SEMESTER – III

21YN71 PROJECT WORK – I

vide Automotive Engineering 21AE71

SEMESTER – IV

21YN81 PROJECT WORK – II

Vide Automotive Engineering 21AE81

PROFESSIONAL ELECTIVE THEORY COURSES (Four to be opted)

21YN09 THERMODYNAMICS OF MATERIALS

3 0 0 3

LAWS OF THERMODYNAMICS: First law of thermodynamics - thermo chemistry, internal energy, heat capacity and enthalpy. Second and third laws of thermodynamics - entropy and statistical interpretation of entropy- combined statement of first and second laws. Concept of free energy - thermodynamic functions - Maxwell's relations - Gibbs-Helmholtz equation - effect of temperature on thermodynamic properties. (11)

THERMODYNAMIC POTENTIALS: Fugacity, activity and equilibrium constant. Clausius-Clayperon equation- effect of pressure on the equilibrium temperature. LeChatelier's principles and Vant Hoff's equation. Sievert's law. (10)

THERMODYNAMICS OF SOLUTIONS: Partial and integral molar quantities- Gibbs - Duhem equation and its applications. Ideal solutions - Raoult's law. Real solutions - activity coefficient - Henry's law - alternative standard states. Mixing functions and excess functions, Regular solutions. (12)

THERMODYNAMICS OF PHASE TRANSFORMATION:, Phase transformations in materials. Ellingham diagrams- free energy-composition diagrams – construction of binary phase diagrams. Simulation of phase diagrams using Thermocalc, DICTRA and PRISMA. . (12)

Total L : 45

REFERENCES:

1. David R Gaskell, David E Laughlin, "Introduction to the Thermodynamics of Materials", Sixth Edition, CRC PRESS, Taylor and Francis, 2018.
2. Porter. D. A, Easterling K E , K.Y.Sherif, "Phase Transformations in Metals and Alloys", 3rd edition, Chapman and Hall, London, 2009.
3. Upadhaya G S, Dube R K, "Problems in Metallurgical Thermodynamics and Kinetics", e-edition, Pergamon, 2013.
4. Saunders, Miodownik , "CALPHAD (Calculation of Phase Diagrams): A Comprehensive Guide", Pergamman Press, 1998.

21YN10 CHARACTERIZATION TECHNIQUES

3 0 0 3

OPTICAL MICROSCOPY: Optical microscopy - imaging theories - Bright field, Oblique and Dark field illumination. Phase contrast, polarized light and hot stage microscopy. Interference techniques, Introduction to colour Metallography. Quantitative Metallography – image analysis- Calibration techniques. (10)

DIFFRACTION TECHNIQUES: Crystallography concepts - Reciprocal space. Diffraction of X-rays- Bragg's law - Atomic scattering and geometrical structure factors. Factors influencing the intensities of diffracted beams. Types of Diffractometer, Powder X-ray diffractometer. Structure Analysis - Phase identification, lattice parameter, crystal structure and lattice strain determinations. Introduction to SAXS,GISAXS,LEED,RHEED and Neutron Diffraction. (12)

ELECTRON MICROSCOPY: Interactions between electron beam and sample - Secondary electrons. Backscattered electrons, X-Ray Continuum, Characteristic X- Rays and Auger electrons. Photon-specimen interactions – Absorption and secondary fluorescence. Construction of electron microscopes - Lens aberrations, Image formation in EM; SEM- EBSD, Transmission Electron Microscopy - specimen preparation techniques - BF, DF and SAD techniques. Introduction to HRTEM. Energy Dispersive Spectroscopy, Wavelength Dispersive Spectroscopy- Application to materials. (12)

SURFACE AND THERMAL ANALYSIS: Atomic Force Microscopy, Scanning Tunneling Microscopy, and X-Ray Photoelectron Spectroscopy. Spectroscopic analysis- Atomic Absorption Spectroscopy, UV/Visible spectroscopy, XRF, Fourier Transform Infrared Spectroscopy, Raman spectroscopy. Thermo Gravimetric Analysis, Differential Thermal Analysis, Differential Scanning Calorimetry, Thermo Mechanical Analysis and dilatometry - Applications. (11)

Total L : 45

REFERENCES:

1. Angelo P C, "Materials Characterization", Reed Elsevier India Pvt Ltd, 2013

2. Yang Leng, “Materials Characterization -Introduction to Microscopic and Spectroscopic Methods”, John Wiley & Sons pvt. Ltd Singapore, 2013.
3. Cullity B D , Stock S R, “Elements of X-ray Diffraction”, 4th edition, Prentice Hall, Inc, 2017.
4. Sam Zhang, Lin Li, Ashok Kumar; “Materials Characterization Techniques” CRC press, 2008.
5. ASM Handbook, “Materials Characterization”, ASM international, Volume 10, USA, 2019.

21YN11 IRON AND STEEL MAKING

3 0 0 3

INTRODUCTION: Historical background - evolution of modern iron and steel making - overview of iron and steel making in India and abroad - general layout of integrated steel plants - Overview of blast furnace iron making and modern steel making. Raw materials for blast furnace iron making: metallurgical coke - coke manufacture - by-product coke ovens - iron ores - iron ore beneficiation - agglomeration methods - principle and mechanism of sintering, pelletization, fluxes. (10)

IRON MAKING: Layout, constructional features of the blast furnace- charging equipment- burden distribution- gas cleaning- hot blast stoves- operational irregularities - Physical chemistry of blast furnace reactions - carbon-oxygen reaction and gas-solid reactions- reactions in stack- bosh and hearth - RAFT calculations - blast furnace productivity - fuel efficiency - modern developments - sponge iron production and smelting reduction processes - alternate routes of iron making. (13)

STEEL MAKING: Physical chemistry of primary steel making – Slag and slag making - carbon, silicon, manganese and phosphorus reactions. Refractories for steel making. BOF plant practice: input materials, pre-treatment of hot metal prior to steel making. LD process - plant and equipment - metallurgical features of oxygen steel making - slag-metal-gas interactions - bottom blown and bath agitated processes - EAF, CONARC and EOF processes. (12)

SECONDARY STEEL MAKING: Deoxidation practices - ladle furnace. Dephosphorization and desulphurization and decarburization methods - vacuum degassing methods - Injection metallurgy- clean steel technology- stainless steel making. Steel Ingots - fundamentals of solidification - rimming, capped and killed steels - ingot defects. Continuous casting of steel - heat transfer and solidification - continuous casting of slabs and blooms - metallurgical defects. (10)

Total L: 45

REFERENCES:

1. Ahindra Ghosh , Amit Chatterjee, “Iron Making and Steel Making - Theory and Practice”, PHI Learning Private Ltd., New Delhi, 2015.
2. Wakelin D H (ed), “The Making, Shaping and Treating of Steel: Iron Making”, The AISE Steel Foundation, 2004.
3. Fruehan.J.R (ed.), “The Making, Shaping and Treating of Steel: Steel making, The AISE Steel Foundation, 2004.
4. Tupkary R J ,Tupkary V R, “An Introduction to Modern Iron Making”, Khanna Publishers, New Delhi, 2015.
5. Tupkary R J , Tupkary V R, “An Introduction to Modern Steel Making”, Khanna Publishers, New Delhi, 2015

21YN12 SURFACE DEGRADATION OF MATERIALS

3 0 0 3

CORROSION FUNDAMENTALS: Forms of corrosion – Principles of electrochemistry: Faraday’s laws of electrolysis - electrochemical cell analogy - emf / galvanic series - reference electrodes - standard half cell – Free energy and Nernst equation – polarization, over potential, passivity and transpassivity - mixed potential theory - Pourbaix diagram for metal-water systems – review of aqueous corrosions and mechanically assisted corrosion - high temperature, microbiological and stray current corrosion. (13)

EVALUATION AND PREVENTION OF CORROSION: Corrosion rate measurement - classification of corrosion tests - laboratory tests : weight loss method, indicator tests, susceptibility test, planned interval test and electrochemical methods of corrosion testing – field corrosion tests - ASTM standards - NDT techniques for corrosion monitoring – location analysis - factors influencing corrosion – corrosion prevention: design, material selection, cathodic and anodic protection, inhibitors, coatings, and painting. (11)

CASE STUDIES IN CORROSION: Corrosion failures of pipelines and boilers – Corrosion failures in petrochemical, marine and automobile components – Corrosion failures in biomedical implant. (10)

FRICTION AND WEAR: Friction of engineering materials – lubrication types and purposes. Wear of engineering materials – Wear types and mechanisms – delamination theory – debris analysis - case studies on wear failures. Wear and friction testing methods – ASTM standards. (11)

Total L : 45

REFERENCES:

1. Uhlig's Corrosion Handbook, Edited by R. Winston Revie, Third Edition, John Wiley & Sons, Inc, 2011.
2. Pierre R. Roberge, “Corrosion Engineering – Principles and practice”, McGraw Hill, 2008.
3. Mars Fontana , Corrosion Engineering, Third Edition, McGraw Hill Education, 2005.
4. ASM Handbook Volume 13A, “Corrosion: Fundamentals, Testing, and Protection”, Edited by Stephen D. Cramer and Bernard S.Covino, Jr., 2003.

5. Prasanth Sahoo, “Engineering Tribology”, PHI Learning, 2005.

21YN13 PARTICULATE TECHNOLOGY

3 0 0 3

POWDER PRODUCTION AND CHARACTERIZATION: Classification of powder production techniques - preparation of metallic, ceramic and composite powders and their characterization. Basic concepts of sampling and characterization. Techniques for detailed analysis of composition, particle size, shape, apparent and tap densities, particle size distribution and surface area of powders. (11)

POWDER CONDITIONING AND CONSOLIDATION: Annealing of powders - mixing and blending - equipment. Techniques of compaction- die compaction- methods, problems and design considerations. Properties of green compacts. High density processing: Cold Isostatic Pressing, powder rolling and powder forging. (11)

SINTERING AND FINISHING: Theory of solid state and liquid phase sintering. Stages in sintering, structure and property changes. Sintering mechanisms with examples. Other types of sintering. Sintering furnaces-types. Sintering atmospheres- types, production ,properties and applications - Properties of sintered compacts. High temperature consolidation-Hot pressing and Hot Isostatic Pressing. (HIP). Finishing and secondary operations. (11)

POWDER METALLURGY PRODUCTS: Steps in the production of self lubricating bearings, friction materials, carbide tools, cermets, dispersion strengthened alloys and magnetic materials- scope, advantages, limitations and specific examples - Important P/M alloys: Iron base, Aluminium base, Nickel base, titanium base alloys, refractory metals and their processing. Applications of commercial P/M Alloys in automobile, aerospace, defence, industrial nuclear and miscellaneous applications. (12)

Total L: 45

REFERENCES:

1. Angelo P C and Subramanian R, “Powder Metallurgy Science, Technology and Applications”, Prentice Hall of India, New Delhi, 2012.
2. ASM Metals Handbook, Volume 7, “Powder Metallurgy, Edited by Prasan K. Samal and Joseph W. Newkirk, 2015.
3. Upadhayaya G S, Upadhayaya A and Tagaki K, “Powder Metallurgy-Science Technology and Materials”, Universities Press, UK, 2011.
4. Randall M German, ”Powder Metallurgy Science”, Princeton, N.J Metal Powder Industries Federation,USA,1994.

21YN14 METALLURGY OF STEELS

3 0 0 3

CARBON STEELS: Plain carbon steels- effect of alloying elements on Fe-C diagram - composition, structure, properties and heat treatment. Specifications and designations for various steels- AISI/SAE, BIS, EN/ISO, ASTM and UNS standards. (10)

SPECIAL STEELS: HSLA, bainitic and micro alloyed steels- thermo-mechanical processing. DP steels, IF steels, CP steels, TRIP steels, TWIP steels, MBIP steels, Low density high strength steels (Fe-Al-Mn steels) - line pipe steels. heat treatment processes, structure - property correlation. (12)

STAINLESS STEELS: Composition, structure, property - effect of alloying elements - heat treatment and applications of ferritic, martensitic, austenitic, precipitation hardening, duplex, nickel free austenitic stainless steels and High Nitrogen Stainless(HNS) steels – Specifications - AISI, EN, UNS standards. (12)

STEELS FOR SPECIFIC APPLICATIONS: Manufacture, structure, property, heat treatment and applications of maraging steels, silicon steels, high manganese steels, tool steels and high temperature steels- Cr-Mo, Cr-Mo-V, and Cr-Mo-V-Nb steels and cryogenic steels. (11)

Total L: 45

REFERENCES:

1. P.C.Angelo, B.Ravisankar, “Introduction to Steel- Processing, Properties and Applications”, CRC Press, Taylor & Francis Group, Florida, U.S.A. 2019.
2. Balram Gupta, “Aerospace Materials volume 1- 4”, S Chand and Co., New Delhi, 2002.
3. Donald S Clark, W R Varney, “Physical Metallurgy for Engineers”, Affiliated East West Press, New York, 1987.
4. Lula R, “Stainless Steels”, ASM, Ohio, 1990.

21YN15 METALLURGY OF NONFERROUS ALLOYS

3 0 0 3

COPPER ALLOYS: Properties and applications of metallic copper - influence of alloying elements in copper alloys - classification of copper base alloys, their compositions, heat treatment, microstructure, properties and applications. (10)

ALUMINIUM : Properties and uses of metallic aluminium - classification of aluminium alloys, wrought and cast alloys; heat treatable and non-heat treatable alloys - Physical metallurgy of Al alloys, effect of alloying elements and impurities; properties - strengthening mechanisms in non-heat treatable alloys and heat treatable alloys. (11)

MAGNESIUM ALLOYS: Properties and applications of magnesium and magnesium alloys; influence of alloying elements - Al, Mn, Zn, Si, Ag, Th, Zr; classification-cast alloys and wrought alloys. Properties and applications of low melting alloys **TITANIUM**: Introduction; Ti and its alloying capability, alloying elements - alpha and beta stabilizers, alpha titanium alloys; beta titanium alloys and alpha-beta titanium alloys – structure-property correlation. (12)

NICKEL AND OTHER ALLOYS: Metallurgy of nickel base alloys - alloying elements and their effects-Nickel base superalloys composition - melting - solid solution alloys, precipitation hardenable alloys and ODS alloys. Heat treatment, properties and applications - Nickel-iron base alloys, heat treatment, properties and applications. Zirconium alloys, refractory metals and precious metals. (12)

Total L : 45

REFERENCES:

1. P.C. Angelo, B. Ravisankar, " Non ferrous alloys: Structure, Properties, and Engineering Applications, Cengage Publisher, 2018.
2. Balram Gupta, "Aerospace Materials" volume 1- 4, S Chand and Co., New Delhi, 2002.
3. Donald S Clark, W R Varney, "Physical Metallurgy for Engineers", Affiliated East West press, New York, 1987.
4. Amol A. Gokhale, N Eswara Prasad Biswajit Basu , "Light Weighting for Defense, Aerospace, and Transportation (Indian Institute of Metals Series) 2019

21YN16 POLYMERS AND CERAMICS

3 0 0 3

POLYMERS: Classification-thermoset, thermoplastics and elastomers. Structure of polymers- crystalline and amorphous polymers - concept of Glass Transition Temperature (Tg). Polymerization- types and mechanisms with examples-Degree of Polymerization - molecular weight of polymers-numerical problems. Polymer additives-Examples and applications of engineering plastics. Elastomers - types, properties, examples and applications. (10)

PROCESSING AND SELECTION OF POLYMERS: Mechanical behaviour of polymers**:** viscoelasticity, creep and stress relaxation in polymers - yielding and fracture of polymers - crazing of polymers. Processing of thermoset and thermoplastic polymers: blow moulding, injection moulding, vaccum forming, thermoforming and compression moulding - selection criteria for polymers with examples. (11)

STRUCTURE AND FORMING OF CERAMICS: Common ceramic crystal structures - Pauling's Rules-Silicate Structures. Structure of covalent ceramics - Structure of glasses and their properties. Defects in ceramic structures - simple problems involving Packing Fraction, critical radius ratio and theoretical density. Solution synthesis routes-Sol-gel, combustion synthesis and precipitation methods. Slip and slurry casting and their applications-Powder processing of ceramics-hot pressing, Hot Isostatic Pressing, Cold Isostatic Pressing and sintering- Liquid Phase sintering. (12)

PROPERTIES AND APPLICATIONS OF ENGINEERING CERAMICS: Elasticity and brittle fracture - toughening mechanisms, Weibull statistics and design - thermal shock resistance. Glass-elastic behaviour, strength and fracture. Mechanical, electrical, thermal and optical properties of engineering ceramics - examples and applications - Bioceramics - examples and applications. (12)

Total L: 45

REFERENCES:

1. Gowariker V R, Viswanathan N V, Jayadev Sreedhar, "Polymer Science", New Age International P Ltd.,2005.
2. Michael Barsoum, "Fundamentals of Ceramics", CRC press ,2nd edition,2020.
3. Barry Carter C. Grant Norton M, "Ceramic Materials: Science and Engineering", Springer Science, USA, 2007.
4. Kingery W D, "Introduction to Ceramics", John Wiley, USA, 1960.

21YN17 COMPOSITE MATERIALS

3 0 0 3

INTRODUCTION: Definitions-Composites - reinforcements and matrices. Types of reinforcements: fibres - continuous and discontinuous fibres. Particulates - Large and dispersed particles, laminar composites. Types of matrices - metals, ceramics and polymers. Classification of composites: Metal Matrix Composites, Ceramic Matrix Composites and Polymer Matrix Composites. Particulate composites, fibre reinforced composites and structural composites. Properties and applications of composites - comparison with monolithic materials. (12)

MANUFACTURING METHODS: Metal and Ceramic Matrix Composites: Powder Metallurgy, stir casting, squeeze casting, centrifugal casting, in-situ techniques, infiltration, spray deposition and electroforming. Polymer matrix composites: Hand and spray layup techniques, injection moulding, filament winding, pultrusion, resin transfer moulding and autoclave moulding. Fibre/Matrix Interface and

measurement of interface strength. Joining Methods: Joining - Advantages and disadvantages of adhesive and mechanically fastened joints. Bond strengths - test procedures. (12)

MECHANICAL PROPERTIES: Stiffness and Strength: geometrical aspects - volume and weight fraction. Unidirectional continuous fibre, discontinuous fibers, short fiber systems, woven reinforcements - Mechanical Testing: determination of stiffness and strengths of unidirectional composites; tension, compression, flexure and shear. (10)

STRUCTURAL COMPOSITES: Laminate, sandwich and monolithic structures. Laminates: plate stiffness and compliance – Assumptions. Strains, Stress Resultants, Computation of Stresses, Types of Laminates: symmetric laminate, antisymmetric laminate, balanced laminate, quasi-isotropic laminate, cross-ply laminate, angle ply laminate. Orthotropic laminate. Laminate moduli, Hydrothermal stresses. (11)

Total L: 45

REFERENCES:

1. Mathews F, Rawlings R D, “Composite Materials: Engineering and Science”, CRC Press and Wood head Publishing Limited, 2002.
2. Krishnan K Chawla, “Composite Materials Science and Engineering”, Springer, 2012.
3. Hull D, Clyne T W, “An Introduction to Composite Materials”, Cambridge University Press, 1996.
4. Balasubramanian M, Composite Materials and Processing, CRC Press, 2020.
5. Chawla K K, “Ceramic Matrix Composites”, Second Edition, Springer, Switzerland, 2003.

21YN18 BIOMATERIALS

3 0 0 3

INTRODUCTION TO BIOMATERIALS: Need for biomaterials. composition and properties. Biocompatibility, bio-active, bio-inert, corrosion resistance, strength and weight. Metallic biomaterials: stainless steels, cobalt-chromium alloys, titanium alloys, noble metals, merits and demerits. Ceramic biomaterials: calcium phosphates, alumina, zirconia and titania. Polymeric biomaterials: methacrylates, lactic acid derivatives and silicone rubber. (11)

SYNTHESIS OF BIOMATERIALS: Physical methods: electrophoresis - chemical methods: Sol-gel, combustion synthesis, cathodic deposition, anodization and precipitation methods, Mechanical methods: Mechanical alloying. Effect of alloying elements (like Na, Mg, Sr, Ag, carbonates) on compatibility bio-coatings and bio-mimetic materials properties and examples. Biomimetic coating techniques: plasma spraying, sol-gel, electrochemical methods, laser and ion-implantation. Characterization: coating roughness, adhesion strength, wettability and contact angle measurements. . (12)

CHARACTERIZATION OF BIOMATERIALS: Important characterization techniques – principles and applications of biological microscope, Transmission Electron Microscope (TEM), Atomic Force Microscopy (AFM), Inductively Coupled Plasma – Atomic Emission Spectroscopy (ICP - AES) technique, Magnetic Resonance Imaging and their application to biomaterials. (11)

IN-VITRO AND IN-VIVO STUDIES: Corrosion: leaching studies in Simulation Body Fluid) (SBF), Polarization, Impedance, Open Circuit Potential measurements. In-vitro cell culture: cell seeding, cytotoxicity, MTT assay, protein quantity measurements, In-vivo studies: surgical procedure, removal torque measurement. Pathological studies (11)

Total L: 45

REFERENCES :

1. Sujatha V Bhat, “Biomaterials”, Narosa Publishing House, New Delhi, 2002
2. Narayanan R, “Surface Modification of Titanium for Bio materials applications”, Nova Publishers, Newyork, 2010
3. Joon B Park, Joseph D Bronzino, “Biomaterials principles and Applications”, CRC Press, London, 2003
4. Seeram Ramakrishna, Murugan Ramalingam, Sampath Kumar T S, Winston O. Soboyejo, "Biomaterials: A Nano Approach", CRC Press, 2010.

21YN19 EMERGING MATERIALS

3 0 0 3

NANOMATERIALS: Introduction-structure and properties of nanomaterials - carbon nanostructures-production methods. Characterization of nanomaterials - properties of nanomaterials. Nanomaterials for optical, bio, electrical, electronics, magnetic and other functions-applications. (11)

METALLIC AND CERAMIC MATERIALS: High strength alloys, quasicrystals, immiscible alloy systems and in-situ composites, metallic glasses, single crystals, metallic foams, Shape Memory Aloys-advantages and applications. Insulators, ceramic matrix composites, biomaterials - need, properties. advantages and applications. Thin films, coatings - glass ceramics. (11)

HIGH AND LOW TEMPERATURE MATERIALS: Introduction-high and low temperature materials, superconductors, super magnetic materials, high entropy alloys, dispersion strengthened alloys, intermetallics, super-alloys-refractories-their advantages and applications. (11)

MATERIALS PROCESSING AND CONSOLIDATION TECHNIQUES: Mechanical alloying, Rapid Solidification Processing, Melt spinning, atomization techniques, sol-gel, Self-Propagating High Temperature Synthesis - processing capabilities - process parameters - examples

and advantages. Consolidation techniques for ceramics and metallic powders - Cold and Hot Isostatic Pressing, Powder extrusion, Equal Channel Angular Pressing and Spark Plasma Sintering. (12)

Total L: 45

REFERENCES:

1. Liebermann. H H, “Rapidly Solidified Alloys: Processes, Structure, Properties, Applications”, Marcel Dekker,Inc,1993.
2. Brian Cantor, “Automotive Engineering: Light weight, Functional and Novel Materials”, Taylor and Francis,1993.
3. Fujiwara T, Ishii Y, “Quasicrystals-Handbook of Metal physics”, Elsevier, 2008.
4. Reed R C, “The Superalloys: Fundamentals and Applications”, Cambridge University Press, UK, 2009.

21YN20 HEAT TREATMENT OF ALLOYS

3 0 0 3

HEAT TREATMENT FUNDAMENTALS: Diffusion and Fick’s laws - Mechanism of formation of austenite - austenitic grain size - measurement and control of austenite grain size - decomposition of austenite. Construction of TTT and CCT diagrams. Brief discussion on bainitic and martensitic transformations. Heat treatment furnaces, thermocouples, quenching methods, fixtures, furnace atmosphere, and temperature control. Design of heat treatment furnaces. (11)

HEAT TREATMENT OF STEEL: Effect of alloying elements on Fe-C diagram - types of annealing, normalizing and hardening-quenching media-tempering. Hardenability measurement: Grossman’s critical diameter method and Jominy end-quench method. Influence of alloying elements on hardenability. Temper brittleness, control of retained austenite - sub-zero treatment. Austempering and martempering - thermo-mechanical treatments. (12)

HEAT TREATMENT OF SPECIFIC ALLOYS: Bulk and surface hardening processes. Thermal and thermo-chemical surface hardening processes. Heat treatment of micro-alloyed steels, tool steels, stainless steels, maraging steels, spring steels and cast irons. Age hardening of aluminium alloys, brass and bronzes, magnesium alloys, titanium alloys and nickel alloys. Design for heat treatment. (12)

HEAT TREATMENT PROCESS AND DEFECT CONTROL: Oxidation of steels and its prevention, Decarburisation of steels and its prevention. Finishing operations after heat treatment-removal of scales-alkaline detergent cleaning, straightening process, control of heat treating process-incoming steel inspection. Quality control of heat treated components, heat treatment defects - causes and remedies. (10)

Total L: 45

REFERENCES:

1. Ashok Rajan, Sharma TV Sharma C P, “Heat Treatment: Principles and Techniques”, Prentice Hall of India, 2011.
2. Vijendra singh, “Heat Treatment of Metals”, Standard Publishers and Distributors, 2012.
3. Karl Erik Thelning, “Steel and its Heat Treatment”, Butterworth-Heinemann, 2013.

21YN21 SURFACE MODIFICATION TECHNOLOGY

3 0 0 3

INTRODUCTION: Introduction to thermodynamics of surfaces-surface dependent properties - physical, chemical and mechanical. Surface degradation and their characteristics - analysis of surface initiated degradations. Approaches and classifications of surface engineering techniques. Introduction to surface cleaning techniques (physical, mechanical and chemical). Surface modifications techniques- Summary of surface modification methods applicable to metals and alloys. Economics and design of surface engineering processes. (11)

MECHANICAL, THERMAL AND CHEMICAL METHODS: Conventional methods: shot peening, shot blasting, sand blasting, flame hardening, induction hardening. Directed energy beam assisted surface engineering techniques - Ion, electron beam and LASER assisted surface engineering techniques. Solid state diffusion assisted surface modifications - C, N_2 and B based coatings, emerging surface modification techniques - Electroless deposition, sol-gel coating, micro-arc oxidation methods. Testing methods of coatings. (10)

PAINTING AND VAPOUR DEPOSITION METHODS: Surface painting- basic paint technology, essential concepts of paint formulation and paint properties, paint preparation (pigment dispersion), surface preparation and paint application techniques and their charecteristics. Thin film technologies - metallic and ceramic thin films by Physical Vapour Deposition (PVD) technique (thermal evaporation, sputtering and ion plating) and Chemical Vapor Deposition (CVD) technique. Diamond Like Carbon (DLC) coatings. Testing methods. (12)

SPRAYING METHODS: Flame spraying processes, Wire Arc Spraying process, Cold Gas Dynamic Spray Coating (CGDSC), Plasma spraying, Detonation Gun (D-gun) coating, High Velocity Oxy Fuel (HVOF) coating. Hard facing, LASER cladding, Thermal Barrier Coatings. Testing methods for these coatings. (12)

Total L : 45

REFERENCES:

1. Dearnley P A, “Introduction to Surface Engineering”, Cambridge University Press, 2017

2. Antonello Astarita , T.S. Sudarshan , Antonino Squillace and Pierpaolo Carlone 'Surface Modification Technologies (Key Engineering Materials)", Transtech publications, 2019.
3. Lech Paw Lowski, "Science and Engineering of Thermal Spray Coatings", 2nd Edition, Wiley, 2008.
4. Sumio Sakka, Handbook of Sol-Gel Science and Technolgoy Processing Characterization and Applications", Springer, 2005.
5. Bunshah R F, "Handbook of Deposition Techniques for Films and Coatings", Elsevier, 1994.

21YN22 CASTING SIMULATION AND DESIGN

3 0 0 3

OVERVIEW OF CASTING PROCESSES: Introduction to casting simulation-types of casting simulation software, requirement and methoding of castings. Optimization of casting defects- cause-effect diagram, fish bone diagram, WHY method and FMEA. (12)

CASTING DESIGN AND ANALYSIS: Minimum section thickness, hot spots and hot tears, junctions, ribs, and bosses. Design for moulding, core making and cleaning. Design for continuous casting. (11)

COMPUTER SIMULATION OF CASTING PROCESSES: Mould filling simulation, solid modeling, thermal analysis, solidification simulation, feeder size and weight calculations, mold-metal filling optimization. Cost benefits of solidification simulation. (12)

DESIGN FOR CASTABILITY: Product design for castability-process friendly design and castability analysis. Prediction of cooling curves - local microstructures and mechanical properties of metals and alloys. Prediction of mould erosion, sand burnt-on, sand penetration and sand inclusions. (10)

Total L : 45

REFERENCES:

1. Ravi B, "Metal Casting Computer-Aided Design and Analysis", PHI learning Private Limited, 2011.
2. John Campbell "Complete Casting Hand Book Metal Casting Processes: Metallurgy, techniques and design", Butterworth-Heinemann publication, 2015.
3. Kuang-Oscar-Yu, " Modelling for Casting and Solidification Processing", CRC Press, 2019.

21YN23 QUALITY CONTROL IN FOUNDRIES

3 0 0 3

INTRODUCTION TO QUALITY CONTROL: Definition of quality control- need for quality improvement and control- dissemination of quality information- quality and cost analysis-quality control and inspection-responsibility for quality control- quality control through standardization- quality control organization. Quality planning - record and documents. Reliability Engineering approach. (12)

STATISTICAL QUALITY CONTROL: Introduction- probability and probability distributions - binomial, Poisson and normal distributions - Statistical Quality Control (SQC)-Statistical Process Control (SPC) in foundries- Process capability indices- process variables in foundries -acceptance control charts-applications of control charts in foundries - numerical examples. (11)

INSPECTION METHODS AND QUALITY APPRAISAL: Need for inspection – inspection of castings- equipment and techniques methods to reduce energy consumption in foundry. Environmental pollution control. Experts system for casting defects analysis-accuracy evaluations and analysis of dimensions-Quality Function Deployment (QFD)-case studies on casting defect analysis. (11)

QUALITY MANAGEMENT SYSTEM AND TOTAL QUALITY CONTROL: Quality policy- quality system and its activities -reporting and reviewing- Quality control system: quality system documentation-corrective and preventive actions-third party inspection- Planning and management of foundry–quality assurance system- ISO standards for quality system- Important clauses in ISO:9000 specifications, ISO 9001/9002 (IS 14002) specifications-essential steps in implementing the quality system for ISO:9000- QS:9000 quality system- some case studies. (11)

Total L: 45

REFERENCES:

1. Jain P L, "Quality Control and Total Quality Management", Tata McGraw Hill Publishing Company, New Delhi, 2006
2. Jain P L, "Principles of Foundry Technology", Tata McGraw Hill Publishing Company limited, New Delhi, 2017
3. Ramana Rao T V, "Metal Casting Principles and Practice", New Age International Publishers, New Delhi, 2010.
4. Srinivasan N K, "Foundry Engineering", Fourth Edition, Khanna Publishers, New Delhi , 2012.

21YN24 FUNDAMENTALS OF SOLIDIFICATION

3 0 0 3

THERMODYNAMICS AND TRANSPORT PHENOMENA IN SOLIDIFICATION: Length scales in solidification-thermodynamics of solidification-driving forces for solidification in metals and alloys. Nucleation and growth kinetics- General conservation transport equations: flux laws, heat transport during solidification process-Laws of heat transport, variable heat of fusion of metals and variable heat capacity of metals and alloys. (12)

MICROSTRUCTURE AND DEFECT CONTROL: Planar crystal growth in pure metals and binary alloys-cellular and dendritic crystal growth in pure metals and binary alloys- diffusion controlled growth of crystals in binary alloys- transition in growth morphologies, solutal, thermal and capillary control growth in binary alloys-macro and micro segregation models in binary alloys- physics and control of shrinkage porosity in binary alloys. (11)

SOLIDIFICATION OF COMMERCIAL ALLOYS: Eutectic and peritectic solidifications of binary alloys - solidification of titanium alloys, magnesium alloys, aluminium alloys and Metal Matrix Nano Composites -Directional Solidification: single crystal growth techniques-heat transfer requirement for Directional Solidification - Directional Solidification of Nickel base super alloys-investment casting of single crystal turbine blades, bulk single crystal growth of electronic materials. (12)

NUMERICAL MODELLING OF SOLIDIFICATION: Macroscale modelling of solidification: enthalpy method, specific heat and temperature recovery method-discretization and solutions of governing equation-microscale modelling of solidification-heterogeneous nucleation and dendrite growth models and microporosity models-overview of Phase Field and Monte-Carlo models. (10)

Total L : 45

REFERENCES:

1. Doru Michael Stefanesu, Science and Engineering of Casting Solidification, Second edition, Springer, 2009.
2. Hasse Fredriksson, Ulla Akerlind, Solidification and Crystallization Processing in Metals and Alloys, First Edition, Wiley Publisher, 2012.
3. ASM Handbook Volume 15: Casting, ASM International, 2010.
4. Martin Eden Glicksman, Principles of Solidification, Springer, 2011.
5. https://nptel.ac.in/noc/courses/noc18/SEM1/noc18-me09/Transport phenomena in Materials
6. https://nptel.ac.in/courses/113/104/113104073/ Fundamentals of Material Processing

21YN25 WELDING PROCEDURES AND QUALIFICATIONS

3 0 0 3

WELDING CODE PRACTICE: Review of welding metallurgy of important alloys-fundamentals, equipments, electrodes / filler metals classifications as per AWS. Familiarization of codes: ASME B&PV Code - sections IIC and IX. Essential variables, non-essential variables and supplementary essential variables. Welding Procedure Specification (WPS), Procedure Qualification Record (PQR) and Welding Procedure Qualification (WPQ) formats test requirements - qualifying range for varying values of essential variables. (11)

WPS OF FERRITIC STEELS: Preparation of WPS's for SMAW, GTAW, GTAW+SMAW, GMAW, SAW, SMAW+SAW, GTAW+SAW – preparation of WPS for carbon steels, low alloy steels, Cr-Mo steels with Post Weld Heat Treatment (PWHT) and without PWHT, stress relieving- other heat treatments. Welding of plates - 2 to 200 mm thickness. Preparation of WPS for dissimilar welding and weld overlaying involving ferritic grade steels. (11)

WPS OF STAINLESS STEELS AND NON-FERROUS ALLOYS: Preparation of WPS for metal joining using process variation: SMAW, GTAW, GTAW+SMAW, GMAW, SAW, SMAW+SAW, GTAW+SAW. WPS for stainless steels, nickel alloys, copper alloys, titanium alloys, aluminium alloys. Preparation of WPS for dissimilar metal joining for. SMAW, GTAW+SMAW. WPS for welding of stainless steels to carbon steels, copper alloys to carbon steels-Preparation of WPS for weld overlay of stainless steels over carbon steel, nickel alloys over carbon steels, copper alloys over carbon steels, stellite over carbon steels and stainless steels. (13)

PQR AND WPQ: Testing of weldments as per codes and standards. Preparation of PQR for selected WPS. Preparation of WPQ for selected WPS for various processes, material thicknesses, positions for butt welding, fillet welding and weld overlay. Model PQR for WPS of butt welding, fillet welding and weld overlay. (10)

Total L: 45

REFERENCES:

1. ASM Handbook, "Welding, Brazing and Soldering", ASM international, Volume 6, USA, 2017.
2. Sindo Kou, "Welding Metallurgy", 3rd edition, John Wiley & Sons, 2020.
3. "ASME Boiler & Pressure Vessel Code Section IIC", ASME International, 2015.
4. "ASME Boiler & Pressure Vessel Code Section IX", ASME International, 2015.
5. API Standard 1104, "Welding of Pipelines and Related Facilities", API, 2013.
6. AWS D1.1, "Structural Welding Code", American Welding Society, 2010.

21YN26 WELDING APPLICATION TECHNOLOGY

3 0 0 3

QUALITY ASSURANCE IN WELDING: Overview of welding processes and weldabilty, mechanical and metallurgical effects on welding, quality control and assurance in welding. Overview of welding discontinuities. Welding procedures and performance qualification for quality assurance. Welding automation and importance of welding fixtures for high quality welding. (12)

WELDING OF AEROSPACE AND AUTOMOTIVE COMPONENTS: Types of loads applied on components and joint design configurations. Specific materials and processes used in fabrication of aerospace structures-welding issues encountered in aerospace alloys: austenitic stainless steels, aluminum, titanium and nickel alloys. Specific processes and materials used for fabrication of automotive structures and components-challenges in thin sheet welding-specific methods to enhance fatigue life structures like truck frames, under frames and railway bogie frames. Specific processes used for fabrication of thin walled structures for stainless steel metro coaches -guidelines as per relevant codes & standards (11)

WELDING OF STRUCTURES IN HEAVY ENGINEERING SECTOR: Loads and stresses in welded structure-failure modes in static and dynamically loaded structures-welded connections used in structures. Design requirements of static and dynamically loaded structures-weld joint configurations-weld symbols. Materials, consumables and processes used in fabrication of structures-specific metallurgical issues encountered in the fabrication of boilers, ships and building structures and measures to overcome these issues. Specific methods to enhance fatigue life of welded structures-guidelines for welding of structures as per AWS D1.1 structural welding code. (11)

WELDING IN PRESSURE VESSEL FABRICATION: Loads and stresses in pressure vessel components -failure modes in pressure vessels: Design requirements of pressure vessels-type of weld joint configurations used in pressure vessel components-weld category and joint efficiency. Specific materials, consumables and processes used in the fabrication of boilers & pressure vessels, air receiver tanks, vessels for low temperature service, line pipes used in petro-chemical sector. Inspection of welds, guidelines for fabrication of pressure vessels and piping as per ASME sec VIII & welding of line pipes as per API 1104 hydro testing of pressure vessels. (11)

Total L : 45

REFERENCES:

1. Standard Methods of Mechanical Testing of Weldments-AWS B 4.0-2016, Published by AWS committee-2016.
2. AWS Structural welding code D 1.1 2020.Published by AWS committee.-2020.
3. ASME Boiler And Pressure Vessel Code Sec VIII DIV 1 -2019, published by ASME in 2019.
4. ASME Boiler and Pressure Vessel Code, Section IX: Welding and Brazing Qualifications-ASME BPVC.IX-2019.
5. ASME Boiler and Pressure Vessel Code, Section II: Materials - Part C: Specifications for Welding Rods, Electrodes and Filler Metals; ASME BPVC.II.C-2019, Published By ASME Committee in 2019.

21YN27 NONDESTRUCTIVE TESTING

3 0 0 3

SURFACE TECHNIQUES: Discontinuities and defects - basics of Visual Testing (VT)-remote visual examination of components using optical and mechanical aides -Visual Inspection of welds. Basics of Penetrant Testing (PT) - precleaning methods, penetrant groups and penetrant removal techniques-types of developers, inspection procedures, sensitivity and resolution-interpretation of indications-applicability and limitations. Fluorescent Penetrant Test (FPT) - codes and standards of VT and PT - practical demonstrations of VT and PT. (11)

MAGNETIC AND ELECTROMAGNETIC TECHNIQUES: Magnetic Particle Testing (MT): Magnetisation techniques - inspection techniques - indication classification - test equipment and accessories – demagnetisation - codes, procedures and acceptable standards - interpretation of indications. Eddy Current Testing (ET): Principle, impedance, impedance plane diagrams, skin effect, depth of penetration. Sensors, equipment and accessories - applications of ET. (12)

ULTRASONIC TECHNIQUES: Properties of sound waves - generation of ultrasound - interaction of ultrasound with matter and boundaries - type of probes - test methods - test equipment - instrumentation-test variables and Inspection procedures. Principles of DGS / DAC methods - codes, procedures and acceptance standards. Ultrasonic Testing (UT) calibration with IIW blocks - inspection of welds and castings-practical demonstration of UT. (11)

RADIOGRAPHY TECHNIQUES: Sources of radiation and their characteristics- X-ray and Gamma ray Radiography Test (RT)- radiation protection and radiation detectors-Film Radiography (FR) and Digital Radiography (DR)-sensitivity and definition. Image Quality Indicators (IQI) and other accessories-characteristics of discontinuities-exposure parameters. Procedures and acceptance standards-Interpretation of radiographs-RT of castings, welds and pipes-practical demonstrations of RT film interpretation. (11)

Total L: 45

REFERENCES:

1. ASM Handbook, “Non-Destructive Evaluation and Quality Control”, ASM international, Volume 17, USA, 2017.
2. Baldev Raj, Jayakumar T, Thavasimuthu M, ‘’ Practical Non-destructive Testing’’, Woodhead Publishing, 2009.
3. www.ndt-ed.org.

21YN28 ADVANCED NDT TECHNIQUES

3 0 0 3

MATERIAL IDENTIFICATION TECHNIQUES: Need for advanced NDT-global frame work: new and high critical applications-product safety and reliability, in-line diagnostics-security monitoring. Positive Material Identification (PMI): Introduction, principle-typical methods: X-ray Fluorescence (XRF) and Optical Emission Spectrometry (OES): relative merits, limitations and applications. LASER Shearography Testing (LST)-Principle, speckle and fringe patterns - applications. (10)

SURFACE TECHNIQUES: Alternative Current Field Measurement (ACFM): principle, procedure and applications. Magnetic Flux Leakage (MFL): principle, instrumentation and applications. Remote Field Testing (RFT): principle, instrumentation and applications. Acoustic Pulse Reflectometry (APR): principle and applications-heat exchanger tube inspection. (10)

ULTRASOUND TECHNIQUES: Phased Array Ultrasonic Testing (PAUT): Principle - wave sweeping, focusing, and steering-probes - scanning and display-interpretation of results - potential applications. Time of Flight Diffraction (ToFD): principles of operation, flaw size determination, applications and reliability. Guided Wave Ultrasonic Testing (GWUT): principle, procedure, advantages and applications. Acoustic Emission Testing (AET): principle, procedure, advantages and applications. (13)

RADIATION TECHNIQUES: Microwave Testing (MWT): principle, instrumentation and applications. Digital Radiography Testing (DRT)-Computed Radiography (CR), Direct Radiography (DR), Real Time Radiography (RTR), Industrial Computed Radiography (ICT) X-Ray Back Scatter Technique (BSRT) and Neutron Radiography Technique (NRT): Principle, instrumentation, detection of image, advantages and applications. Infrared Thermography Technique (IRT): principle, image capturing, active and passive sources, detector types and applications. (12)

Total L: 45

REFERENCES:

1. Songling Huang, Shen Wang, "New Technologies in Electromagnetic Non-destructive Testing", Springer Series in Measurement Science and Technology, 2016.
2. Ed Lampman R S, Ed Zorc B T, "ASM Handbook, Volume 17 - Nondestructive Evaluation and Quality Control", Twelfth Printing, ASM International,2014.
3. Zoughi R , "Microwave Non-Destructive Testing and Evaluation Principles - Volume 4", Springer, Netherlands, 2011.
4. Advanced Practical NDT Series , "Introduction to Phased Array Ultrasonic Technology Applications", Olympus, USA, 2004.

21YN29 ADDITIVE MANUFACTURING

3 0 0 3

INTRODUCTION: Overview and classification of Additive Manufacturing (AM) processes. Process chain - AM technology in product development-materials for Additive Manufacturing Technology - applications. CAD and reverse engineering: digitization techniques – model reconstruction-data processing for Additive Manufacturing Technology- CAD model preparation, part orientation and support generation –model slicing –tool path generation – Softwares for Additive Manufacturing Technology. (10)

ADDITIVE MANUFACTURING SYSTEMS: Classification–liquid based systems-Stereo Lithography (SL) - principle, equipment, process, advantages and applications. Solid based systems - Solid Ground Curing (SGC) and Fused Deposition Modeling (FDM) - principle, process, advantages and applications, Laminated Object Manufacturing (LOM) - bonding mechanisms-materials - principle, process and advantages and applications. Case studies on SL, SGC, FDM , LOM approaches. Wire Arc Additive Manufacturing (WAAM). (10)

POWDER BASED ADDITIVE MANUFACTURING SYSTEMS: Direct process powder-bed systems – Selective LASER Melting (SLM), LASER curing and Direct Metal LASER Sintering (DMLS) and Electron Beam Melting (EBM) – principles, process, advantages and applications. Powder-fed systems - LASER cladding, directed energy deposition and LASER metal deposition. Three dimensional printing – principle- process, advantages and applications- LASER Engineered Net Shaping (LENS)- Introduction to direct rapid tooling and indirect rapid tooling. Case studies in SLM, 3D Printing and LENS. (12)

DESIGN FOR AM AND APPLICATIONS: Design tools for AM-part orientation- removal of supports-hollowing out parts-inclusion of undercuts and other manufacturing constraints - interlocking features, reduction of part count in an assembly-identification of markings/ numbers, application. Material relationship, application in design, application in engineering, analysis and planning for aerospace, automotive, jewelry and coin industries. Examples from aerospace, defense, automobile, RP, medical and bioengineering as well as general engineering industries. (13)

Total L : 45

REFERENCES:

1. Chua C K., Leong K F, Lim C S., “Rapid Prototyping: Principles and Applications”, Third Edition, World Scientific Publishers, 2010.
2. Gebhardt A., “Rapid Prototyping”, Hanser Gardener Publications, Germany, 2003.
3. Liou L W, Liou F W., “Rapid Prototyping and Engineering Applications: A Tool Box for Prototype Development”, 2nd edition, CRC Press, 2019.

4. Kamrani .K., Nasr E.A., “Rapid Prototyping: Theory and Practice”, Springer,USA, 2006.
5. Ian Gibson, David W Rosen, Brent Stucker, Additive Manufacturing Technologies: Rapid Prototyping to Direct Digital Manufacturing, 2nd Ed. Springer Nature,USA, 2014.

21YN30 MATERIAL AND PROCESS MODELING

3 0 0 3

INTRODUCTION TO CALPHAD APPROACH : Thermodynamic parameters for solid solution modelling – configurational entropy, enthalpy and free energy – chemical potential - free energy vs composition diagram - evolution of phase diagrams based on regular solution model -sub regular solution model- Redlitch-Kister polynomial - phase diagram determination by diffusion couple technique. (10)

DIFFUSION MODELS : Diffusion equation – introduction, numerical solution for diffusion equation – finite difference method, implicit and explicit methods, Kampmann-Wagner Numerical Model – periodic boundary condition - Fourier-spectral techniques–discretization techniques and coding methods using MATLAB / OCTAVE / C++/ Python. (10)

MICROSTRUCTURE MODELLING : Introduction – Phase Field Modelling – Cahn-Hilliard equation and Allen-Cahn equation for simulation of phase separation behavior, order-disorder transformation in binary systems – discretization techniques and numerical solutions using computational tools. Grain growth model using Allen-Cahn equation, precipitate growth model, grain growth in multi-grain systems- Fan-Chen model. (12)

PROCESS MODELLING : Computational models – solubility of gases during melting, charge calculations in melting, gating and riser design in casting, forging and rolling load calculations. Modelling of welding processes: thermal modeling - single domain approach - handling phase change- analytical solutions, fluid flow in the weld pool-zones, numerical solutions- solute segregation profiles. (13)

Total L: 45

REFERENCES:

1. David A. Porter, Kenneth E. Easterling, Mohamed Sherif , “Phase Transformations in Metals and Alloys”, 3rd Edition, CRC Press, 2009.
2. David R. Gaskell, “Introduction to the Thermodynamics of Materials”, 5th Edition, CRC Press, 2008.
3. Saunders, Miodownik , “CALPHAD (Calculation of Phase Diagrams): A Comprehensive Guide”, Pergamman Press, 1998.
4. Suzana G Fries, Bo Sundman, “Computational Thermodynamics: The Calphad Method, by Hans Lukas”, Cambridge University Press, 2007.
5. Barber Z H “Introduction of Materials Modeling”, Maney Publishing, 2005.

21YN31 MATERIALS SELECTION

3 0 0 3

MATERIALS AND DESIGN: Design process - types of design - design requirements. Role of materials in design - strategically important categories of materials - design strengths and weakness of these materials. Material properties and their importance in materials selection- bulk mechanical and non-mechanical properties, surface properties, processing abilities and cost. Materials property charts and material records. (12)

FACTORS OF MATERIAL SELECTION: Driving forces for materials selection - central problems in materials selection - technical and non - technical Factors, developing functional requirements for an application – rules and types of functional specifications. Shape and its types - shaped material, microscopic or microstructural shape factors. Manufacturing Processes - process attributes, process selection diagrams - process cost model - availability, recyclability, reparability, environmental considerations and legal aspects. (10)

MATERIALS SELECTION PROCESS: Materials selection methods: screening and ranking - weighted ranking. Performance indices-materials selection charts-deriving property limits and material indices for tie rod, beam and shafts. Structural indices-shape factors, efficiency of standard sections, material limits for shape factors - material indices which include shape - co-selection of material and shape. (10)

SPECIFIC MATERIAL SELECTION APPLICATIONS: Rotating beams transferring moment - bicycle frame for light weight concept, heat absorbing material with tailored thermal expansion (vs. e.g. silicon in microelectronics device), wear resistant floor with antistatic properties, shell for a mobile phone, outdoor furniture, light and stable tooling for plastic injection moulding, shielding cover for engine exhaust system (behind the catalyst), brake discs for car, exhaust valve (car engine), aircraft landing gears, surgical knives and bone replacements, acid storage tanks and fuel carrying pipes. (13)

Total L: 45

REFERENCES:

1. Ashby M F, “Materials Selection in Mechanical Design”, 4th edition, Butterworth - Heineman, New York, 2011.
2. Dieter G E, Linda C. Schmidt, “Engineering Design: A Materials and Processing Approach”, 5th edition, McGraw-Hill, 2012.
3. ASM Handbook, “Materials Selection and Design”, ASM international, Volume 20, USA, 1997.