SEMESTER I

21YN01 STATISTICAL QUALITY CONTROL AND DESIGN OF EXPERIMENTS

3 1 0 4

STATISTICAL QUALITY CONTROL: Methods and philosophy of statistical process control – chance and assignable causes of quality variation, statistical basis of control charts - control charts for variables - $\bar{X}$, R - control charts for attributes – p, np, c and u charts. (10+3)

ACCEPTANCE SAMPLING: Lot-by-Lot acceptance sampling for attributes – single sampling plans for attributes, double and sequential sampling plans, acceptance sampling by variables - chain sampling, continuous sampling, skip-lot sampling plans. (12+4)

DESIGN OF EXPERIMENTS: Fundamentals of experimental design, guidelines for designing experiments, Analysis of Variance, experiments with one factor, completely randomized design, randomized block design, factorial experiments, Latin square design. (12+4)

RESPONSE SURFACE METHODOLOGY: Empirical models – linear regression models, estimation of parameters in linear regression models, confidence interval and hypothesis testing in multiple regression, 2-level factorial design – 2^3 design, design for fitting second order models – class of Central Composite Design. (11+4)

Total L: 45 +T: 15 = 60

REFERENCES:

1. Amitava Mitra, “Fundamentals of Quality Control and Improvement”, John Wiley and Sons, New Jersey, 2016.
2. Douglas C Montgomery, “Introduction to Statistical Quality Control”, John Wiley & Sons, New York, 2019.
3. Eugene L Grant, Richard S Leavenworth, “Statistical Quality Control”, Tata Mc-Graw Hill, New Delhi, 2016.
4. Raymond H. Myers, Douglas C. Montgomery, Christine M. Anderson Cook, “Response Surface Methodology: Process and Product Optimization Using Experimental Designs”, John Wiley and Sons, 2016.
5. Ronald E Walpole, Raymond H Myers, Sharon L Myers and Keying Ye, “Probability and Statistics for Engineers and Scientists”, Pearson Education, New Delhi, 2016.

21YN02 PHASE TRANSFORMATIONS

3 1 0 4

CRYSTALLOGRAPHY & PHASE EQUILIBRIA: Crystalline, nano-crystalline and amorphous structures. Crystal Systems – brief discussion of BCC, FCC and HCP structures. Defects in atomic arrangements- types of defects (point, line and area) and their significance - Solid solution types- Rules for formation of solid solutions and compounds – Fundamental concepts of phase diagrams- discussion of isomorphous and eutectic systems - Fe-C equilibrium diagram. (11 + 3)

DIFFUSION: Mechanisms and modes of diffusion – Laws of diffusion - mass transfer in porous materials and related transport phenomena. Interfaces and surfaces: free energy of interfaces, grain boundaries and interphase interfaces, coherent and incoherent interfaces. Recrystallization and grain growth - transformations with short range diffusion. (11 + 4)

FUNDAMENTALS OF PHASE TRANSFORMATIONS: Time scale for phase transformations- types of transformations. Thermodynamic basis of phase transformations (nucleation & growth, spinodal decomposition and massive transformations) - transformation kinetics- kinetics of solid state reactions occurring at elevated temperatures – nucleation**,** growth and overall transformation kinetics - Sintering & crystallization in ceramics and glass forming systems. (12 + 4)

SOLID STATE PHASE TRANSFORMATIONS: Diffusion controlled transformations – Pearlitic and Bainitic transformations - mechanism, nucleation and growth kinetics- Factors influencing the transformations - effect of alloying elements. Diffusionless transformation - characteristics, thermodynamics and kinetics, nucleation and growth, morphology and crystallography of martensitic transformation in steels - Nonferrous martensites- Shape Memory Effect. Precipitation hardening – kinetics - precipitate coarsening.
(11 + 4)

Total (L=45 +T=15): 60

REFERENCES:

1. Reed Hill. R. E , Reza Abbaschian, "Physical Metallurgy Principles", Thomson Asia, Singapore 2003.
2. Porter. D. A, Easterling K E , K.Y.Sherif, “Phase Transformations in Metals and Alloys", 3rd edition, Chapman and Hall, London, 2009.
3. Sharma. R. C, Phase Transformations in Materials, CBS Publisher, 2002.
4. Raghavan. V, “Solid State Phase Transformations", Prentice Hall of India, New Delhi, 1990.

21YN03 DEFORMATION AND STRENGTHENING MECHANISMS

3 1 0 4

DISLOCATION THEORY: Theoretical cohesive strength - dislocation types, Burgers Vector and dislocation loops - dislocations in FCC, BCC and HCP. Stress fields and energies of dislocations, forces on dislocations, forces between dislocation- interaction of dislocations, dislocation intersection, dislocation multiplication, dislocation pileups, Interaction with point defects. (12 + 4)

PLASTIC DEFORMATION OF CRYSTALS: Slip in a perfect lattice, slip by dislocation movement, Peierls-Nabarro stress, Critical Resolved Shear Stress for slip- deformation of single crystals and polycrystalline materials - deformation by twinning - concept of strain hardening- factors influencing strain hardening. (11 + 4)

STRENGTHENING MECHANISMS: Grain boundaries - Low angle and high angle grain boundaries. Grain boundary strengthening, Hall-Petch relation- Grain Boundary Engineering- Yield point phenomenon and strain aging. Solid solution strengthening - factors influencing solid solution strengthening. Work hardening, transformation hardening and texture strengthening. (11 + 4)

STRENGTHENING BY SECOND PHASES: Precipitation hardening -conditions for precipitation hardening - aging - formation of precipitates - coarsening of precipitates and Critical Fiber Length. Mechanism of strengthening. Dispersion strengthening-factors influencing dispersion hardening. Fiber strengthening- Rule of Mixtures- discontinuous and continuous fiber composites- factors influencing the strength of fiber composites, Critical Fiber Length. (11 + 3)

Total L: 45+T: 15: 60

REFERENCES:

1. Dieter G E, "Mechanical Metallurgy", Third edition, McGraw Hill Education, 2017.
2. Courtney T H, "Mechanical Behaviour of Materials", Waveland press Inc, 2005.
3. Hull D, Bacon D J, "Introduction to Dislocations", Fourth Edition, Butterworth, 2001.
4. Meyers M. A, Chawla K. K, "Mechanical Behaviour of Materials", Prentice Hall Inc, NY, 2017.
5. Shetty M N, “Dislocations and Mechanical Behaviour of Materials”, Prentice Hall India Learning P Limited, New Delhi, 2013.

21YN04 METALLURGY OF CASTING

3 0 0 3

SOLIDIFICATION OF METALS AND ALLOYS: Solidification pure metals and alloys - effect of composition, moulding materials and cooling rate on solidification pattern of alloys - segregation patterns in steel castings. Types of Shrinkage- linear and volume shrinkages - example calculations. Centre line feeding resistance - solidification rate: Chvorinov's Rule, calculation of solidification time in metals and alloys. Directional Solidification of castings - hot tearing criteria. (11)

STEEL CASTINGS: Melting furnaces and foundry practice for steel castings- composition control: desulphurization and dephosphorization - degassing and de-oxidation of steels. Methoding of castings – gating and riser design - fluidity of steel castings- BIS, EN, ISO and ASTM standards for steel castings . Metallurgy of carbon, low alloy, high Mn, and stainless steels. Heat treatments of different classes of steel castings as per specifications - defects in steel castings. (11)

CAST IRONS: Melting furnaces and foundry practice for various cast irons - composition control - desulphurization, inoculation and Mg treatment for ductile iron. Specifications for cast irons and standards (BIS, EN, ISO and ASTM). Types of cast iron – effect of normal elements- influence of composition and cooling rate. Production of grey cast iron, SG iron, malleable iron, CG Iron, Austempered Ductile iron and alloy cast irons. Heat treatment of different cast irons as per specifications- defects in cast irons. (11)

NON FERROUS CASTINGS: Melting furnaces and foundry practice for non-ferrous alloys: composition control and degassing - gating and riser design - Non ferrous alloys specifications as per BIS, EN, ISO and ASTM standards. Metallurgy of aluminum, copper, magnesium, titanium and nickel alloy castings. Heat treatment for various non ferrous alloy castings as per specifications. Defects in non-ferrous alloy castings. (12)

Total L: 45

REFERENCES:

1. Richard W Heine, Carl R Loper and Philip C Rosenthal, “Principles of Metal Casting”, Tata McGraw Hill. Publication. Co., 2012.
2. ASM Handbook, “Casting”, ASM international, Volume 15, USA, 2015, 2nd Edition.
3. John Campbell, “Casting”, Elsevier Publishing Amsterdam, 2011.
4. Foseco Ferrous Foundryman's Handbook / Edition 11, Butterworth – Heineman, USA - 2000
5. Foseco Non-Ferrous Foundryman's Handbook Edition 11, Butterworth – Heineman, USA - 1999

21YN05 METALLURGY OF FORMING

3 0 0 3

FUNDMENTALS OF METAL FORMING: Basic concepts of yield criteria - components of stress, principal stresses in 2D and 3D - state of stress - hydrostatic and deviatoric components of stress. Von Mises and Tresca yield criteria – comparison of yield criteria. Mechanics of metal forming, forming analysis - slab method, flow stress determination - flow curve from true stress - strain curve, effect of temperature in metal forming - dynamic recovery and recrystallisation - strain rate effects - metallurgical structures - effect of friction in forming analysis - deformation zone geometry - workability. Deformation Mechanism Maps - concept of softening. (12)

FORGING, ROLLING AND EXTRUSION: Forging - classification: open die forging and closed die forging - die design - presses and hammers - calculation of forging loads - friction hill diagram - defects, causes and remedies - applications, Rolling : types of rolling mills - flat and shape rolling - forces and geometrical relationship in rolling - analysis of rolling load, torque and power - rolling defects - applications. Extrusion: direct and indirect extrusion - hydrostatic extrusion. Analysis of extrusion - tube extrusion - defects causes and remedies - applications. (11)

DRAWING AND SHEET METAL FORMING: Drawing - rod and wire drawing processes - die and die materials. Analysis of wire drawing, defects in rod and wire drawing. Tube drawing processes – types - analysis of tube drawing - production of seamless pipe and tube - defects in tube drawing - residual stresses in drawing of rods, wires and tubes. Sheet metal characteristics, - sheet metal forming materials - operations - shearing, bending, wrap forming, spinning, stretch forming, deep drawing and redrawing - practical considerations affecting drawability - Forming Limit Diagram (FLD) – defects - applications. (11)

OTHER FORMING PROCESSES: Superplastic Forming: Superplasticity - materials – mechanism of superplastic deformation – methods and applications of superplastic forming. High Energy Rate Forming (HERF) Processes: high velocity forming - explosive forming – types - electro hydraulic forming - methods and applications - electromagnetic forming – methods and applications. Petro forge system - rubber pad forming – methods and applications. Incremental forming. Severe Plastic Deformation Process : metallurgical characteristics and structural changes during Severe Plastic Deformation processes – ECAP, Cryo rolling, Accumulative roll bonding, repetitive corrugation and straightening - methods and applications. (11)

Total L : 45

REFERENCES:

1. Dieter G E , "Mechanical Metallurgy", Third edition, McGraw Hill Education, 2017.
2. AvitzurB , "Metal Forming - Processes and Analysis", Tata McGraw Hill, 2005.
3. “ASM Metals Handbook: Forming and Forging, Volume 14", 9th Edition, ASM International, 1989.
4. Rowe G W , "Principles Industrial Metalworking Processes", CBS Publishers & Distributors Pvt Ltd, New Delhi, 2005.
5. Hosford.W.F, Caddell.R.M , "Metal Forming -Mechanics and Metallurgy", Cambridge University Press, 2011.
6. “Handbook of Mechanical Nanostructuring – Vol 1” Ed by Mahmood Aliofkhazraei, Wiley-VCH Verlag GmbH & Co, Germany. 2015.

21YN06 Research Methodology and IPR

vide Automotive Engineering 21AE06

21YN72 AUDIT COURSE I

vide Automotive Engineering 21AE72

21YN51 MICROSTRUCTURAL ANALYSIS LABORATORY

0 0 4 2

LIST OF EXPERIMENTS:

1. Macro and Micro Examination of Castings and Welds.
2. Inclusion rating of Steels and Grain size measurement in Ferritic and Austenitic Steels.
3. Study of morphology and characteristics of graphites in various cast irons.
4. Identification of plain carbon and alloy steels from their microstructures.
5. Determination of mechanical working and heat treatment condition of steels.
6. Evaluation of ferrite and austenite content in different types of stainless steels.
7. Study of microstructures of hardened steels and tool steels.
8. Microstructural examination of Al – Si Cast Alloys, Brasses and Bronzes.
9. Microstructural examination of Inconel, Stellite and Alpha – Beta Titanium alloys.
10. Microstructural investigations on Carburized and borided steels.

Total P: 60

REFERENCES:

1. Microstructural Analysis Laboratory Manual - Department of Metallurgical Engg., PSG College of Technology, 2021
2. George F. Vander Voort, “Metallography: Principles and Practice”, ASM International, 1999.
3. ASM Handbook Volume, 9, Metallography and Microstructures, ASM International, 2004.

21YN52 MODELING AND SIMULATION LABORATORY

0 0 4 2

LIST OF EXPERIMENTS

1. Free energy calculations and CALPHAD approach - basics.
2. Construction of free energy – composition curves using MATLAB / Octave softwares.
3. Construction of phase diagrams and calculation of phase fractions using MATLAB / Octave softwares.
4. Construction of isothermal and non- isothermal cooling curves for ferrous alloys using TC-PRISMA software.
5. Study of precipitation kinetics in Steels using TC - PRISMA software.
6. Simulation of Scheil Solidification of Steels using Thermo Calc software.
7. Numerical modelling introduction – Finite difference method and Fourier Transforms.
8. Numerical solutions of diffusion equations using MATLAB /Octave software.
9. Study of diffusion behavior of carbon in steels using DICTRA software.
10. Study of homogenization of binary Fe-Ni alloy using DICTRA software.

REFERENCES:

1. Modeling and Simulation Laboratory Manual - Department of Metallurgical Engg., PSG College of Technology, 2021.

Total P: 60

SEMESTER II

21YN07 METALLURGY OF WELDING

3 1 0 4

BASICS AND POWER SOURCES: Joining techniques - Welding processes and classes - welding terminology - AWS specifications for classification. Metal transfer modes - polarity and shielding gases. Power sources - Static and dynamic characteristics - CC and CV power source designs - current and voltage relationships. Solid state power sources - wave form controlled power sources. (11 + 4)

WELDING PROCESSES: Fundamentals – equipment and consumables, welding variables. Process variations and weld quality in gas welding - Shielded Metal Arc Welding, Gas Tungsten Arc Welding, Gas Metal Arc Welding, Flux Cored Arc Welding, Submerged Arc Welding, Stud Arc Welding, Thermit Welding ,Resistance Welding, Electron Beam Welding, Laser Welding, Friction welding, Friction Stir Welding, Ultrasonic welding , diffusion bonding and explosive welding. (12 + 4)

WELDING METALLURGY: Heat flow in welding - weld metal cooling curves - peak temperature and cooling rate calculations. Weld metal solidification - gas-metal and slag-metal reactions - weldment terminology - solid state transformation during welding - microstructural changes in cold worked, transformation hardened and age hardened alloys during welding. (11+3)

FERROUS AND NON FERROUS WELDING METALLURGY: Welding of carbon steels, low alloy steels, stainless steels and cast irons: metallurgical difficulties, Process selection, filler metal selection and safe welding procedures. Welding of Aluminum alloys, Nickel alloys and Titanium alloys: metallurgical difficulties, process selection, filler metal selection and safe welding procedures. Weldability testing and testing of weldments. (11 + 4)

Total L:45+ T:15 : 60

REFERENCES:

1. Cary H B , "Modern Welding Technology",6th edition,Pearson, 2005.
2. Sindo Kou, "Welding Metallurgy", 3rd edition, John Wiley and Sons, 2020.
3. “AWS Welding Hand Books, Volume 1 to 5", 9th Edition, American Welding Society, 2013.
4. Lancaster J F, "Metallurgy of welding", 6th edition, Woodhead Publishing Series, Elsevier, 1999.

21YN08 FAILURE MECHANISMS AND ANALYSIS

3 1 0 4

FRACTURE MECHANICS: Failure - definition and modes - instant and progressive modes of material failure - permanent deformation. Fracture types and modes – ductile, brittle, intergranular and transgranular. Griffith Theory and Orowan’s modification. Fracture Mechanics: Irwin’s approach to fracture mechanics - strain energy release rate - stress intensity factor - K_{IC} determination. LEFM and EPFM approaches - concepts of J-integral, CTOD and R-Curve. (10 + 3)

ANALYSIS OF FAILURE: Common causes of failure - design deficiencies, improper material selection, material defects, manufacturing defects, inadequate reliability testing, abusive usage, poor maintenance and service life anomalies. Steps in metallurgical failure analysis – fractography - root-cause analysis - failure prevention concepts. Discussion of fish bone diagram, Pareto diagram, Failure Mode Effect Analysis (FMEA) and Fault Tree Analysis (FTA). (12 + 4)

FAILURE CAUSED BY MECHANICAL FORCES: Failure due to static overloading with example case studies – yielding, bending and buckling. Failure due to dynamic overloading with case studies - fatigue, creep, fatigue – creep interaction, stress rupture and low temperature embrittlement. Failure due to contact interaction with case studies - wear, erosion and abrasion - related case studies. (11 + 4)

FAILURE CAUSED BY OTHER FACTORS: Failure due to corrosion – corrosion types, erosion corrosion, pitting corrosion, hydrogen assisted blistering, stress corrosion cracking, corrosion fatigue and hydrogen embrittlement. Failure caused by defects: classification of defects. Defects during primary processing – casting, forming and welding defects- defects during machining and heat treatment. Effect of defects on the service properties of components. important case studies. . (12 + 4)

Total (L: 45 + T : 15) : 60

REFERENCES:

1. Dieter G E , "Mechanical Metallurgy", Third edition, McGraw Hill Education, 2017.
2. ASM Handbook, “Failure Analysis and Prevention Volume 11”, ASM International, USA, 2002.
3. Charles R Brooks And Ashok Choudhury, “Failure Analysis of Engineering Materials” McGraw-Hill Professional Engineering, 2001.
4. Colangelo V J and Heiser F A, “Analysis of Metallurgical Failures”, John Wiley & Sons, Inc., USA, 1987.
5. Kannadi Palankeezhe Balan, “Metallurgical Failure Analysis: Techniques and Case Studies” 1st Edition, Elsevier, 2018.

21YN82 AUDIT COURSE II

vide Automotive Engineering 21AE82

21YN53 MATERIAL PROCESSING LABORATORY

0 0 4 2

List of Experiments:

1. Testing of sand used in green sand moulding.
2. Sand casting of low melting alloys and composition analysis using OES.
3. Weld cracking susceptibility tests – Implant test and Varestraint test.
4. Demo on SICO (Strain Induced Crack Opening) test using Thermo-Mechanical simulator
5. Determination of n and K from tension test.
6. Determination of friction coefficient using ring compression test.
7. Compaction and sintering of metal powders with and without ceramic reinforcements.
8. Hardening of EN 8 and EN 19 grade steels with quenchants and subsequent tempering.
9. Solutionizing and Age hardening of Aluminum alloys and their characterization.
10. Molten salt boronizing of steels and nickel alloys.

Total P : 60

REFERENCES:

1. Material Processing Laboratory Manual - Department of Metallurgical Engg., PSG College of Technology, 2021.

21YN54 QUALITY INSPECTION LABORATORY

0 0 4 2

List of Experiments:

1. Vickers micro hardness survey on welded steel and aluminum samples as per ASTM E 18 and 384 standards.
2. Transverse and all weld tension test on steel welds as per ASTM A 370 – E8 standard.
3. Guided bend test for ductility of welds as per ASTM E190-92 standard.
4. Electrochemical evaluation of materials and coatings using ASTM G150 standard.
5. Pin on Disc Wear Testing as per ASTM G 99 standard.
6. Visual inspection of castings and welds as per ASME B&PV Code Section V, Subsection A, Article 9 and Section VIII.
7. Penetrant Inspection of components as per ASME B&PV Code Section V, Subsection A, Article 6 and Section VIII
8. Magnetic particle inspection of Ferromagnetic parts as per ASME B&PV Code Section V, Subsection A, Article 7 and Section VIII.
9. Ultrasonic Inspection of components as per ASME B&PV Code Section V, Subsection A, Article 4 and Section VIII
10. Interpretation of RT film radiographs and digital radiographs as per ASME B&PV Code Section V, Subsection A, Article 2 and Section VIII.

Total : 60

REFERENCES:

1. Quality Inspection Laboratory Manual - Department of Metallurgical Engg., PSG College of Technology, 2021..
2. Handout copies of the above standards

21YN61 INDUSTRIAL VISIT AND TECHNICAL SEMINAR

vide Automotive Engineering 21AE63

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.

OPEN ELECTIVES

21YN91 DATA ANALYTICS

3 0 0 3

INTRODUCTION : Big data-Volume, Velocity, Variety, Veracity - Business Intelligence, Data Science- - Types of Analytics –Descriptive, diagnostic, predictive, prescriptive analytics, Data Analytics Lifecycle Overview – Discovery – Preparation – Model Planning. Introduction to R and python, basic programming. (11)

EXPLORATORY DATA ANALYSIS : Data collection, Data preprocessing – understanding the data, basic visualization - dealing with outliers - dealing with null value- data standardization - scaling of data, Correlation, Multi collinearity - diagnostics, treatment, dimensionality reduction techniques, principle component analysis (PCA), Factor Analysis – applications. (10)

MACHINE LEARNING: Introduction, types of machine learning algorithms, model building – unsupervised learning algorithms – Association rule mining, conjoint analysis, clustering, K means clustering, supervised learning algorithms - - types, linear and logistic regression analysis, Decision tree, classification and regression techniques, random forest, KNN, Naviebayes, LDA, support vector machines, Artificial Neural network, ensemble methods, applications in metallurgical and materials science data. (13)

TEXT ANALYTICS, TIME SERIES FORECASTING AND WEB SCRAPPING - Text analytics - word cloud, sentiment analysis, web and social media analysis, time series data, components, stationery of the data, exponential smoothing model, Holt-winters model, ARIMA model – applications, web scrapping – introduction and applications. (11)

Total L: 45

REFERENCES:
1. EMC Education Services, "Data Science and Big data Analytics: Discovering, Analyzing, Visualizing and Preserving Data", Wiley, USA, 2015.
2. Seema Acharya, Subhashini Chellapan, "Big Data and Analytics", Wiley, USA, 2015.
3. Mohammed Guller, "Big Data Analytics with Spark", Apress, USA, 2015.
4. Bart Baesens, "Analytics in a Big Data World: The Essential Guide to Data Science and its Applications", Wiley, USA, 2014.
5. Peter Zadrozny and Raghu Kodali, "Big Data Analytics using Splunk", USA, 2013.

21YN92 OPTIMIZATION TECHNIQUES

3 0 0 3

MODELLING WITH LINEAR PROGRAMMING : Objective function – Two variable LP model - Graphical LP – Selected LP applications: Blending and refining & manpower management- Simplex method – Artificial starting solution – Special cases in simplex method – sensitivity analysis- Duality and post optimal analysis**:** Definition of dual problem – prime dual relationship – economic interpretation of duality –dual simplex method – generalized simplex method –post optimal analysis (12)

ADVANCED LINEAR PROGRAMMING: Revised simplex method: Development of the Optimality and Feasibility Conditions - Revised Simplex Algorithm - Bounded-Variables Algorithm – duality – parametric linear programming – goal programming (11)

INTEGRATED LINEAR PROGRAMMING AND DYNAMIC PROGRAMMING : Branch & bound algorithm – Cutting plane algorithm – Illustrations: capital budgeting and Either-Or and If-Then Constraints -Recursive Nature of Computations in DP - Knapsack/Fly-Away models - Equipment Replacement Model (11)

NONLINEAR PROGRAMMING: Introduction and formulation of models, Classical optimization methods, equality and inequality constraints, Lagrange multipliers and Kuhn-Tucker conditions, quadratic forms, quadratic programming problem, Wolfe's method. (11)

Total L : 45

REFERENCES:
1. Hamdy A. Taha, "Operation research an introduction", Pearson, eight edition, 2007.
2. Kanti Swarup, Man Mohan and P.K.Gupta, "Introduction to Operations Research", S.Chand & Co., 2006
3. Pant J C, "Introduction to Operations Research", Jain Brothers, New Delhi, 2008.
4. Kambo N S "Mathematical Programming Techniques", East-West Pub., Delhi, 1991.
5. Srinivasan G, "Operations Research – Principles and applications" , PHI, second edition,2010.
6. Ramamurthi P, "Operations Research", Newage International publishers, second edition, 2007.