adopted for some common products such as slabs, blooms, billets, plates, sheets etc Rolling defects and their control.
Forging - Classification & processes, load for circular & rectangular plate. Calculation of Forging load under sticking and slipping Plain strain forging analysis. Manufacture of rail wheels and tyres.

Module II **(12 Hours)**

Extrusion - Classification & processes, force & variables affecting it. Deformation and defects in extrusion Calculation of extrusion pressure under plain strain conditions, production of tubes and seamless pipes
Drawing of Wires and Tubes- Processes, drawing stress. Calculation of drawing loads, drawing defects.
Sheet metal Forming- Forming methods, Forming limit criterion, Special Forming techniques in formed products: deep drawing and redrawing. Formability diagrams, Defects in formed products.

Module III **(12 Hours)**
Special forming methods such as high energy forming: explosive forming, electro hydraulic and magnetic forming processes
Non Destructive Testing: Scope and significance of non destructive testing. Principles, equipment, specifications and limitations of liquid penetrant, Magnetic particle, Eddy current, Ultrasonic and Acoustic emissions, and Radiography (X-Ray and Gamma Ray).

Books for reference:

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

2. Roll Pass Design, The United Steel Companies Ltd., U.K.

3. C. Suryanarayana, Testing of Metallic materials.

4. C. Russak, G. W. Rowe, Principles of Industrial Metal Working Processes**.**

5. Baldev Raj, Practical Non Destructive Testing.

Joining of Materials (3-0–0) Credits: 03

Module I **(12 Hours)**
Theory and classification of welding processes Gas, arc, resistance, pressure, submerged arc, TIG, MIG, plasma arc and electron beam welding including spot welding laser welding and diffusion welding. electrodes for welding of structural steels, coating, constituents and their functions, types of coatings, current and voltage selection for electrodes for welding,.

Module II **(12 Hours)**
Power sources; The influence of power sources on welding, Metal transfer and heat flow in fusion welding. Metallurgical effects of the weld thermal cycles Metallurgy of welding of structural steels, HAZ. Metallurgy of fusion welding of ferritic and austenitic steels, cast iron etc. Metallurgical principles of welding nonferrous alloys, Cu alloys, Al alloys etc., welding pool solidification, structure of welds,. Fusion Zone: Basic

solidification concepts, Weld metal solidification, Post solidification phase transformations, Weld metal chemical inhomogenity.

Module III (12 Hours)

Residual welding stresses and stress relieving treatments. Design of welded joints, welding defects and their remedies. Inspection and testing of weldments. Brazing and soldering, consumables used, methods of brazing, fluxes used, their purposes and flux residue treatment.. Joining of ceramics and plastics. Weldability of common engineering materials like carbon and alloy steels, cast irons, stainless steels, Al- and Cu- based alloys, Welding defects and its remedies.

Books for reference:

1. J.F.Lancaster, Allen and Unwin, Metallurgy of Welding.
2. R.L.Little, Welding and Welding Technology, TMH.
3. A.C. Davies, Welding, Cambridge University Press.
4. Sefarin, Metallurgy of Welding, John Wiley.
5. K. Weman, Welding Processes Handbook, Woodhead.

Physics of Materials (3-0-0) Credits: 03

Module I (12 Hours)

Crystallography: Crystalline and amorphous structures, Elements of crystal symmetry, symmetry elements and axes, two, three, four and six fold symmetry, review of atomic bonding. Order-disorder transformations: Ordering, Degrees of long range and short range ordering, Anti phase domain, super lattice, Elements of super lattice theories, properties and applications.

Module II (12 Hours)

Electron theory of Metals: Heisenberg's uncertainty principle, Schrodinger's equation, free electron theory, Zone theory, Density of states, Fermi energy level, Application of zone theory to alloy phases; Conductors and insulators, semi conductors, P- and N- type semi conductors. Optical properties, Refraction, Absorption, Absorption in dielectrics, photographic images, Luminescence, Lasers.

Module III (12 Hours)

Magnetic Properties: Dia, Para and Ferro- magnetism, Domain theory of Ferro magnetism, Anti ferromagnetism and Ferrites, Hysteresis loop, soft magnetic materials, Hard magnetic Materials, Super conductivity, BCS theory, Type- I and Type- II super conductors. Thermoelectric properties of metals and semiconductors, ionic and superionic conductivity in solids. Different types of dielectric materials, ferro, antiferro and ferri-electric materials. Piezo electric materials.

Books for Reference:

1. Reed Hill R.E., Physical Metallurgy Principles, Affiliated East West.
2. Kakani S.L. and Kakani A., Materials Science, New Age International.
3. Higgins R.A., Engineering Metallurgy, Standard Publishers.
4. Raghavan V., Materials Science and Engineering, PHI.

5. Mauraka S.P. and Peckrar M.C., Electronic Materials Science and Technology, Academic Press.

6. Rose-innes A.C. and Rhoderick E.H., Introduction to Superconductivity, Pergamon press, Oxford.

7. Srivastava C.M. and Srinivasan C., Science of Engineering Materials, New Age Pub., New Delhi.

8. Kittel C., Introduction to Solid State Physics, John Wiley.

9. Streetman B.G., Solid State Electronic Devices, Prentice Hall, New Delhi.

10. Goldman A., Van Nostrand, Modern Ferrite Technology, New York.

PRACTICALS / SESSIONALS

Physical Metallurgy and Materials Testing (0-0-6) Credits: 04

A minimum of 16 nos. of experiments to be conducted from the suggested list given below:

1. Annealing treatment of a cold worked steel and comparison of the annealed microstructure with the cold worked structure.
2. Normalizing treatment of steel and comparison of the microstructure with annealed structure.
3. To study the quenched structures of steel – quenched in oil, water and brine solution.
4. To study the quenched and tempered structures of steel –
   - (i) low temperature tempering.
   - (ii) medium temperature tempering.
   - (iii) high temperature tempering.
5. To study the recrystallization behaviour of pure metal (iron / copper).
6. To study the effect of time and temperature on grain size of a metal (grain growth) (iron/ copper).
7. To study the nucleation rate and growth rate of pearlite in eutectoid steel.
8. To study the susceptibility of a steel to harden by quenching (hardenability) by Jominy test.
9. Pack carburizing of 0.2% carbon steel and to measure the diffusion coefficient of carbon in steel.
10. To study the microstructure of tool steels, stainless steels and other high alloy steels.
11. Austempering of steels and S G cast irons.
12. To carry out age hardening of non ferrous alloys.
13. Determination of hardenability of steels.
14. To determine the Vickers Hardness Number of the given Samples.
15. To determine the Brinell Hardness Number of the given Samples.
16. To determine the Rockwell Hardness of the given samples.
17. To determine the impact strength of the given samples by Charpy and Izod Impact Tests.
18. To determine the tensile properties of the given materials using Universal Testing Machine (UTM) – yield strength, tensile strength, % elongation, % reduction of area.
19. To determine the compression strength of the given sample.
20. To determine the fatigue strength of the given sample.
21. To determine the drawability of aluminium / steel sheet by Erichsen cup test.
22. To study the ultrasonic flaw detector and determine the cracks within a sample.

23. To determine the cracks in a sample using the magnetic crack detector.

Pre-thesis work and Seminar **(**0-0-3) Credits: 02

2^{nd} Semester
Professional Core

Characterization of Materials (3-1-0) Credits: 04

Module I (12 Hours)

Introduction, Classification of characterization techniques for materials: macro and micro-characterization structure of solids.
Bulk averaging techniques: Thermal characterization techniques**:** Theory, Instrumentation, methodology, applications. DTA, DTA, DSC, TGA, dilatometry, resistivity/ conductivity. Diffraction methods: X-ray diffraction, X-ray topography, residual stress measurement techniques, small angle X-ray and neutron scattering.

Module II (12 Hours)

Electron microscopy techniques: Scanning electron microscope, Modes of operation, Study of surface topography and elemental composition analysis, Electron probe analysis (EPMA/ EDX, WDS) and Auger Spectroscopy. Transmission electron microscopy, Imaging and different modes, bright and dark field imaging, selected area diffraction (SAED) pattern, specimen preparation techniques. Advanced microscopic techniques: AFM, FIM, STM etc.

Module III (12 Hours)
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Chemical characterization techniques: Principle underlying techniques, Emission spectroscopy, Atomic absorption spectroscopy, X-ray spectrometry, infrared spectroscopy and Raman spectroscopy.Chromatography techniques: Principles of gas chromatography, mass spectrometry, liquid and ion chromatography. Surface characterization techniques: principles underlying techniques of ELES, Auger Spectroscopy,

Books for reference:

1. Materials Characterization, Metals Handbook, Vol 10, ASM
2. Kaufman E.N., Characterization of Materials, Wiley Publishers
3. Barett, C.S. and Massalski, T.B., Structure of Metals, Pergamon Press, Oxford.
4. Cullity B.D., Elements of X-ray Diffraction, Addison-Wesley, 1978
5. Williams, D.B. and Barry Carter C., Transmission Electron Microscopy, Plenum Press.
6. Goldstein J.I., Lyman C. E., Scanning Electron Microscopy and X-Ray Microanalysis.
7. Machenzie R.C., Differential Thermal Analysis.
8. Phillips Victor A. Modern Metallographic Techniques and their application.

Process Metallurgy (3-1-0) Credits: 04

Module I (12 Hours)
Introduction: Scope of extractive Metallurgy, Occurrence of Metals in Nature, Minerals

diagrams for oxides and sulphides. Introduction to mineral beneficiation, sampling, liberation studies and its importance. Unit operation of Comminution, Grinding, Size separation, Classification, Concentration, Froth flotation, Magnetic and electrostatic separation, Dewatering and drying

Module II (12 Hours)

Pyrometallurgy: Ore preparation, Calcination, Roasting, Predominance area diagram, Roasting and Ores, Elementary concepts of extraction of Metals from their ores. Ellingham practice, Reduction smelting, Matte smelting, Converting, Role of Slags. Refining Methods: Fire refining, Liquation, Poling, Cupellation, Vacuum distillation, Zone refining, Electrolytic refining.

Hydrometallurgy: Ore preparation, Leaching practice, Bio leaching, Kinetics of leaching, Role of oxygen in leaching, Recovery of metals from leach liquor by solvent extraction, ion exchange, precipitation, cementation and electro winning methods.

Module III (12 Hours)

Electrometallurgy: Theory of electrodeposition, Faraday’s Laws, Electrode potential, EMF series, Nernst equation, Hydrogen over voltage, Electro winning, Pourbaix diagram. Calculation of material and heat balances pertaining to some important metal extraction process.

Flow sheets: Typical flow sheets for beneficiation of iron, gold, copper, lead-zinc sulphide ores, rock phosphate, beach sand, uranium and other industrial minerals. Problems related to the process metallurgy

Books for reference:

1. Newton J., Extractive Metallurgy, Wiley.
2. Gilchrist J.D., Extraction Metallurgy, Pergamon.
3. Rosenqvist T., Principles of Extractive Metallurgy, McGraw Hill.
4. Ghosh Ahindra, Chatterjee A., Ironmaking and Steelmaking Theory and Practices, PHI Pvt. Ltd.

Professional Elective-III (Any one)

Mineral Engineering (3-0-0) Credits: 03

Module I (14 Hours)

Introduction to mineral beneficiation, sampling, liberation studies and its importance.
Comminution: Fundamentals of comminution, crushing -- construction and operational features of jaw, gyratory, cone and roll crushers. Grinding: Theory of ball mill, rod mill, critical speed of the mill, open circuit and closed circuit, circulating load. Size separation: Sieving and screening, laboratory sizing and its importance, representation and interpretation of size analysis data, industrial screening. Classification: Movement of solids in fluids, free setting and hindered settling of particles, different types of classifiers, e.g. sizing and sorting classifiers used in mineral industry.

Module II (12 Hours)

Concentration: Gravity separation, concentration criteria, jigging, flowing film concentration and tabling, dense media separation. Froth flotation: Theory, reagents used in floatation processes, machines and practice. Magnetic and electrostatic separation: Theory and application of magnetic and electrostatic separation techniques in mineral industry. Dewatering and drying: Theory and practice of thickening; filtra320tion and drying.

Module III (12 Hours)

Flow sheets: Typical flow sheets for beneficiation of iron, gold, copper, lead-zinc sulphide ores, rock phosphate, beach sand, uranium and other industrial minerals.

Agglomeration techniques: Sintering, palletizing, briquetting and their applications in ferrous and non-ferrous metal industries, testing of agglomerates.

Important mineral deposits in India.

Books for reference

1. Gaudin A. M., Principle of Mineral Dressing.
2. Richards R. H. and Locks C. E., Text Book of Ore Dressing.
3. Taggart A.E., Element of Ore Dressing.
4. Taggart A.E., Handbook of Mineral Dressing- Ores and Industrial Minerals.
5. Trusscott S.J., Textbook of Ore Dressing.
6. Jain S.K., Ore Dressing.
7. Willis Berry A, Mineral Processing Technology.

Fuels, Furnaces & Refractories (3-0-0) Credits: 03

Module I (12 Hours)

Fuels: Classification, Their merits and limitations
Solid Fuels- Origin of coal, its types, properties, proximate and ultimate analysis, Coal Washing, Preparation and blending methods, application of coal. Coke making by beehive and by product ovens. Modern practices of coke making, Principles of graphitization and reactivity. Characterization of coke and coal. Selection of reductant fuel for BF, DRI, COREX, Cupola and Pit furnaces. Liquid and gaseous fuels- Types and uses of liquid and gaseous fuels. Flame characteristics. Burners for liquid, gas and pulverized coal. Synthesis and reformation of gas for direct reduction. Producer and water gas.

Module II (12 Hours)
Furnaces: Classification of Furnaces, Basic working principles of fuel fired, resistance, induction and arc furnaces. Energy conservation measures in furnaces. Heat losses in furnaces: Heat balance and furnace efficiency. Advantages and disadvantages of various kinds of furnaces: Laboratory furnaces; oil fired furnaces, soaking pits, reheating furnaces, and annealing furnaces, muffle furnaces, salt and lead bath furnaces. Heating of bodies in furnaces.
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Module III (12 Hours)
Refractories: Classification of refractories, Properties and application of fireclay, silica, chromite, graphite, magnesite, dolomite, zirconia, silicon carbide, silimanite and kyanite refractories. Phase diagrams of refractories. Criteria for selection of refractories for the different furnaces. Refractories used in ferrous and nonferrous industries.

Books for reference:

1. Gilchrist J.D., Fuels, Furnaces and Refractories.
2. Mishra M.L., Refractories manufacture properties and uses.
3. Chesti A.R., Refractories manufacture properties and application
4. Chester, Steel Plant Refractories.
5. Norton, Refractories.
6. Trinks & Mawhinney, Industrial Furnace, Vol. –I & II.
7. Erthrington, Modern Furnace Technology.
8. Thring, Science of Flames and Furnaces
9. Pasckis & Pearson, Industrial Electric Furnaces and Applications.
10. Gutheris & Wakerins, Vacuum Equipment and Techniques.

Ferrous Metallurgy (3-0-0) Credits: 03

Module I (14 Hours)

Introduction: Blast furnace principles and practice for iron making, Reactions: B.F profile , Stove and gas cleaning units, instrumentation , refractory used in B.F and stove Principles of iron and steel making reactions, viz decarburization, dephosphorization, Desulphurization, silicon& manganese reaction.
Slag Theories: Molecular & ionic theories, Interpretation of the above reactions in terms of ionic theory of slag: Fe-C-O, Fe-O-H phase equilibrium, Reaction in stack, bosh and hearth, formation of primary slag , bosh slag and hearth slag . Slag composition and its control, Metal –slag reactions, control of hot metal composition

Module I (14 Hours)

LD Process: Design of converter & lance, Quality of raw materials charged, Operation of the converter and control of bath and slag composition. Chemical reactions involved Temperature and residual bath oxygen control. Use of oxygen sensor, some characteristics of L.D blow viz emulsion formation, slopping, maneuvering lance height for dephosphorisation and dacarburisation. Catch carbon technique, Recovery of waste heat, OBM/Q-BOP process, Concept and operation of the process. Mixed/ combined blowing process. Oxygen top blowing with inert gas purging at bottom, Oxygen top blowing with inert and oxidizing gases at bottom, Oxygen top and bottom blowing, Steel making Scenario in India.

Module I (14 Hours)

Open hearth Furnace: modification into twin hearth, operational principle, advantages.
Electric arc furnace: Advantages, charging, melting and refining practices for plain carbon and alloys steels. Use of DRI in arc furnaces and its effect on performance. UHP electric arc furnace with DC supply. Duplex processes of stainless steel making using VOD, AOD and CLU.
Induction Furnace: Advantages, Principles of induction heating, Use in steel industry. Deoxidation of liquid steel: Requirement of deoxidizers, deoxidation practice, Stoke's law, use of complex deoxidizers, Inclusions and their influence on quality of steel. Killed, semi killed and rimming steels.

Reference Books:

1. Biswas A.K., Principles of Blast Furnace Iron Making, SBA.
2. Ghosh Ahindra, Chatterjee A., Ironmaking and Steelmaking Theory and Practices, PHI Pvt. Ltd.
3. Tupkary R.H., Introduction to Modern Iron Making, Khanna Publishers
4. Gupta S.S. and Chatterjee A., Blast Furnace Iron Making, SBA New Delhi.
5. Tupkary R.H., An Introduction to Modern Steel Making, Khanna Publishers.
6. G.R. Bashforth, The Manufacture of Iron and Steel, Chapman & Hall.
7. Edneral F.P., Electrometallurgy of Steel and Ferroalloys, Vol. 1&2, Mir.

Powder Metallurgy (3-0-0) Credits: 03

Module I (12 Hours)
Production of powders:
Mechanical, Chemical, Electrolytic and atomization Methods. Commercial production of metallic powders**.** Characterization of metal powders: Chemical composition and structure: Particle size and their shape, apparent and tap density, pressing properties and their determination: Powder flow, compressibility and porosity measurements:

Module II (12 Hours)

Treatment of metal powders: Behaviour of powder during compaction. Die compaction: Types of presses: Tooling and design: Modern methods of powder consolidation, Isotactic pressing: Roll compaction, Powder extrusion and forging, Slip casting, evaluation of sintered products.

Module III (12 Hours)

Sintering furnaces and atmosphere: Stages of sintering, driving forces for sintering, mechanism of sintering, liquid phase sintering, hot processing:
Iron, copper and aluminium base P/M alloys: Porous materials: Friction and Antifriction materials: Brushes, Heavy alloys, Cemented carbides: Cermets, Electrical contact materials.

Books for reference:

1. German R.M., Powder Metallurgy Science

2. Lenel F.V., Powder Metallurgy

3. Hirschhorn J.S., Powder Metallurgy.

4. Goetzel C., Treatise on Powder Metallurgy – vol. 1&2.

5. Sands R.L. & Shakespeare C.R., Powder Metallurgy Practice and Applications.

6. Hausner H. H. & Mal M., Handbook of Powder Metallurgy –- 2nd Ed.

Professional Elective-IV (Any one)

Non Ferrous Metallurgy (3-0-0) Credits: 03

ModuleI (12 Hours)

General principles of extraction of metals from oxides and sulphides; Mineral resources of Non ferrous metals in India; Their production, consumption and demand. Future of Non ferrous metal industries in India. Aluminium: Bayer's process and factors affecting its operation, Hall- Heroult process: Principle and practices, anode effect, refining of aluminium. Alternate methods of production of alumina and aluminium.

Module II (12 Hours)

Copper: Roasting of sulphides, Matte smelting, Converting; Refining, By-products recovery; Recent developments, Continuous copper production processes, Hydrometallurgy of Copper.
Zinc: Pyrometallurgy of Zinc; Principle and practices of roasting; sintering and smelting;
Hydrometallurgy of Zinc. Lead: Agglomeration of galena concentrates and roasting, blast furnace smelting, refining of lead bullion.

Module III (12 Hours)

Uranium: Process for the digestion of uranium ores; Purification of crude salts; Production of reactor grade UO_2.Titanium: Methods of upgrading Ilmenite; Chlorination of Titania, Kroll and Hunter processes; Consolidation and refining. Other Metals: Simplified flow sheets and relevant chemical principles of extraction of Ni, Mg, Au, Ag, Sn, Zr.

Reference Books:

1. Ray H.S., Sridhar R. & Abraham K.P., Extraction of Non Ferrous Metals, Affiliated East West.

2. Biswas A.K. & Davenport W.G., Extractive Metallurgy of Copper, Pergamon.

3. Zelikman A.N., Krein O.E. & Samsonov G.V., Metallurgy of Rare Metals, Israel Program for Scientific Translation.

4. Burkhin A.R. (ed), Production of Al & Al_2O_3, Wiley.

Alternative Routes of Iron Making (3-0-0) Credits: 03

Module I (12 Hours)
Characteristics of raw materials and their preparation. Thermodynamics and Kinetics aspects.

Direct Reduction Processes:
Reduction of Iron bearing materials in shaft furnace, rotary kiln, retort and fluidized bed with special reference to reductant, energy consumption and operational problems.

Module II (12 Hours)

Commercially available processes like SL/RN, ACCAR, Krup-CODIR, Kinglon Meter, MIDREX, HyL, Purofer, Iron Carbide, etc.

Module III (12 Hours)

Uses of DRI in steel making, iron making and foundries; effect on DRI on EAF performance and product characteristics.

Smelting Reduction Processes:
COREX, ROMELT, Fluidized bed reactors, Hismelt etc. Present status of alternative methods of iron making in India.

Books for reference:

1. Chatterjee Amit, Alternative Routes of Iron Making, PHI.

2. Chatterjee Amit, Beyond the Blast Furnace.

3. Sarangi A., Sarangi B., Sponge Iron Production in Rotary Kiln, PHI.

4. Jerome Feinman & Donald R. Mac Rae, Editiors: Direct Reduction of Iron, Allied Publishers Ltd.

Ferro Alloys Technology (3-0-0) Credits: 03

Module I (14 Hours)

Ferro Alloys Technology:
Survey of Ferro-alloy industries in India and their future prospects.
Physico-chemical principles of ferro-alloy making, principles of carbothermic and metallothermic reduction.

Ferro-alloy furnaces: Submerged arc furnaces, selection for transformer capacity, secondary voltage and current, furnace dimensions, size and spacing of electrodes, mechanical equipments, charging devices and dust collection system.

Module II (12 Hours)

Electrodes used in ferro-alloy furnaces: graphitised and self baking electrodes, properties and uses.

Production of ferro-manganese, ferrochrome, ferrosilicon and silico-calcium by carbothermy, production of FeCr, FeTi, FeB, FeNb, FeMo, and FeV by metallothermy. Recovery of vanadium from ores and production of FeV.

Module III (12 Hours)

Charge calculations in production of ferro-alloys.
Use of plasma arc for production of ferro-alloys.
Use of ferro-alloys in Iron and Steel industries (deoxidation and alloy making).

Books for Reference:

1. Riss and Khodorovasky, Production of Ferro-Alloys.

2. Elyutin V.P., Production of Ferro-Alloys.

3. Edneral F.P., Electro-metallurgy of Steel and Ferro-Alloys, Vol. 2.

Biomaterials (3-0-0) Credits: 03

Module I **(12 Hours)**

Introduction: Definition of Biomaterials: Performance of Biomaterials; Brief Historical Background.

Metallic Implant Materials: Stainless Steels; Co-Based Alloys; Ti and Ti-Based Alloys; Dental Metals; Other Metals; Corrosion of Metallic Implants.

Ceramic Implant Materials: Structure–Property Relationship of Ceramics; Aluminum Oxides (Alumina); Zirconium Oxides (Zirconia); Calcium Phosphate; Glass-Ceramics; Other Ceramics; Carbons; Deterioration of Ceramics.

Module II **(12 Hours)**

Polymeric Implant Materials: Polymerization and Properties; Effect of Structural Modification and Temperature on Properties; Polymeric Implant Materials; High-Strength Thermoplastics; Deterioration of Polymers.

Composites as Biomaterials: Structure; Mechanics of Composites; . Applications of Composite Biomaterials; Biocompatibility of Composite Biomaterials.

Structure–Property Relationships of Biological Materials: Proteins; Polysaccharides; Structure–Property Relationship of Tissues.

Tissue Response to Implants: Normal Wound-Healing Process; Body Response to Implants; Blood Compatibility; Carcinogenicity.

Module III **(12 Hours)**

Soft Tissue Replacement: Sutures, Skin, and Maxillofacial Implants: Sutures, Surgical Tapes, and Adhesives; Percutaneous and Skin Implants; Maxillofacial and Other Soft-Tissue Augmentation.

Blood Interfacing Implants: Blood Substitutes and Access Catheters; Cardiovascular Grafts and Stents; Blood Vessel Implants; Heart Valve Implants; Heart and Lung Assist Devices; Artificial Organs.

Hard Tissue Replacement: Long Bone Repair: Wires, Pins, and Screws; Fracture Plates; Intramedullary Devices; Acceleration of Bone Healing.

Joints and Teeth: Joint Replacements; Spinal Implants; Dental Restorations and Implants; Interface Problems in Orthopedic and Dental Implants.

Books for reference:

1. Park Joon and Lakes R.S., Biomaterials - An Introduction, Third Edition, Springer.

2. Ratner B.D., Hoffman A.S., Schoen F.J., Lemons J.E., Biomaterials Science: An Introduction to Materials in Medicine, Academic Press.

Professional Elective-V (Any one)

Advanced Casting Processes (3-0-0) Credits: 03

Module – I (12 hours)

Principles of casting design, pattern design considerations, pattern allowances, pattern design and construction. Features of moulding processes, equipments, mechanizations, forces acting on moulds, mould factors in metal flow, molding factors in casting design.

Module – II (12 hours)

Design of different types of cores and core prints Fundamentals of fluid flow, design of gating system, slag traps and filters etc. Types of binders and their uses in mould and core makings. Melting practices as adopted for a few metals and alloys.

Module – III (12 hours)

Concept of directional and progressive solidification, Time of solidification and Chowrinov rule, differential methods of feeder design, feeding distance, feeding efficiency, feeder aids. Feeding characteristics of alloys, types of gates and risers. gating ratio. Yield of casting and prescription for its augmentation.

Books for Reference:

1. Heine R.W., Lopper C.R. & Rosenthal P.C., Principles of Metal Casting, McGrawHill.
2. Davis, G.J., Solidification in Casting, Applied Sciences.
3. Beeley P.R., Foundry Technology, Butterworth.
4. Kondic V., Metallurgical Principles of Foundry, Edward Arnold.

Composite Materials (3-0-0) Credits: 03

Module I (12 Hours)
Introduction, classification, strengthening mechanism in composites, types of reinforcement-metallic and nonmetallic fibers, whiskers and particulates;

Metal matrix and ceramic matrix composites:

Technology for production of composites - liquid metal route, powder metallurgy and mechanical working for metal matrix and ceramic matrix composites - processing routes including reaction sintering combustion synthesis, infiltration and in-situ processes;

Module II (12 Hours)
Processing of intermetallic composites, Comparison of MMCs and CMCs.

Polymer composites:
Matrices, thermoplastic and thermosetting; Reinforcements - continuous and discontinuous fibres - glass, aramid, polyester, and carbon fibres; surface characteristics; hybridisation techniques, Fillers and their uses, autoclave, hand lay-up techniques etc.,

Module III (12 Hours)
Fabrication methods of polymer matrix composites:

Filament winding; Resin injection moulding; extrusion, calendering, pultrusion, degradation of fibers.

Sandwich structures, foam core type arrangements; Honey comb structures.

Application of composites: Aerospace, marine, automobile, dental products.
Design aspects, carbon-carbon and carbon - epoxy based composites, mechanical properties.

Books for reference:

1. Matthews and Rawlings, Composite Materials: Engineering and Science, CRC Press.
2. K K Chawla, Composite Materials: Science and Engineering, Springer.
3. D.Hull and T.W. Clyne, An Introduction to composite material, Cambridge University press.
4. Taya, M. and Arsenault, R.J., Metal Matrix Composites, Thermomechanical Behaviour, Pergamon Press, Oxford.
5. Suresh, S., Martensen, A. and Needleman, A., Fundamentals of Metal Matrix Composites, Butterworth, Heinemann.

Nano Materials (3-0-0) Credits :03

Module – 1 (12 hours)

Introduction: Types of nanomaterials, emergence of nanotechnology, bottom-up and top-down approaches, challenges in nanotechnology.

Nanoparticles: synthesis of metallic nanoparticles, semiconductor nanoparticles, oxide nanoparticles (sol-gel processing); vapour phase reactions, solid phase segregation.

Nanowires: Synthesis of nanowires by evaporation – condensation growth, VLS or SLS growth, stress induced recrystallization, template based synthesis, electrospinning, lithography.

Thin Films: fundamentals of film growth, PVD, CVD and ALD.

Module – II (12 hours)

Special Nanomaterials: Carbon fullerenes and nanotubes, micro and mesoporous materials, core-shell structures, organic – inorganic hybrids, nanocomposites and nanograined materials.

Nanostructures fabricated by physical techniques: lithography - photolithography, electron beam lithography, X-ray lithography, FIB lithography; nanolithography - STM, AFM, NSOM; soft lithography; assembly of nanoparticles and nanowires and other methods of microfabrication.

Module – III (12 hours)

Characterization and properties of nonmaterials: Structural characterization by XRD, SAXS, SEM, TEM, SPM, gas adsorption; Chemical characterization by spectroscopy techniques; Mechanical properties; Optical, electrical and magnetic properties.

Applications of nanomaterials: molecular electronics and nanoelectronics, nanobots, biological applications, catalytic applications, quantum devices, carbon nanotube emitters, nanofluids.

Books for reference:

1. Cao G., Nanostructures and Nanomaterials: Synthesis, Properties and Applications, Imperial College Press.
2. Gagotsi Y., Nanomaterails Handbook, (Ed.), Taylor and Francis.
3. Poole C. P. and Owee F. T., Introduction to Nanotechnology, Willey Press.
4. Edlstein and Cammarate, Nano Materials Synthesis, Properties and Applications.
5. Bandyopadyay A.K., Nano Materials, New age Publications.
6. Pradeep T., Nano - The Essentials, TMH.
7. Koch,C. Nanostructured Materials: Processing, Properties and applications, William Andrew Publishing.

Engineering Materials (3-0-0) Credits: 03

Module I (12 Hours)
Introduction, Classification of Engineering Materials, selection of materials and Their Applications, Structure property Relationship.
Engineering Alloys:
Low carbon steels, Mild steels, Medium carbon steels, High strength structural steels, Tool steels, Stainless steels, High temperature alloys, Cast irons, The light alloys, Copper and its alloys, Bearing alloys

Module II (14 Hours)
Introduction to ceramics, common ceramic crystal structure, silicates, clay minerals, graphite, carbides etc.: Pauling rules, crystal binding and cohesive energy co-ordination, structural imperfections, diffusion, ceramic phase equilibrium diagram, nucleation, grain growth, sintering and vitrification, microstructure development of ceramics whitewares, refractories, technical ceramics and abrasives. Mechnacial behaviour of Structural ceramics-Brittleness of ceramics, Concept of fracture toughness and different toughness measurement techniques, Elastic modulus, Strength measurement and Weibull theory of strength variability, Concept of various toughening mechanisms; Processing and Properties of ceramic composites- Examples of toughened particle reinforced composites, Whisker reinforced composites, Fibre reinforced composites; Recent advances in Structural Ceramics- Functionally graded ceramic composites, Bioceramics and composites.

Module III (12 Hours)
Structure and Properties of amorphous and semi crystalline polymers, Polymer Conformation and Configurations, Factors determining Crystallinity of Polymers, Semicrystalline Polymers. Structure and Properties of Rubbers and Elastomers, Thermoset and thermoplastic Elastomers, Crystallization of Elastomers. Fabrication and Processing of polymer, Mechanical behaviour of different polymers, Polymer matrix composites,

Books for Reference:

1. Basu B. and Balani K.,Advanced in Structural Ceramics, Wiley 2011

2. Avner S.H., Introduction to Physical Metallurgy – McGrawHill.
3. Callister William D Jr , Materials Science and Engineering: An Introduction.
4. Chawla Krishna K, Composite Materials – Science and Engineering.
5. Kingery, Bowen and Uhlmann, Introduction to Ceramics.
6. ASM Handbook Volume 21: Composites

PRACTICALS / SESSIONALS

Materials Processing and Process Metallurgy Lab. (0-0-6) Credits: 04

A minimum of 16 nos. of experiments to be conducted from the suggested list given below:

1. Physical examination and identification of minerals.
2. Crushing of ore/ coal in a jaw crusher and to study the size analysis of the product.
3. To study the jaw crusher and determine the actual capacity and reduction ratio.
4. Verification of Rittinger's Law of crushing in a jaw crusher.
5. Crushing of ore/ coal in a roll crusher and to study the size analysis of the product.
6. Crushing of ore/ coal in a gyratory crusher / pulveriser and to study the size analysis of the product.
7. Crushing of ore/ coal in a cone crusher and to study the size analysis of the product.
8. To study the effect of grinding with grinding time in cylindrical ball mill and rod mill.
9. To separate coal from a mixture of coal and stones or quarts by zigging and determine the weight fractions of the products.
10. To separate a mixture of two minerals of different densities by gravity concentration using Wilfley Table and determine the weight and density of each fraction of the products.
11. Beneficiation of ore pulp mix using flotation cell.
12. To separate a mixture of iron and sand using magnetic separator and determine its efficiency.
13. Screening of ore/ coal using vibrating screen and determine its effectiveness.
14. Proximate analysis of coal and coke.
15. To determine calorific value of coal and coke using bomb calorimeter.
16. To determine bulk density of coal sample.
17. To determine true density of coal sample.
18. To determine shatter and abrasion indices of coal and coke.
19. To determine flash point and fire point of a given sample such as kerosene oil, diesel, petrol by Pensky-Marten's apparatus or Cleveland open cup apparatus.
20. To determine viscosity of oil by Engler viscometer and the water number in the apparatus.
21. To determine effect of temperature on kinematic viscosity of glycerene by Redwood viscometer.
22. Kinetic studies of oxidation of copper.
23. Kinetic studies of reduction of iron ores.

24. Kinetic studies of decomposition of calcium carbonate.
25. Kinetic studies of decomposition of magnesium carbonate.
26. To study the flow of gases through beds of solid particles.
27. Determination of heat transfer coefficient by using Newton's Law of cooling.
28. Leaching of sulphide ores.
29. Press moulding of polymers and polymer based composites.
30. Compaction of metal powders and determination of green density.
31. Sintering of metal powders and determination of sintered density.

Pre-thesis work and Seminar (0-0-3) Credits: 02

Comprehensive Viva-Voce – I (0-0-3) Credits: 02

3rd Semester

Open Elective

Degradation of Materials (3-0-0) Credits: 03

Module I **(14 Hours)**

Technological importance of corrosion study, corrosion as non equilibrium process, corrosion rate expressions, electrochemical principles of corrosion-cell analogy, concept of single electrode potential, reference electrodes, e.m.f. and galvanic series-their uses in corrosion studies, polarization, passivity.

Different forms of corrosion-uniform attack, galvanic, crevice, pitting, intergranular, selective leaching, erosion, stress corrosion cracking-their characteristic features, causes and remedial measures.

Module II **(12 Hours)**

Principles of corrosion prevention-material selection, control of environment including inhibitors, cathodic and anodic protection, coatings and design considerations. Corrosion testing methods.

Introduction to high temperature corrosion, Pilling-Bedworth ratio, oxidation kinetics, oxide defect structures, Wagner-Hauffe valence approach in alloy oxidation, catastrophic oxidation, internal oxidation.

Module III **(12 Hours)**

Considerations in high temperature alloy design, prevention of high temperature corrosion -use of coatings.

Liquid metal attack - liquid metal embrittlement, preventive measures.

Chemical degradation of non-metallic materials like rubbers, plastics, ceramics etc.

Hydrogen damage - types, characteristics, mechanism and preventive measures.

Books for reference:

1. Fontana, M.G., Corrosion Engineering, McGraw-Hill.
2. Uhlig H.H., Corrosion & Corrosion control, John Wiley & Sons.
3. Evans, Introduction to Metallic Corrosion.
4. Glasstone S., Introduction to Electrochemistry.
5. Banerjee S.N., An Introduction to Science of Corrosion & its Inhibition, Oxonian Press Pvt. Ltd.

Tribology of Materials (3-0-0) Credits: 03

Module I **(12 Hours)**

Background and importance of Tribology; A system approach to Tribology; Characterization of tribosurfaces; mechanics of solid contacts; Hertzian and non-hertzian contact. Contact pressure and deformation in nonconformal contacts, friction in contacting rough surfaces, sliding and rolling friction, various laws and theory of friction and frictional heat generation; role of contact temperature.

Module II (12 Hours)

Different modes of wear; Wear and wear types; Mechanisms of wear - Adhesive, brasive, corrosive, erosion, fatigue, fretting, etc., Wear of metals and non-metals. Wear models - asperity contact, constant and variable wear rate, geometrical influence in wear models, wear damage. Wear in various mechanical components, wear controlling techniques. Tribological testing techniques and analysis of the worn surfaces.

Module III (12 Hours)

Different wear resistant materials; recent research results illustrating the performance of surface coatings, bulk materials and composite materials in tribological contacts. Lubrication; Importance and properties of lubricants.

Books for reference:

1. K.C. Ludema, Friction, Wear, Lubrication - A Text book in Tribology, CRC press.
2. Jamal Takadoum, Materials and Surface Engineering in Tribology.
3. Hutchins, Tribology.
4. Bharat Bhusan, Principle and Application of Tribology.
5. Bharat Bhusan, Introduction to Tribology.

Surface Engineering (3-0-0) Credits :03

Module I (12 Hours)

Introduction: Concept of surface engineering, significance, methods of manufacturing and application of surface layers.

Solid surface: significance of the surface, geometrical, mechanical and physic-chemical concept of the surface, phase and interphase surface, surface energy and surface phenomena.

Surface dependent engineering properties, viz., wear, friction, corrosion, fatigue, reflectivity, emissivity, etc.; common surface initiated engineering failures; mechanism of surface degradation; importance and necessity of surface engineering; classification and scope of surface engineering in metals, ceramics, polymers and composites, tailoring of surfaces of advanced materials.

Module II (12 Hours)

Surface protection (Physical); surface modification (Chemical) techniques: classification, principles, methods, and technology; conventional surface engineering methods: carburising, nitriding, cyaniding, diffusion coating, hot dipping, galvanizing etc.; electrochemistry and electro-deposition; scope and application of conventional surface engineering techniques in engineering materials; advantages and limitations of conventional processes.

Module III (12 Hours)

Recent techniques of producing surface layers: formation of surface layers by mechanical, thermo-mechanical, thermal, thermo-chemical, electrochemical, physical techniques; electron beam technology; laser technology; ion implantation; glow discharge method and CVD technology; vacuum deposition by physical techniques (PVD).

Books for reference:

1. Tadeusz Burakowski and Tadeusz Wierzchon, Surface engineering of metals - principles, equipments, technologies, CRC press.

2. Davis, J.R., Surface Engineering for Corrosion and Wear Resistance, Edited, ASM International.

Modelling and Computer Application in Metallurgy (3-0-0) Credits: 03

Module I (12 Hours)

Fundamentals of Modeling, processes modeling and physical modeling. Numerical methods for solution of ordinary differential equations. Application of regression analysis and curve fitting techniques.

Module II (12 Hours)

Calculation of phase diagrams, stereographic projections. Computer applications for energy & material balance in B.F. and BOF Steel making processes.

Module III (12 Hours)

Numerical solution of partial differential equations pertinent to heat, mass & momentum transfer. Computer applications in solidification, potential energy diagrams and experiments in metallurgy. Analysis of test data using softwares.

Reference Books:

1. Chapra S.C. and Canale S.C., Numerical Methods for Engineers, Tata McGraw Hill.

2. Szekley J.S., Evans J.W. and Brimakombe J.K., The Mathematical and Physical Modelling of Primary Metals Processing Operations, Wiley.

Secondary Steel Making (3-0-0) Credits: 03

Module I (12 Hours)

Secondary steel making principles and practices: Objectives and techniques adopted in secondary steel making. Ladle metallurgy: Outline of inert gas stirring: CAS/CAS (OB), Ladle furnace, vacuum degassing of steel and related processes.

Module II (14 Hours)

Transport phenomena in ladles: Role of slag and powders in inclusion control: Desulphurization, Dephosphorisation. Modification of inclusion morphologies, production of ultra low carbon, ultra low sulphur, ultra low phosphorus and inclusion free steels.

Module III (14 Hours)

Tundish metallurgy: Evaluation of tundish hydrodynamic performances: Solidification phenomena: Conventional, continuous and near net shape casting phenomena. Powder injection systems. Production of alloy steel through post solidification treatments (VAR, ESR); Refractories used in secondary steel making furnaces, their properties and selection criteria. Process selection in secondary steel making.

Reference Books:

1. Ghosh A., Secondary Steelmaking- principle & Applications, CRC Press.
2. Ghosh A., Principles of Secondary Steelmaking Processing and Casting of Liquid Steel, Oxford & IBH Publication.
3. Ghosh Ahindra, Chatterjee A., Ironmaking and Steelmaking Theory and Practices, PHI Pvt. Ltd.

PRACTICALS / SESSIONALS

Thesis Part-I Credits: 14

4^{th} Semester

PRACTICALS / SESSIONALS

Thesis Part-II		Credits: 20
Technical Seminar	(0-0-3)	Credits: 02
Comprehensive Viva-Voce-II	(0-0-3)	Credits: 02