INDIAN INSTITUTE OF TECHNOLOGY PATNA

Department of Metallurgical and Materials Engineering

B.Tech. program in

Metallurgical and Materials Engineering

Indian Institute of Technology Patna

Course curriculum according to NEP

INDIAN INSTITUTE OF TECHNOLOGY PATNA

Department of Metallurgical and Materials Engineering

Academic Program: Bachelor of Technology (B.Tech.) in Metallurgical and Materials Engineering

NOTE: PLO, CLO to be drafted in view of program and courses, and CLO to be mapped with PLO.

Program Learning Objectives:	**Program Learning Outcomes:**
Program Goal 1: The B.Tech program in Metallurgical and Materials Engineering aims to equip graduates with the necessary knowledge, skills, and values to succeed in professional careers related to metallurgical and materials engineering.	**Program Learning Outcome 1a:** Upon successful completion of the B.Tech program in Metallurgical and Materials Engineering, graduates will be able to identify, formulate, and analyse complex engineering problems related to metallurgical and materials engineering. **Program Learning Outcome 1b:** Students will be able to understand the science behind the functioning mechanism of metals, ceramics, polymers and glass
Program Goal 2: Apply fundamental principles of science and engineering to solve complex problems in metallurgical and materials engineering and cultivate critical thinking and problem-solving skills in students to address real-world challenges in the metallurgy and materials domain.	**Program Learning Outcome 2:** Student will be able to apply research-based knowledge and methodologies, including experimental design, data analysis, and interpretation, to investigate complex problems in metallurgical and material engineering. Graduates will be capable to carry out research work in their area of interest either in academic area or in industry.
Program Goal 3: Expose the students to the scientific and engineering concepts on metals, ceramics, polymer and composites and apply engineering principles to design, develop, and improve materials and processes for specific applications.	**Program Learning Outcome 3a:** Students will be well versed with the concepts of microscopic analysis, characterization techniques, metallurgical testing, polymer synthesis & analysis, nano & electro ceramics, plasma-coating and flash sintering, mineral beneficiation & process metallurgy. **Program Learning Outcome 3b:** Students will be able to design and develop new engineering materials with desired properties based on demands of various engineering sectors.
Program Goal 4: To impart hand-on exposure to modern	**Program Learning Outcome 4a:** Students will be able to correlate the theoretical concepts with the

laboratory equipment through structured laboratory experiments.	experiments and will be ready to apply the experimental knowledge in industries. **Program Learning Outcome 4b:** Students will be ready for quality control, higher studies and research work in the domain of metallurgical and materials engineering.
Program Goal 5: To inculcate research aptitude in the students and prepare the students to be industry-ready after the completion of their B. Tech. programme.	**Program Learning Outcome 5:** Students will be able to design solutions for complex engineering problems related to materials, considering public health, safety, cultural, societal, and environmental factors. In addition, apply ethical principles and commit to professional ethics and social responsibility as a metallurgical and materials engineer. Graduate will be able to launch start-ups as entrepreneur to create job opportunities in the country.

Course Number Pattern (revised format for all programs): XXnmPQ
XX: Department/Branch Code
n: Year/Level
m: Semester
PQ: Course number of the Department for a semester under a programme
Ex: MA1101: Mathematics course for first year (level one) in first semester with course number 01 for the department (Maths) at that level.
CS3241: Computer Science and Engineering course for third year (level three) in second semester with course number 41 for the Department (CSE) at that level.

GATE/IES(UPSC) syllabus to be covered on priority in the core courses itself to enable students ready for such examinations.

On completion of 1st Year when the students move to their respective branches, it is imperative that:

1. **Department would focus on core competency in 3rd, 4th & 5th Semester to enable the students develop enough understanding of core fundamentals to enable them opt for Electives of their choice based on their interest. Accordingly, a right balance between core and elective is required to be maintained 6th Semester onwards.**
2. **All core courses upto 5th Semester should comprise a right combination of content for the lecture course clubbed with lab skill (experiment, computation, design) / tutorial accordingly as a composite credit structure for the course in the L-T-P format.**
3. **The total number of courses in a Semester till 6th Semester should not be more than six.**
4. **Inter Disciplinary Elective (IDE) floated by a Department with their Departmental Course Code would not be available to the students of the parent Department.**
5. **For Minor Course proposals, each interested Department should propose a pool of theme based course structure comprising of minimum 16 credits to be offered as Minor. For e.g. a Department offering Minor in AI or VLSI or CSE or Maths & Computing or Structural Design, Management, Economics etc. may propose courses comprising of minimum 16 credits with proper theme and knowledge base to be awarded as Minor Degree in the specific area of knowledge. Currently, it is proposed to have 10% credit of the total B. Tech. credit for consideration of the award of Minor Degree.**
6. **The option for theme based Minor Courses, as approved by the Senate, to the students would start from 6th Semester onwards.**
7. **The Minor would be permitted to only those students who obtain CPI ≥ 7.5 at the end of Semester V as an essential pre-requisite.**
8. **All the Departments must provide all the Elective baskets together with the revised syllabus.**
9. **There should be no core course in 7th and 8th Semester.**
10. **The credit of each semester should be around 20. In a semester, total course should not be more than six (6) and the total credit of the program should be in the range of 163-170.**

Sl. No.	Subject Code	SEMESTER III	L	T	P	C
1.	MM2101	Introduction to Metallurgical and Materials Engineering	3	0	0	3
2.	MM2102	Mineral Processing and Process Metallurgy	3	0	3	4.5
3.	MM2103	Thermodynamics and Phase Equilibria	3	0	3	4.5
4.	MM2104	Transport Phenomena	3	1	0	4
5.	MM2105	Fundamentals of Polymer Science and Technology	3	0	0	3
6.	HS21XX	HSS Elective-I	3	0	0	3
TOTAL			**18**	**1**	**6**	**22**

Sl. No.	Subject Code	SEMESTER IV	L	T	P	C
1.	MM2201	Iron and Steel Making	3	1	0	4
2.	MM2202	Techniques of Materials Characterization-I	3	0	3	4.5
3.	MM2203	Phase Transformation and Diffusion	3	1	0	4
4.	MM2204	Mechanical Behaviour of Materials	3	0	3	4.5
5.	MM2205	Welding and Solidification	3	0	0	3
6.	XX22PQ	IDE-I	3	0	0	3
TOTAL			**18**	**2**	**6**	**23**

Sl. No.	Subject Code	SEMESTER V	L	T	P	C
1.	MM3101	Thermomechanical Processing of Metallic Materials	3	0	2	4
2.	MM3102	Computational Materials Science	2	1	0	3
3.	MM3103	Engineering Polymers	3	0	2	4
4.	MM3104	Ceramic Science and Technology	3	0	2	4
5.	MM3105	Metallography and Heat Treatment Laboratory	0	0	2	1
6.	MM31PQ	IDE-II	3	0	0	3
TOTAL			**14**	**1**	**8**	**19**

INDIAN INSTITUTE OF TECHNOLOGY PATNA

Department of Metallurgical and Materials Engineering

Sl. No.	Subject Code	SEMESTER VI	L	T	P	C
1.	MM3201	Techniques of Materials Characterization-II	3	0	3	4.5
2.	MM3202	Corrosion and Corrosion Prevention	3	0	2	4
3.	MM3203	Functional Materials	3	0	0	3
4.	MM3204	Non-ferrous Metals and Alloys	3	0	0	3
5.	MM3205	Capstone Laboratory	0	0	4	2
6.	MM3206	Metals Processing Laboratory	0	0	3	1.5
TOTAL			**12**	**0**	**12**	**18**

Sl. No.	Subject Code	SEMESTER VII	L	T	P	C
1.	MM41XX	Departmental Elective-I	3	0	0	3
2.	MM41XX	Departmental Elective-II	3	0	0	3
3.	HS41XX	HSS Elective-II	3	0	0	3
4.	XX41PQ	IDE-III	3	0	0	3
5.	MM4198	Summer Internship*	0	0	12	3
6.	MM4199	Project – I	0	0	12	6
TOTAL			**12**	**0**	**24**	**21**

Note :

*** For specific cases of internship after VI" Semester, the performance evaluation would be made on joining the VII Semester and graded accordingly in the VII‘ Semester:**

Note :

a) (i) Summer internship (*) period of at least 60 days' (8 weeks) duration begins in the intervening vacation between Semester VI and VII that may be done in industry / R&D / Academic Institutions including IIT Patna. The evaluation would comprise **combined grading based on host supervisor evaluation, project internship report after plagiarism check and seminar presentation at the Department (DAPC to coordinate)** with equal weightage of each of the three components stated herein.

a) (ii) Further, on return from internship, students will be evaluated for internship work through combined grading based on host supervisor evaluation, project internship report after plagiarism check, and presentation evaluation by the parent department with equal weightage of each component.

b) (i) In the VII semester, students can opt for a semester long internship on recommendation of the DAPC and approval of the Competent Authority.

b) (ii) On approval of semester long internship, at the maximum two courses (properly mapped/aligned syllabus) at par with institute electives may be opted from NPTEL and / or

SWAYAM and the other two more should be done at the institute through course overloading in any other semester (either before or after the internship) and/or during following summer semester.

b) (iii) The candidates opting two courses from NPTEL and / or SWAYAM would be required to appear in the examination at the Institute as scheduled in the Academic Calendar.

Sl. No.	Subject Code	SEMESTER VIII	L	T	P	C
1.	MM42XX	Elective III	3	0	0	3
2.	MM42XX	Elective IV	3	0	0	3
3.	MM42XX	Elective V	3	0	0	3
4.	MM4299	Project – II	0	0	16	8
TOTAL			**9**	**0**	**16**	**17**
GRAND TOTAL(Semester I to VIII)			**166**			

ELECTIVE GROUPS

Department Elective - I						
SL No.	**Subject Code**	**Department Elective - I**	**L**	**T**	**P**	**C**
1	MM4101	Environmental Sustainability and Industrial Safety	3	0	0	3
2	MM4102	Glass Science and Technology	3	0	0	3
3	MM4103	Semiconductor Materials and Devices	3	0	0	3

Department Elective - II						
SL No.	**Subject Code**	**Department Elective - I**	**L**	**T**	**P**	**C**
1	MM4104	Thin Films	3	0	0	3
2	MM4105	Heat treatment of Metals and Alloys	3	0	0	3
3	MM4106	Creep, Fatigue Fracture	3	0	0	3

Department Elective - III						
SL No.	**Subject Code**	**Department Elective - I**	**L**	**T**	**P**	**C**
1	MM4201	Smart Polymers	3	0	0	3
2	MM4202	Energy Materials	3	0	0	3

Department Elective - IV						
SL No.	**Subject Code**	**Department Elective - I**	**L**	**T**	**P**	**C**
1	MM4203	Electroceramics	3	0	0	3
2	MM4204	Biomaterials	3	0	0	3

Department Elective - V						
SL No.	**Subject Code**	**Department Elective - I**	**L**	**T**	**P**	**C**
1	MM4205	Crystallographic Texture and Analysis	3	0	0	3
2	MM4206	Furnace and Refractories	3	0	0	3
3	MM4207	Composite Science and Technology	3	0	0	3

Interdisciplinary Elective (IDE) Courses for B. Tech. (Available to students other than Dept. of MME)

SL No.	Subject Code	Interdisciplinary Elective (IDE)	L	T	P	C
1	MM2206	Structure and Properties of Materials	3	0	0	3
2	MM3106	Microscopy and X-ray Diffraction	3	0	0	3
3	MM4107	Nanomaterials	3	0	0	3

Minor in Material Science & Engineering:

SL No.	Subject Code	Subject Name	L	T	P	C
1	MM2101	Introduction to Metallurgical and Materials Engineering	3	0	0	3
2	MM2202	Techniques of Materials Characterization	3	0	3	4.5
3	MM3103	Engineering Polymers	3	0	0	3
4	MM3203	Fundamental Materials	3	0	0	3
5	MM4103	Semiconductor Materials and Devices	3	0	0	3

Total Credits: 16.5

Semester	I	II	III	IV	V	VI	VII	VIII	**Total**
Credit	23.5	22.5	22	23	19	18	21	17	**166**

INDIAN INSTITUTE OF TECHNOLOGY PATNA

Department of Metallurgical and Materials Engineering

MM2101 Introduction to Metallurgical and Materials Engineering (3-0-0) 3 credits

Course learning objectives (Complies with PLOs 1 and 3)
- To understand the theoretical description of crystal and bonding in solids
- To understand the atomic arrangement and defects in crystalline materials
- To understand the structure-property correlation in materials

Course learning outcomes
Upon completion of this course the student will be able to:
- Identify the properties of material with respect to their crystal structure and bonding
- Correlate the influence of defects on material properties
- Correlate the structure of crystalline materials with their properties.

Bonding in solids: Concept of energy versus interatomic separation for atoms, bonding in solids, primary interatomic bonding, secondary bonding. Properties of differently bonded solids. Property of materials in relation to crystal symmetry. Tensors.

Structure of crystalline solids: Basic idea of lattice, crystalline and non-crystalline materials, unit cell, crystal systems, indexing planes and directions, Miller indices, coordination number, packing of atoms, voids, elements of symmetry.

Defects in solids: Point, linear, planar and volume defects, equilibrium concentration of vacancies, Types of dislocations, Burgers vectors, slip systems, grain boundaries, twin and stacking faults.

Mechanical properties of materials: Concept of stress and strain, Hooks law, elastic and plastic deformation, tensile properties, hardness.

Structure-property correlation: Introduction to ceramic, polymer and composite – processing, structure, properties and applications.

Text Book:

1. Materials Science and Engineering, an Introduction: William D. Callister, 7th Ed., John Wiley and Sons, 2007.
2. Materials Science and Engineering: V. Raghavan, 6th Ed., Prentice Hall India, 2015.

Reference Book:

1. Physical Foundation of Materials Science: Günter Gottstein, Springer, 2004.
2. An Introduction to Metallurgy: Sir Alan Cottrell, 2nd Ed., Universities Press, 2000.

INDIAN INSTITUTE OF TECHNOLOGY PATNA

Department of Metallurgical and Materials Engineering

MM2102 Mineral Processing and Process Metallurgy
(3-0-3) 4.5 credits

Course learning objectives (Complies with PLOs 2 and 4)

- To understand various mineral processing techniques for metal extraction
- To understand process technology for mineral beneficiation, extraction and refining of metals, especially non-ferrous metals.

Course learning outcomes

Upon completion of this course the student will be able to:

- Apply appropriate knowledge for: Mineral Beneficiation (comminution and separation; extraction and refining of metals)
- Appreciate the importance of scientific concepts for mineral beneficiation, extraction of non-ferrous metals from ores including their refinement

Mineral Engineering: Minerals of economic importance, laws of comminution, Principles of separation technologies (Gravity Separation, Froth Floatation, magnetic separation & Electrostatic separation) Beneficiation efficiency ratios and two product mass balance equation.
Principles of Process Metallurgy: Thermodynamics (Free energy, Ellingham diagram, Predominance area Diagram), Kinetics (Rate laws, Order of reactions, solubility of gases in metal, Arrhenius Equation).
Pyrometallurgy: Principles of drying, calcination, roasting, smelting (including flash smelting); Extraction of Fe, Cu, Pb, Ni, Mg, Zn, Ti.
Hydrometallurgy: Theory of leaching, Leaching techniques (bacterial leaching, Pressure leaching), leaching solvents, solvent extraction, Ion exchange, Cementation process, Examples (Bayer's process for Alumina and Sherritt-Gorden process for Cu, Ni, Co), rare metals.
Electrometallurgy: Principles of electrolysis, Faraday's law of Electrolysis, Electro winning & electrorefining, Electrolysis of Fused salt (extraction of aluminium through Hall Heroult process), Electrolysis of aqueous salt (extraction magnesium from sea-water through Dow's process).
Refining of metals: Principles & Techniques of refining: Selective dissolution, Liquation, zone refining, chemical and electrochemical method.

Text Book:

1. Mineral Processing Technology: B.A. Wills, 8th Ed., Butterworth Heinemann, Elsevier, 2015
2. Extraction of Nonferrous metals: H.S. Ray, R. Sridhar & K.P. Abraham, Affiliated East-West Press, 2018
3. Principles of extractive metallurgy: H.S. Ray & A. Ghosh, New Age International Publishers, 3rd Edition, 2019

Reference Book:

1. Chemical Metallurgy: J.J. Moore, 2nd Edition, Elsevier, 1990

MM2102 Mineral Processing and Process Metallurgy Laboratory

Crushing of ore: Jaw crushers, grinding mills, reduction ratio, Rittinger's law of crushing, industrial particle size control.

Size distribution of ores: Sieve analysis, mesh number and size, ASTM standard, sieve shaker, vibratory shaker, ball milling.

Particulate separation: Gravity separation, solid liquid separation, froth floatation process (phosphate and copper), magnetic separation, electrostatic separation.

Beneficiation of ores: coal and ores of copper, zinc, iron

Hydro and pyrometallurgy: Leaching techniques,

Text Books:

1. Principles of Mineral Dressing: A.M. Gaudin, Tata McGraw Hill, 1980.
2. Extraction of Non-ferrous Metals: H.S. Ray and K.P. Abraham, East West Press, 2006.
3. Mineral Processing, M.R. Pryor, Springer, 1965.

INDIAN INSTITUTE OF TECHNOLOGY PATNA

Department of Metallurgical and Materials Engineering

MM2103 Thermodynamics and Phase Equilibria
(3-0-3) 4.5 credits

Course learning objectives (Complies with PLOs 2, 4 and 5)

- To understand how thermodynamics is fundamental to the study of materials engineering
- To apply the thermodynamics for engineering problem solving
- To understand the stability criteria of various systems (vapour-solid, solid liquid, liquid-vapour) under consideration

Course learning outcomes

Upon completion of this course, the student will be able to:

- Understand the practical implication of laws of thermodynamics
- Apply the laws of thermodynamics to solve common industrial important reactions
- Appreciate the implications of various systems in metallurgical/allied industry

Introduction to Thermodynamics: Concept of state, reversible and irreversible processes, path and state functions, extensive and intensive properties, kinetic theory of gases.
First Law of Thermodynamics: Internal energy, enthalpy, constant volume and pressure process, isothermal and adiabatic process and heat capacity.
Second Law of Thermodynamics: Equilibrium, entropy, most probable microstate, statistical concepts of entropy, Thermodynamical functions, Maxwell's relations, Gibbs-Helmholtz stability.
Third Law of Thermodynamics: Gibbs free energy vs temperature and Gibbs free energy vs. pressure, Clausius-Clapeyron equation, P-T diagram.
Thermodynamic stability of materials. Ellingham diagram and its importance, application of electrochemical series.
The behaviour of solutions, Phase equilibria, and phase diagram: Ideal solution, Gibb's-Duhem equation, Raoults, and Henry's law, the activity of a component, concept of chemical potential, regular solutions, free energy-composition diagrams for ideal and regular solutions and its relation to phase diagram, Gibbs phase rule, eutectic and eutectoid, peritectic and peritectoid diagrams. Ternary phase diagrams. Binodal and spinodal decomposition in metals, ceramics and polymers.

Text Books:

1. Introduction to Metallurgical Thermodynamics: David R. Gaskell, McGraw Hill, 4th Ed., 2009.
2. The laws of thermodynamics, P. Atkins, Oxford University Press. 2010
3. Phase Transformation: Porter and Easterling.

Reference Books:

1. Physical Chemistry of Metals: L. Darken and R.W. Gurry, McGraw-Hill, 1953.
2. Thermodynamics of Solids: Richard A. Swalin, 2nd Ed., Wiley, 1972.

INDIAN INSTITUTE OF TECHNOLOGY PATNA

Department of Metallurgical and Materials Engineering

MM2103 Thermodynamics and Phase Equilibria Laboratory

Introduction to programming using MATLAB/Python: Basics, loops, IF-Else conditioning, functions, solving equations
Calculations of enthalpy, entropy, and free energy variation with temperature using MATLAB/Python for metals using sp. heat data from the database
Calculation of driving force of phase transformation, concept of undercooling and supercooling using MATLAB
Constructions of free energy vs composition diagram using ideal and regular solution models at different temperatures using MATLAB/Python and the concept of the isomorphous, eutectic phase diagram and miscibility
Introduction to Thermo-Calc software, concept of CALPHAD, phase equilibria, property diagrams, and phase diagrams of multicomponent alloys using the Thermo-Calc software

Text Books:

1. Introduction to Metallurgical Thermodynamics: David R. Gaskell, McGraw Hill, 4th Ed., 2009.
2. Atkins' Physical Chemistry: Twelfth Edition, Peter Atkins, Julio de Paula, and James Keeler, 2022, ISBN: 9780198847816
3. Phase Transformation: Porter and Easterling.
4. Getting Started with MATLAB: A Quick Introduction for Scientists and Engineers, 7e: Rudra Pratap, Oxford University Press, 2017, ISBN: 978-0-19-060206-2
5. An Introduction to Python Programming for Scientists and Engineers: Johnny Wei-Bing Lin, Hannah Aizenman, Erin Manette Cartas Espinel, Kim Gunnerson, Joanne Liu, Cambridge University Press, 2022, ISBN 1108753485, 9781108753487

Reference Books:

1. Physical Chemistry of Metals: L. Darken and R.W. Gurry, McGraw-Hill, 1953.
2. Thermodynamics of Solids: Richard A. Swalin, 2nd Ed., Wiley, 1972

INDIAN INSTITUTE OF TECHNOLOGY PATNA

Department of Metallurgical and Materials Engineering

MM2104 Transport Phenomena
(3-1-0) 4 credits

Course learning objectives (Complies with PLOs 1)
- To develop fundamental concepts governing the transport of momentum, energy and mass
- To demonstrate the common mathematical formulation of transport problems to the students

Course learning outcome
Upon completion of the course, students will be able to:
- Estimate transport properties such as viscosity, conductivity and diffusivity.
- Develop the conservative equations of laws of momentum, energy and mass

Dimensional Analysis: Introduction; Dimensions and Units; Buckingham's π theorem.
Momentum Transfer: Fluid Properties and fluid as a Continuum; Viscosity; Dimensional Formula and Units of Viscosity; Effect of Temperature and Pressure on Viscosity; Laminar flow and Turbulent flow; Flow: Rate and continuity equation; Losses in Pipes; Head loss due to friction; Flow measurement; Flow past immersed objects, packed & fluidized beds.

Heat Transfer: Modes of Heat Transfer: Introduction to conduction, convection, and radiation; Conduction: Heat transfer through a wall, Composite walls with materials in series, Composite walls with materials in parallel, Multidimensional heat transfer problems; Convection: Types of Convection, Film heat transfer coefficients, Newton's Law of Cooling; Radiation: Black body radiation; Law: Stefan-Boltzmann, Kirchhoff's Law; Radiation Properties: Emissivity, Receiving Properties; Radiation heat transfer; Factors affecting: Thermal conductivity of gases, liquids, solid metals and alloys; Heat transfer with change of phases: solidification, melting problems.

Mass transfer: Diffusion; Laws of diffusion; Fick's first law of diffusion; Fick's second law of diffusion; Factors affecting Mass transfer coefficient k, Parameters affecting convective mass transfer; Application of dimensionless analysis; Homogenization of alloys; Formation of surface layers.

Introduction to kinetics: Basic kinetic laws, order of reactions, rate constant, elementary and complex reactions, rate limiting steps and Arrhenius equations, theories of reaction rates - simple collision theory, activated complex theory.

Text Books:
1. Fundamentals of Heat and Mass Transfer; 5th Edition; F.P. Incropera and D.P. DeWitt, 2006; Wiley India.
2. Transport Phenomena; 2nd Edition; R. Byron Bird, Warren E. Stewart, Edwin N. Lightfoot; 2021; John Wiley & Sons, Inc.
3. Fundamentals of Momentum, Heat, and Mass Transfer; 4th Edition; Welty, James, Charles E. Wicks, R. E. Wilson, and Gregory L. Rorrer; 2000; New York: John Wiley and Sons Inc.,
4. Kinetics of Materials: R.W. Balluffi, S.M. Allen, and W.C. Carter, Wiley, 2005.

Reference Books:

1. Fundamental of Transport Phenomena and Metallurgical Process Modeling; Sujay Kumar Dutta; 2022; Springer
2. Transport Processes and Separation Process Principles; 4^{th} Edition; C. J. Geankoplis; PHI Learning Private Limited., New Delhi.
3. Transport Phenomena in Materials Processing; D. R. Poirier, G. H. Geiger; 2016; Springer International Publishing.

INDIAN INSTITUTE OF TECHNOLOGY PATNA

Department of Metallurgical and Materials Engineering

MM2105 Fundamentals of Polymer Science and Technology (3-0-0) 3 credits

Course learning objectives (Complies with PLOs 1, 2 and 3)

- To understand the structure-property correlation in polymers
- To develop knowledge of the mechanics underlying various polymerization techniques and polymer reactions
- To understand the variables controlling the physical characteristics of polymers

Course learning outcomes

Upon completion of this course the student will be able to:

- Recognize how polymers' structures and properties relate to one another.
- Choose appropriate polymerization techniques for polymer synthesis
- Select suitable characterization methods to characterize the polymers

Basic concepts: Molecular forces, chemical bonding, Configuration, Conformation, tacticity, molecular weight studies, molecular weight distribution, transitions in polymers, viscoelasticity, types of macromolecules, classification of polymers.

Structure and property relationships: Amorphous and crystalline nature of polymers, factors affecting crystallization and melting, glassy state and glass transition temperature and factors influencing the glass transition temperature.

Polymerization techniques: General features of chain growth polymerisation - initiators, generation of initiators, free radical, anionic and cationic polymerization, ring opening polymerization, general features of step growth polymerization - mechanism of step growth polymerization, coordination polymerization, kinetics of addition, condensation and coordination polymerization, copolymerization mechanism and kinetics, homogeneous polymerization techniques- bulk, solution, heterogeneous polymerization techniques- emulsion, suspension, solid phase polymerisation.

Polymer solutions: Thermodynamics of polymer solutions, solution properties of polymers, solubility parameter, polymer chains' conformation in polymer solutions: Flory-Krigbaum and Flory-Huggins theories, solution viscosity, osmotic pressure, molecular size and molecular weight.

Testing and characterization: End group analysis, colligative property measurement, light scattering, ultra-centrifugation, viscosity methods, gel permeation chromatography, IR, NMR, XRD, microscopy, thermal characterization, rheology/viscoelasticity, Mechanical properties testing - tensile, flexural, compressive, abrasion, endurance, fatigue, hardness, tear, resilience, impact and toughness.

Advanced polymerization techniques: ATRP, RAFT.

Text books:

1. F.W. Billmeyer, Textbook of polymer science, 3rd ed., John Wiley & Sons, Asia, New Delhi, 1994.
2. R.J. Young and P. A. Lovell, Introduction to Polymers, 2nd ed., CRC Press (Taylor and Francis Group) 2004.

Reference book:

1. G. Odian, Principles of Polymerization, 4th ed., Wiley-Interscience, 2004.
2. P. Gosh, Polymer Science and Technology, Mc-Graw Hill, 2002.

3. Joel R. Fried, Polymer Science and Technology, 2nd ed., PHI Learning Private Limited, 2009.
4. V.R. Gowariker, N.V. Viswanathan, J. Sreedhar, Polymer Science, New Age International, 2010.

INDIAN INSTITUTE OF TECHNOLOGY PATNA

Department of Metallurgical and Materials Engineering

MM2201 Iron and Steel Making
(3-1-0) 4 credits

Course learning objectives (Complies with PLOs 2, 3 and 5)
- To understand the scientific principles for the production of iron and steel
- To understand process technology of ironmaking, steelmaking and continuous casting
- To introduce the emerging trends in iron and steelmaking technologies

Course learning outcomes
Upon completion of this course the student will be able to:
- Appreciate the complexities in the production of iron and steel
- Apply the acquired knowledge to various processes like BF ironmaking, BOF steelmaking, Casting, EAF steelmaking etc
- Appreciate the latest green iron and steelmaking techniques

Ironmaking: Routes of modern steel making (BF-BOF, DRI-EAF), Thermodynamics of Ironmaking, Burden preparation (sintering, pelletization, coke making), Blast furnace Ironmaking (Design, operation, reactions and zones, direct & indirect reduction, burden distribution, Auxiliary fuel injection, RAFT calculations, RIST Diagram, Aerodynamics, development trends).

Alternate routes of ironmaking: Sponge ironmaking, Smelting Reduction.

Steelmaking

Principles of Steelmaking: Basic thermodynamics & Kinetics of steelmaking.

Primary Steelmaking: LD steelmaking converter, design, reactions, operations, refractories, development trends like Post combustion & slag splashing; EAF steelmaking.

Secondary steelmaking: Ladle metallurgy, vacuum degassing, Inclusion refining.

Casting of steel: Ingot Vs Continuous Casting, Continuous casting (Tundish Metallurgy, defects in CC products), neat net shape casting etc.

Future trends: Clean steel & Hydrogen-assisted steelmaking.

Text Book:

1. A first course in iron and steelmaking; Dipak Mazumdar; Universities Press, 2014
2. Ironmaking & Steelmaking: Theory and Practice; Ahindra Ghosh and Amit Chatterjee, PHI Learning, 2004.

Reference Book:

1. The Making, Shaping and Treating of Steel: Ironmaking Volume: Steelmaking Volume and Casting Volume, R.J. Fruehan (ed.), The AISE Steel Foundation, 2004.

INDIAN INSTITUTE OF TECHNOLOGY PATNA

Department of Metallurgical and Materials Engineering

MM2202 Techniques of Materials Characterization - I
(3-0-3) 4.5 credits

Course learning objectives (Complies with PLOs 1, 3 and 4)
- To understand how material characterization is of paramount importance to the study of materials science
- To understand the strength and weaknesses of different characterization techniques
- To gain hands-on training on different characterization techniques

Course learning outcomes
Upon completion of this course, the student will be able to:
- Understand the working principle and applications of various characterization techniques
- Choose an appropriate technique to characterize various microstructural aspects
- Characterize the microstructure of various materials by themselves

Introduction: Importance and the need for materials characterization, crystal system, miller indices, Bravais lattice.
Diffraction: Basics of diffraction and interference of light, Young's double slit experiment, interpretation of diffraction from the single slit and multiple slits.
X-ray Diffraction: Generation of X-Rays, X-Ray Diffraction (XRD), Bragg's Law, Atomic scattering factor, structure factor, indexing of diffraction patterns, selection rules, estimation of peak intensity, phase identification and analysis by XRD, determination of structure and lattice parameters, strain and crystallite size measurements through XRD, effect of temperature on XRD. Reciprocal lattice and Ewald's sphere.
Optical Microscopy: Principles of optical microscopy, magnification, Rayleigh criterion, resolution limitation, Airy disk, depth of focus and field.
Electron diffraction: Wave properties of the electron, electron-matter interactions, ring patterns, spot patterns, and Laue zones.
Scanning Electron Microscopy: Principle, construction, and operation of Scanning Electron Microscope, SE and BSE imaging modes, Elemental analysis using Energy dispersive analysis of X-rays, sample preparation of different materials for SEM.
Transmission electron microscope: Principle, construction, and working of Transmission Electron Microscope (TEM), the origin of contrast: mass-thickness contrast, electron diffraction pattern, Bright field and dark field images, sample preparation.

Text Books:
1. Elements of X-Ray Diffraction: B.D. Cullity and S.R. Stock, 3rd Ed., Pearson, 2001.
2. Scanning Electron Microscopy and X-Ray Microanalysis: Joseph Goldstein, Eric Lifshin, Charles E. Lyman, David C. Joy and Patrick Echlin, 3rd Ed., Springer, 2003.

Reference Books:
1. Transmission Electron Microscopy: A Textbook for Materials Science: David B. Williams and C. Barry Carter, Springer, 2009.
2. Structure of Materials: An Introduction to Crystallography, Diffraction and Symmetry, Marc De Graef, Michael E. McHenry; 2nd Ed., Cambridge University Press, 2012.

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Department of Metallurgical and Materials Engineering

MM2202 Techniques of Materials Characterization – I Laboratory

Sample preparation: Cutting, grinding, and polishing of metal samples. Powder sample preparation.

Practical aspects of X-ray diffraction analysis will be emphasized; hands-on experience in qualitative and quantitative analysis techniques, use of electronic databases, and phase analysis using XRD data. Stereographic projections.

Practical aspects of SEM: Hands-on training in microstructural analysis through SEM, Learning SE, BSE mode, and EDS

Practical aspects of TEM: Hands-on training in DF and BF imaging, basics of SAED pattern analysis

Standard laboratory practices including safety, report writing, and error analysis are also emphasized.

Text Books:

1. Materials Characterization: Introduction to Microscopic and Spectroscopic Methods, Yang Leng; 2nd Ed., Wiley, 2013.
2. Scanning Electron Microscopy and X-Ray Microanalysis: Joseph Goldstein, Eric Lifshin, Charles E. Lyman, David C. Joy, and Patrick Echlin, 3rd Ed., Springer, 2003.

MM2203 Phase Transformation and Diffusion
(3-1-0) 4 credits

Course learning objectives (Complies with PLOs 2 and 3)
- To understand the importance of phase transformation and diffusion in metallurgy
- To explain different types of phase transformations commonly encountered in metallic systems
- To understand the role of diffusion in phase transformations

Course learning outcomes
Upon completion of this course, the student will be able to:
- Grasp how the microstructure of the alloys is influenced by phase transformations
- Acquire a fundamental understanding thermodynamic and kinetics aspects of phase transformation in metals and alloys
- Differentiate the diffusion and diffusionless transformations in selected metallic systems

Fundamentals of Phase Transformations: Introduction to phase transformations, Types of phase transformations, Free energy and chemical potential, Free energy change estimation for phase transformations.
Diffusion in Solids: Fick's laws of diffusion, Solution to Fick’s laws, Uphill diffusion and spinodal decomposition, Kirkendall effect. Structure of surfaces and interfaces, Grain boundaries and phase boundaries, Types of interfaces in materials, Energy of surfaces and interfaces, Interface energy and its impact on material properties.
Nucleation, Growth Theories, and Kinetics of Phase Transformations: Nucleation theories, Homogeneous nucleation, Heterogeneous nucleation, Growth Theories, thermally activated growth, diffusion-controlled growth, interface controlled growth, coupled growth in eutectoid transformations, discontinuous precipitation, the kinetics of phase transformation, JMAK equation, TTT diagrams, CCT diagrams.
Applications and Advanced Phase Transformations: Heat Treatment Processes, Quenching methods: Austempering, Martempering, Annealing, Normalization, Spherodization, and Homogenization, Martensitic transformations, Characteristics of martensitic transformations, Mechanisms and effects on material properties, Applications of TTT and CCT Diagrams, Phase transformations in Polymers and Ceramics, Specifics of phase transformations in polymers, Specifics of phase transformations in ceramics, Practical applications in materials engineering.

Text Books:
1. Solid State Phase transformation: V. Raghavan, Prentice Hall India, 1987.
2. Phase Transformation in Metals and Alloys, D.A. Porter and K. Easterling, 3rd Ed., CRC Press, 2009.

Reference Books:
1. Physical Metallurgy Principles, Robert E. Reed-Hill, Affiliated East-West Press, 2008.
2. Physical Metallurgy, Vijender Singh, Standard Publishers Distributors, 2010.
3. Introduction to Physical Metallurgy, Sidney H. Avner, Tata McGraw-Hill.

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MM2204 Mechanical Behaviour of Materials
(3-0-3) 4.5 credits

Course learning objectives (Complies with PLOs 1, 3 and 4)
- To understand the behaviour of various materials when subjected to various forces/stresses
- To understand the ways through which strength of materials can be improved
- To understand the performance of metallic system during their service in terms of fatigue, fracture and creep

Course learning outcomes
After successfully completing the course, the student will be able to
- Interpret the deformation behaviour of engineering materials under various loading conditions for various applications
- Gain the knowledge of dislocation theory and its correlation to the strengthening mechanisms
- Design materials with improved creep, fatigue and fracture properties

Dislocation theory: Dislocation motion: jogs, kinks, cross-slip, climb, Peierls stress, stress field of dislocation, forces on dislocations, dislocation multiplication, interaction of dislocations with defects, dislocation dissociation, stacking faults.
Plasticity: Elements of plasticity, Von Mises and Tresca criterion, Single Crystal slip, Critically resolved shear stress. Tensile testing (engineering and true), Work-hardening, yield point phenomena, necking. Hardness testing. Mechanical behaviour of polymers and ceramics.
Strengthening Mechanisms: Strain hardening, solid solution strengthening, Dispersion hardening, grain size strengthening and Hall-Petch relationship, Precipitate hardening.
Fracture: Types of fracture, brittle fracture, Griffith's criteria, fracture in ductile material, fracture toughness, notch effects. Linear elastic fracture mechanics and elasto-plastic fracture mechanics. Ductile to brittle transition.
Fatigue: Fatigue testing, S/N curve, low cycle fatigue, structural features, surface effects, mechanisms.
Creep: Creep testing, creep curve, creep mechanisms, diffusion creep, dislocation creep, superplasticity.

Text books:

1. Mechanical Metallurgy: G.E. Dieter, 3rd Ed., McGraw Hill, 2017.

Reference Books:

1. Mechanical Behavior of Materials: Thomas H. Courtney, 2nd Ed., Waveland Press Inc., 2005.
2. Introduction to Dislocations: D. Hull and D.J. Bacon, Butterworth-Heinemann, Elsevier, 2011.
3. Deformation and Fracture Mechanics: R.W. Hertzberg, R.P. Vinci, J.L. Hertzberg, 5th Ed., Wiley, 2012.

MM2204 Mechanical Behaviour of Materials Laboratory

Tensile/compression test: Introduction to UTM, tensile and compression test on aluminium, copper, steel and polymer, plotting engineering and true stress strain curves, calculate tensile properties, effect of strain rate, strain are sensitivity.

Hardness: Micro and macro-hardness of metal, alloy, ceramic and polymer materials, fracture toughness, nanoindentation, determination of elastic modulus, ductility, Jominy hardenability test.

Fracture: fracture surface of metal, ceramic and composites, case study of ductile and brittle fracture.

Fatigue and impact test: Rotary bending fatigue testing on steel and aluminium sample, generation of S-N curve, fatigue limit, Charpy V-notch impact test.

Text Books:

1. Mechanical Metallurgy, George E. Dieter, 3rd Ed., McGraw Hill, 2017.
2. Mechanical Behavior of Materials: Thomas H. Courtney, 2nd Ed., Waveland Press, 2000.

Reference book:

1. Mechanical Properties and Working of Metals and Alloys: Amit Bhaduri, Springer, 2018.

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Department of Metallurgical and Materials Engineering

MM2205 Welding and Solidification
(3-0-0) 3 credits

Course learning objectives (Complies with PLOs 1 and 2)

- To know about the relevance of solidification of metals
- To understand the challenges in joining of metals
- To understand the thermodynamics and kinetics of the solidification and welding processes

Course learning outcomes

After successfully completing the course, the student will be able to

- Gain insight about casting and solidification
- Understand the difficulties of joining metals and come up with solutions
- Appreciate the advancements in the solidification and welding of metals from research and industrial perspectives

Thermodynamics and kinetics of solidification: Thermodynamics of undercooled melts, nucleation process, kinetics of growth, growth mechanisms: continuous growth, stepwise growth.

Solidification of pure metals and alloys: - Role of undercooling and Gibbs-Thomson effect on solidification, solutal undercooling, constitutional undercooling, Mullins-Sekerka instability, cellular and dendritic growth, eutectic growth. single crystal growth techniques, zone refining.

Metal casting: Pattern and moulds designing, feeding, gating, risering, melting and casting practices, different types of casting: sand casting, die casting, pressure casting, continuous casting, investment casting, casting defects and repair, Ingot structure: chill zone, columnar zone, equiaxed zone. rate of solidification, heat transfer during solidification, Biot number.

Welding: Theory and classification of welding, Heat transfer, fluid flow, and solute distribution during welding, submerged arc welding, gas metal arc welding or MIG/MAG welding, TIG welding, resistance welding. Other joining processes, soldering, brazing, diffusion bonding, problems associated with welding of steels and aluminium alloys, defects in welded joints.

Solid state welding technique: Friction welding, friction stir welding.

Test Books:

1. Solidification Processing; Fleming, M.C., McGraw-Hill, N.Y., 1974
2. Science and Engineering of Casting Solidification; Stefanescu, D.M., Kluwar Publications, 2002
3. Applied Welding Engineering: Process, Codes and Standard; R.Singh,. Elsevier Inc.,2012
4. Advanced Welding processes, Norrish, J., Woodhead, Woodhead Publishing, 2006
5. Solidification and Casting, Davies, G.J., John Wiley and Sons, 1973

INDIAN INSTITUTE OF TECHNOLOGY PATNA

Department of Metallurgical and Materials Engineering

MM3101 Thermomechanical Processing of Metallic Materials (3-0-2) 4 credits

Course learning objectives (Complies with PLOs 1, 2 and 4)

- To understand the dynamic phenomena occurring at deformation of materials at elevated temperatures and their kinetics
- To understand different metal forming technologies and their application in controlling the microstructure for specific structural applications

Course learning outcomes

After completion of this course, the student will be able to:

- Understand the deformation behaviour of metallic materials under hot working conditions
- Achieve required properties through microstructure control and apply the knowledge for designing materials for various industrial applications

Microstructure: Concept of microstructure and micro structural features, Introduction to texture.

Crystal plasticity: Deformation in polycrystals, Concept of dislocations and dislocation structures, slip and twinning.

Softening mechanisms: (i) Recovery - mechanism and kinetics, structural changes during recovery. Dislocation migration and annihilation, polygonization, subgrain formation.

(ii) Recrystallization - mechanism and kinetics, JMAK model. Particle stimulated nucleation.

(iii) Grain growth – mechanism and kinetics. Abnormal grain growth.

Hot deformation: Dynamic recovery and dynamic recrystallization.

Forming technologies:

1. Classification of forming processes
2. Mechanics of metalworking (slab and uniform energy methods)
3. Concept of flow stress and its determination
4. Temperature in metal working (hot and cold working)
5. Strain rate effects
6. Role of friction and residual stresses
7. Concept of workability
8. Microstructure characterization after cold rolling/working, extrusion and forging

Case studies:

(i) Production of aluminium beverage cans

(ii) Microstructure and texture control in electrical steels

(iii) Steel for car body applications

(iv) Microstructure control via grain boundary engineering

Text Book:

1. Thermo-mechanical Processing of Metallic Materials: B. Verlinden, J. Driver, I. Samajdar and R.D. Doherty, Pergamon Materials Science, Elsevier, 2007.

Reference Book:

1. Recrystallization and Related Annealing Phenomena, F.J. Humphreys and M. Hatherly, 2nd Eds, Elsevier, 2004.
2. Metal forming: Mechanics and Metallurgy: W.F. Hosford and R.M. Caddell, 4th Ed., Cambridge University Press, 2014.

MM3101 Thermomechanical Processing of Metallic Materials Laboratory

Recovery, recrystallization and grain growth. Hardness measurement on a deformed alloy. Hardness measurements after recovery, recrystallization and grain growth in aluminium alloy. Microstructural evolution

Metal working:

(i) Rolling: Strain calculation, rolling with different strain rates

(ii) Forging: room temperature and high temperature forging, open and closed die forging.

(iii) Extrusion: die design, extrusion of soft metals and alloys

Deformation at various strain rates, Strain calculations.

Effect of temperature and friction during various metal working process, microstructure development.

Text Book:

1. Thermo-mechanical Processing of Metallic Materials: B. Verlinden, J. Driver, I. Samajdar and R.D. Doherty, Pergamon Materials Science, Elsevier, 2007.
2. Metal forming: Mechanics and Metallurgy: W.F. Hosford and R.M. Caddell, 4^{th} Ed., Cambridge University Press, 2014.

MM3102 Computational Materials Science
(2-1-0) 3 credits

Course learning objectives (Complies with PLOs 1 and 2)
- To introduce students to the field of computational materials science
- To learn basic numerical methods to solve ordinary differential equations (ODEs) and partial differential equations (PDEs)
- Role of ODEs and PDEs to solve problems related to materials science and engineering

Course learning outcomes
Upon completion of this course, the student will be able to:
- Understand the importance of modelling and simulation in materials engineering
- Learn numerical techniques to solve ordinary and partial differential equations
- Understand the numerical approaches employed in modelling and simulation in materials science and engineering

Statistical analysis: p-value, confidence levelling, regression and curve fitting.
Introduction to numerical methods: Numerical methods for solving problems. Error estimation, the accuracy of numerical methods. Role of ODEs and PDEs in solving the problems of the physical world
Ordinary differential equations: Euler and Runge-Kutta methods, FFT
Partial differential equations: classification, elliptic, parabolic, and hyperbolic PDEs, Dirichlet, Neumann, and mixed boundary value problems,
Numerical solution of PDEs: relaxation methods for solving elliptic PDEs, explicit and implicit methods, Calculus of variations and variational techniques for solving PDEs, introduction to Finite element method, method of weighted residuals, weak and Galerkin forms
Application of numerical methods to solve problems related to materials science: Diffusion (Carburization), spinodal decomposition, grain growth, solidification, Zener pinning. Coding using modern computer languages.

Text Books:
1. Arfken, G.B., and Weber, H.J., Mathematical Methods for Physicists, Sixth Edition, Academic Press, 2005.
2. W.H., Teukolsky, S.A., Vetterling, W.T., and Flannery, B.P., Numerical Recipes in C/FORTRAN – The art of Scheme of Instruction 2016 Page 278
3. Scientific Computing, Second Edn, Cambridge University Press, 1998.

Reference Books:
1. Lynch, D.R., Numerical Partial Differential Equations for Environmental Scientists and Engineers – A First Practical Course, Springer, New York, 2005

MM3103 Engineering Polymers
(3-0-2) 4 credits

Course learning objectives (Complies with PLOs 1, 3 and 4)
- To support to comprehend the relationship between structure and properties as well as the uses of engineering polymers.
- To disseminate information about the characteristics and uses of engineering polymers.
- To comprehend the purposes of various additives, as well as the kinds, mechanisms, and technical specifications needed for their efficient assessment
- To familiarize the students with standard and methodology in preparing various polymers specimen
- Testing products for predicting product performance

Course learning outcomes
At the end of the course the student will be able to
- Comprehend the significance of engineering polymers
- Acquire fundamental knowledge about characteristics of polymers
- Select appropriate processing, compounding, and additive methods to create various engineering polymeric compound grades
- Will be able to prepare the test sample for various polymer testing operations
- Will be able to measure the polymer properties

Structure property relationship in polymers: The synthesis, characteristics, and uses of thermoplastic engineering polymers include polyesters -PET, PBT, polyacetals, PC, LCPs, modified polyamides, and polyamides.

High temperature resistant thermoplastic engineering polymers, such as PTFE, PCTFE, PVDF, PPO, PPS, polysulphones, PEEK, polyimides, polybenzimidazoles, and aromatic polyamides-Synthesis, properties & applications. Thermoset engineering polymers. Blends of engineering polymers.

Additives and engineering polymer compounding: fillers, plasticizers, lubricants, colorants, fire retardants, coupling agents, blowing agents, UV stabilizer, antistatic agents, anti-blocking agents, slip and anti-slip agents, processing aids, antioxidants, stabilizers, lubricants, and toughening agents.

Engineering polymer processing- Characterization and testing of engineered polymers.

Text books:
1. Engineering Plastics Handbook: James M. Margolis, McGraw Hill, 2006.
2. Plastic Materials: J.A. Brydson, 6th Ed., Elsevier, 1995.

References books:
1. Industrial Polymers, Specialty Polymers, and Their Applications: Manas Chanda, Salil K. Roy, CRC Press, 2008.
2. Specialty Plastics: R.W. Dyson, 2nd Ed., Blackie Academic & Professional, 1988.
3. Modern Plastics Handbook: C.A. Harper, McGraw Hill, 2000.

MM3103 Engineering Polymers Laboratory

Molecular weight studies: Study of gel permeation chromatography (GPC) to determine molecular weight and molecular weight distribution of polymers. Determination of intrinsic viscosity and viscosity average molecular weight of polymers.
Spectroscopy studies: Study of Fourier transform infrared spectroscopy (FTIR) for characterization of the structure of the polymers.
Microscopy studies: Study of the morphology of polymers using optical microscopy (OM), field emission scanning electron microscopy (FESEM), high resolution transmission electron microscopy (HRTEM) and atomic force microscopy (AFM).
Thermal property studies: Study of the thermal properties of polymers using differential scanning calorimetry (DSC), dynamic mechanical analyzer (DMA) and thermogravimetric analyser (TGA). Study of thermal conductivity of polymers.
Electrical property studies: Electrical conductivity, impedance, volume/surface resistivity, dielectric strength, arc resistance and comparative tracking Index
X-ray diffraction studies: Study of X-Ray scattering and X-Ray diffraction methods to determine crystallinity and orientation in polymers.
Mechanical property studies: Tensile strength, compression strength, flexural strength, tear strength, impact strength, hardness and abrasion resistance.

Text books:

1. Vishu Shah, Hand Book of Plastics Technology, John Wiley Interscience Inc., New York.1998.
2. G. C. Ives, J. A. Mead, and M. M. Riley, Hand Book of Plastics Test Methods, I4FFE Books London, 1971.

References books:

1. Handbook of Plastics Analysis, H. Lobo and J. V. Bonilla, Marcel Dekker, 2003.
2. Handbook of polymer Testing Roger Brown, Marcel Dekker Inc, 1999.

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Department of Metallurgical and Materials Engineering

MM3104 Ceramic Science and Technology
(3-0-2) 4 credits

Course Learning Objective (Complies with PLOs 1 and 4)

- To classify ceramic materials and distinguish them from metals and polymers in relation to their properties and behaviours
- To understand the structure of ceramic materials in different length scales and role of processing on structure and microstructure
- To understand different industrially relevant processing operations for making of ceramic materials

Course Learning Outcome

Upon completing of this course, the student will be able to

- Identify the properties of ceramics with respect to their crystal structure and composition (between oxide and non-oxide).
- Interpret microstructure property correlation of sintered ceramic materials based on different processing operations
- Distinguish different ceramic materials and their utility for diverse industrial applications ranging from traditional to advance ceramic sectors

Introduction to Ceramic Science: Bonding in ceramics, Pauling's rules, Ceramic crystal structures (rocksalt, fluorite, spinel, perovskite), Kröger-Vink notation, defects in ceramic. Defect equilibria, Brouwer diagram. Diffusion in ceramics. Fundamentals of glass science.
Ceramic phase diagrams: binary and ternary systems.
Physical properties of ceramics (porosity, bulk density, permeability, water absorption, specific gravity)
Basics of Ceramic Processing: Synthesis and characterization of ceramic powders. selection of refractory raw materials (natural, synthetic, additives, binders) for specific products. Colloidal processing, rheology of suspensions, ceramic forming methods, and drying. Science of sintering, microstructure development.
Properties of ceramics: Fracture behaviour of ceramic materials, The Weibull distribution, Toughening mechanism. Dielectric and piezoelectric ceramics.
Applications of ceramics: Traditional ceramics, Abrasives, and high temperature ceramics (refractories and UHTCs). Glass and glass-ceramics.

Textbooks:

1. Introduction to Ceramics: W.D. Kingery, H.K. Bowen, D.R. Uhlmann, 2nd Ed., Wiley, 1976.
2. Ceramic Processing and Sintering: M.N. Rahaman, Marcel Dekker, 1995
3. Ceramic Materials: Science and Engineering: C. Barry Carter, M. Norton, Springer, 2nd Ed., 2013.

Reference Books:

1. Fundamentals of Ceramics: M.W. Barsoum, McGraw Hill, 1997.
2. Introduction to Ceramics, 2nd Ed., W. David Kingery, H.K. Bowen, Donald R. Uhlmann, Wiley, 1976.
3. A Concise Introduction to Ceramics: G.C. Phillips, VNR Publications, 1991.

MM3104 Ceramic Science and Technology Laboratory

Raw materials: Identification, basic characterisation

Machineries: Demonstration of basic units, Demonstration of Ceramic products

Physical properties: moisture content, Loss on ignition (LOI) of clay, ceramic, Linear and volume shrinkage, Particle size analysis, BET, Gas Pycnometer

Powder processing: solid state reactions, synthesis of powders via chemical routes, basic ceramic processing steps (casting, pressing etc)

Sintering of ceramics: conventional sintering, obtaining sintering S curve, Grain size analysis

Density measurements: Bulk density as per ASTM C20 & C373, Apparent porosity, Archimedes principle, Density of porous ceramic bodies

Properties of ceramic: Selected testing for mechanical, thermal, electronic & optical properties

Text Books:

1. Introduction to Ceramics: W.D. Kingery, H.K. Bowen, D.R. Uhlmann, 2nd Ed., Wiley, 1976.
2. Ceramic Processing and Sintering: M.N. Rahaman, Marcel Dekker, 1995

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Department of Metallurgical and Materials Engineering

MM3111 Metallography and Heat Treatment Laboratory
(0-0-2) 1 credit

Course Learning Objective (Complies with PLOs 3 and 4)
- To understand the metallographic sample preparation of metals
- To understand the basic microstructural analysis of metals

Course Learning Outcome
Upon completing of this course, the student will be able to
- Understand the microstructure of ferrous and nonferrous alloys
- Distinguish the metallographic techniques, microstructure and hardening process different commercially important metal alloys

Metallographic sample preparation: Sample cutting, mounting, grinding, dry and wet polishing. Etching: chemical etching, thermal etching.

Quantification of microstructures: ASTM grain size number, calculating grain size, mean intercept method, Jefferies method, determining volume fraction of phases

Microstructure of ferrous alloys: cast iron, 304 stainless steel, pearlitic steel, annealed and deformed steels, microstructure of quenched and tempered steel.

Microstructure of non-ferrous alloys: Aluminium alloy, copper and brass microstructure, deformed and recrystallized microstructure.

Surface hardening: Carburizing, nitriding of steel, verification of Harris equation.
Hardenability test, Jominy end quench test

Precipitation hardening in Al alloy: Homogenization, solutionized, quenching and ageing of AA7075, hardness measurement.

Text books:

1. The Principles of Metallographic Laboratory Practice: George L. Khel, McGraw Hill, 1949
2. Physical Metallurgy: V. Raghvan, 3rd Ed., Prentice Hall India, 2015.
3. Steel and its Heat Treatment: K.-E. Thelning, 2nd Ed., Butterworth-Heinemann, Elsevier,
4. 1984.
5. Heat Treatment: Principles and Techniques: T.V. Rajan, C.P. Sharma, Ashok Sharma, 2nd Ed.,
6. Prentice Hall India, 2010.
7. Heat Treatment of Metals: Vijendra Singh, Standard Publishers Distributors, 2009

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Department of Metallurgical and Materials Engineering

MM3201 Techniques of Materials Characterization – II
(3-0-3) 4.5 credits

Course learning objectives (Complies with PLOs 3 and 4)

- To understand different aspects materials characterization involving spectroscopy, thermal techniques.
- To learn about non-destructive characterisation techniques
- To obtain hands-on training on different characterization techniques

Course learning outcomes

Upon completion of this course, the student will be able to:

- Understand the basics of thermal and spectroscopic analysis tools
- Gain knowledge on the utility of non-destructive characterisation tools and their industrial utility
- Gain hands on expertise of thermal, spectroscopic, and non-destructive characterisation techniques

Spectroscopy: Vibrational spectroscopy, Principles of vibrational spectroscopy, Infrared and Raman activity, Fourier transform infrared spectroscopy, Raman spectroscopy, Micro-Raman. XPS, XRF. UV-visible spectroscopy: Beer's law, Instrumentation, Quantitative analysis. NMR

Atomic absorption/ emission spectroscopy: ICP methods for compositional analyses, the difference between ICP-mass spectroscopy and optical/atomic emission methods.

Thermal analysis: Instrumentation and principles of techniques used for thermal analysis (DSC, TG-DTA, DMA, EGA), a combined method of thermal analysis and their applications in materials characterization.

Particle/grain characterization: Particle size analysis techniques based on light scattering, DLS, gas adsorption (BET), and Gas pycnometer for density measurement.

Non-destructive techniques: dye-penetration, ultrasonic, radiography, eddy current, acoustic emission and magnetic particle methods.

Textbook:

1. Materials Characterization: Introduction to Microscopic and Spectroscopic Methods; Y. Leng.
2. Fundamentals of Molecular Spectroscopy; C. N. Banwell and E. M. McCash.
3. Surface Analysis: The Principal Techniques; J. C. Vickerman, I. Gilmore.

Reference Books:

1. ASM Handbook: Materials Characterization, ASM International, 2008.
2. Yang Leng: Materials Characterization-Introduction to Microscopic and Spectroscopic Methods, John Wiley & Sons (Asia) Pte Ltd., 2008.
3. Robert F. Speyer: Thermal Analysis of Materials, Marcel Dekker Inc., New York, 1994.

MM3201 Techniques of Materials Characterization – II Laboratory

Sample preparation: Powder sample preparation and pellet preparation through die pressing.

Powder characterization using BET, gas pycnometer.

Thermal properties of materials, identification of materials based on their TG, DSC, and DMA characteristic responses.

Sample characterization through Raman and FTIR.

Standard laboratory practices including safety, report writing, and error analysis are also emphasized.

Non-destructive testing: Radiography, ultrasonic testing.

Text Books:

1. Materials Characterization: Introduction to Microscopic and Spectroscopic Methods, Yang Leng; 2nd Ed., Wiley, 2013.
2. Scanning Electron Microscopy and X-Ray Microanalysis: Joseph Goldstein, Eric Lifshin, Charles E. Lyman, David C. Joy, and Patrick Echlin, 3rd Ed., Springer, 2003.

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Department of Metallurgical and Materials Engineering

MM3202 Corrosion and Corrosion Protection
(3-0-2) 4 credits

Course learning objectives (Complies with PLOs 1, 4 and 5)

- To measure and compare the corrosion rates of two different metals/alloys.
- Hands-on training on electrochemical characterization techniques

Course learning outcomes

Upon completion of this course, the student will be able to:

- Correlate the utility of different electrochemical testing techniques
- Implement and interpret the data of DC and AC corrosion testing

Introduction to terminologies of corrosion experimentation: Oxidation/reduction electrode potential series, listing of half-cell reactions. Practical implications of Nernst equation, standard reference electrode cells, Electrochemical cells, electrolyte, galvanic series, and galvanic corrosion.
Corrosion experiments and rate calculations: Preparation of corrosion test samples per ASTM G1. NACE and ASTM standards for measurements of corrosion rates. Salt spray test methods and standards, stress corrosion cracking tests, immersion corrosion testing per ASTM G3. Corrosion rates calculations from Tafel measurements as per the ASTM G102 standard.
DC-experimental testing techniques: Potentiodynamic polarization measurement as per ASTM G5, potentiosatat, galvanostats, cyclic voltammetry, chrono- amperomtery, chrono-potentiometry, potentiodynamic analysis and Tafel extrapolation and linear polarization resistance methods.
AC-impedance spectroscopy in corrosion measurements: Assessments related to charge transfer resistance and double layer capacitance from impedance tests. Interpretation of Nyquist and Bode plots. Modelling of impedance data to fit the experimental data.
Case studies: Use of AC impedance methods to study the corrosion behaviour of implant alloys.

Text Books:

1. Corrosion Science and Technology, By David Talbot, James Talbot, CRC Press, 1998

Reference Books:

1. K.J. Bundy, J. Dillard, R. Luedemann, Use of A.C. impedance methods to study the corrosion behaviour of implant alloys, Biomaterials, Volume 14, Issue 7, 1993 Pages 529-536.
2. A. Harrington, P. van den Driesch, Mechanism and equivalent circuits in electrochemical impedance spectroscopy, Electrochimica Acta, Volume 56, Issue 23, 2011 Pages 8005-8013.
3. ASTM Corrosion Standards and Electrochemical Measurements in Corrosion Testing, ASTM International.

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Department of Metallurgical and Materials Engineering

MM3202 Corrosion and Corrosion Protection Laboratory

Introduction to terminologies of corrosion experimentation: The arrangement of elements according to their electrode potential, or their tendency to corrode. Listing of half-cell reaction voltages. Practical implications of Nernst equation, standard reference electrode cells, Electrochemical cells, electrolyte, galvanic series, galvanic corrosion.
Corrosion experiments and rate calculations: Preparing, cleaning and evaluating corrosion test specimens per ASTM G1. NACE and ASTM standards for measurements of corrosion rates. Salt spray test methods and standards, stress corrosion cracking tests, immersion corrosion testing per ASTM G31, Pitting and crevice corrosion resistance of stainless steels. Corrosion rates and related information from electrochemical measurements (Tafel slopes) per ASTM G102.
DC-experimental testing techniques: Potentiodynamic anodic polarization measurement per ASTM G5, potentiosatat, galvanostats, cyclic voltammetry, chrono- amperomtery, chrono-potentiometry, potentiodynamic analysis and Tafel extrapolation and linear polarization resistance methods.
AC-impedance spectroscopy in corrosion measurements: Electrochemical impedance spectroscopy (EIS) tests to find out Rp (polarization resistance), Cdl (double layer capacitance) & corrosion rate measurement. Interpretation of Nyquist and Bode plots. Modelling of impedance data to fit the experimental data.
Case studies: Inter-granular corrosion attack in stainless steels, pitting and crevice corrosion resistance of stainless steels, testing performance of coatings in different circumstances in combination with cathodic protection according to ASTM G42. Use of AC impedance methods to study the corrosion behaviour of implant alloys.

Text Books:

1. Corrosion Science and Technology, By David Talbot, James Talbot, CRC Press, 1998

Reference Books:

1. K.J. Bundy, J. Dillard, R. Luedemann, Use of A.C. impedance methods to study the corrosion behaviour of implant alloys, Biomaterials, Volume 14, Issue 7, 1993 Pages 529-536.
2. A. Harrington, P. van den Driesch, Mechanism and equivalent circuits in electrochemical impedance spectroscopy, Electrochimica Acta, Volume 56, Issue 23, 2011 Pages 8005-8013.
3. ASTM Corrosion Standards and Electrochemical Measurements in Corrosion Testing, ASTM International.

MM3203 Functional Materials
(3-0-0) 3 credits

Course Learning Objective (Complies with PLOs 1 and 2)
- To identify various ranges of functions displayed by materials and correlation of the same with respect to their properties
- To understand the fundamental reasons due to which this variety of properties is possible for different materials
- To evaluate the efficacy of a particular material with respect to emerging and conventional industrial applications

Course Learning Outcome
Upon completing of this course, the student will be able to
- Identify the properties of metals, ceramics and polymers in relation to different functional properties
- Understand the fundamental reasons which enable a particular material to display a particular function
- Classify and distinguish different types of functional properties and correlate the same with relevant industrial applications

Free Electron Theory of Metals: Band theory, classification of materials based on band theory viz. conductors, conductors-classification and properties, factors affecting conductivity/resistivity of conductors, various conducting materials: composition, properties and applications.
Resistors: Materials used for heating elements viz. nichrome, kanthal, silicon carbide and molybdenum, their composition, properties and applications
Semiconductors: Intrinsic and extrinsic semi-conductors, II-VI, III-V and IV-IV group semiconductors, effects of doping.
Magnetic materials: Sources of magnetism-orbital and spin motion of electron, types of magnetism: Dia-, para-, ferro-, ferri- and antiferro-magnetism, domain theory, types of magnetic materials: soft and hard magnetic materials and ferrites. GMR.
Ferro-electric, Piezo-electric and Dielectric materials: Principle, materials and their applications; Ferroelectric ceramic materials, Basic Ceramic Dielectric formulation for capacitors. Multi-Layer Capacitors.
Super conductivity: BCS theory, Meissner effect, materials, Type I and II superconductors.

Text Books:
1. Introduction to the Electronic Properties of Materials: David C. Jiles, 2nd Ed., CRC Press, 2001.
2. Electronic Materials Science: Eugene A. Irene, Wiley, 2005.
3. An Introduction to Electronic Materials for Engineers: Zhengwei Li, Nigel M. Sammes, 2nd Ed., World Scientific Publishing Company Pvt. Ltd., 2011.

Reference Books:
1. Electronic Materials and Devices: David K. Ferry, Jonathan P. Bird, Wiley, 2001.
2. Introduction to Magnetism and Magnetic Materials: David Jiles, 3rd Ed., CRC Press, 2015.
3. Electroceramics: Materials, Properties, Applications: A.J. Moulson, J.M. Herbert, Wiley, 2003.

MM3204 Non-ferrous Metals and Alloys
(3-0-0) 3 credits

Course learning objectives (Complies with PLOs 1 and 2)
- To understand the different types of nonferrous alloys
- To understand the physical and mechanical characteristics of nonferrous alloys

Course learning outcomes

Upon completion of this course, the student will be able to:
- Gain in-depth knowledge of non-ferrous alloys, their properties and applications
- Understand the mechanical processing, heat treatments and corrosion of various nonferrous alloys

Non-ferrous alloys: (i) Classification of aluminium alloys, heat treatable and non heat-treatable alloys, tempers, grain refiners, phase diagram, heat treatment, properties and applications.
(ii) Copper alloys, copper-zinc phase diagram, brass and bronze. Properties and applications
(iii) Magnesium and its alloys, properties and applications, corrosion behavior.
(iv) Titanium alloys, alpha, beta, alpha-beta alloys, processing characteristics, properties and applications.
(v) Nickel and cobalt based alloys and superalloys, properties and applications
(vi) Refractory metals-based alloys, intermetallics.
Case studies: Materials design and selection for (i) Automobile engine, (ii) turbine blades and (iii) bio-implants.

Text Books:
1. Physical Metallurgy and Advanced Materials: R.E. Smallman, A.H.W. Ngan, 7th Ed., Butterworth Heinemann, Elsevier, 2007.
2. Physical Metallurgy: Principles and Design: G.N. Haidemenopoulos, CRC Press, 2018.

Reference Books:
1. Concepts in Physical Metallurgy: A. Lavakumar, Morgan and Claypool Publishers, IOP Science, 2017
2. Nonferrous Physical Metallurgy: Robert Raudebaugh, Literary Licensing, 2013.
3. Nickel, Cobalt and their alloys: Joseph R. Davis, ASM International, 2000.

MM3205 Capstone Laboratory
(0-0-4) 2 credits

Course learning objectives (Complies with PLOs 4 and 5)

- To allow students to implement and test their designs, integrating theoretical knowledge with practical application
- To enhance hands-on learning, reinforce theoretical concepts, and promote creativity

Course learning outcomes

After doing the laboratory course the student will be able to

- Apply the knowledge acquired from MME program in real-life situation
- Able to understand theoretical concepts more effectively and come up with new ideas

Capstone projects to be decided by the course instructor

Few suggested projects are:

Environmental Barrier Coatings for Gas Turbine Engines

Finite Element Analysis of Metal Forming

Metal Extraction from Ores obtained from Indian Mines

Development of Aluminium alloys and Study the Effect of Heat Treatment on Properties

Ceramic Musical Instrument Making through Traditional Techniques

Development of Metal Matrix Composite for High Temperature Application

Piezo sensor for Determination of Force Involved in Cricket Shot

Demonstrations of few polymerization techniques for synthesis of porous polymers/ smart polymers/ self-healing polymers

INDIAN INSTITUTE OF TECHNOLOGY PATNA

Department of Metallurgical and Materials Engineering

MM3210 Metals Processing Laboratory
(0-0-3) 1.5 credits

Course learning objectives (Complies with PLO 4)

- To learn various metal casting techniques and identify common casting defects, microstructure of casting
- To learn various metal forming techniques including welding
- To observe the microstructural changes imparted by various processing techniques

Course learning outcomes
After doing the laboratory course the student will be able to
- Understand the different metal casting methods for various applications
- Understand various secondary processing techniques including metal forming and joining
- Understand the effect of various processes on microstructural evolution

Ingot casting: Casting design, Melting furnaces, die casting of metal and alloy, shape casting, moiling, refining and pouring.

Defects in castings: Physical inspection, hot tear cracks, pores, voids.

Solidification microstructures: Dendritic microstructure, grain structure, homogenization, alloying element addition during casting.

Recrystallization and annealing: recrystallization in copper and aluminium alloys.

Shape memory effect: Reversible phase transition in Nitinol.

Welding: arc welding, soldering, friction stir welding, welding microstructures,

Text Books:

1. Heat Treatment: Principles and Techniques: T.V. Rajan, C.P. Sharma, Ashok Sharma, 2nd Ed., Prentice Hall India, 2010.
2. Heat Treatment of Metals: J.L. Smith, G.M. Russel, S.C. Bhatia, Vol. 1, CBS Publishers, 2008.
3. Heat Treatment of Metals: Vijendra Singh, Standard Publishers Distributors, 2009.

Reference Books:

1. Heat treatment of Steel: Hardening, Tempering and Case Hardening: H.R. Badger, Forgotten Books, 2018.

List of department electives

Semester VII (Elective I and Elective II)

Bucket I

MM4121	Environmental Sustainability and Industrial Safety
MM4122	Glass Science and Technology
MM4123	Semiconductor Materials and Devices

Bucket II

MM4124	Thin Films
MM4125	Heat Treatment of Metals and Alloys
MM4126	Creep, Fatigue and Fracture

Semester VIII (Elective III, Elective IV and Elective V)

Bucket I

MM4221	Smart Polymers
MM4222	Energy Materials

Bucket II

MM4223	Electroceramics
MM4224	Biomaterials

Bucket III

MM4225	Crystallographic Texture and Analysis
MM4226	Furnace and Refractories
MM4127	Composite Science and Technology

Inter-disciplinary elective (IDE)

MM2290	Structure and Properties of Materials (IDE I)
MM3190	Microscopy and X-ray Diffraction (IDE II)
MM4190	Nanomaterials (IDE III)

INDIAN INSTITUTE OF TECHNOLOGY PATNA

Department of Metallurgical and Materials Engineering

MM4121 Environmental Sustainability and Industrial Safety (3-0-0) 3 credits

Course learning objectives (Complies with PLOs 1 and 5)

- The ability to select and use the discipline's knowledge, methods, and cutting-edge instruments to domains widely construed as safety, health, and environmental engineering and technology, as well as fire prevention.
- To support students in comprehending the core ideas of sustainable development, including strong and weak sustainability, natural capitalism, steady state, and green economies, as well as equality within and between generations and economic, social, and environmental sustainability.

Course learning outcomes

At the end of the course the student will be able to

- Apply comprehension of engineering principles to identify, evaluate, and control occupational hazards.
- Recognize and promise to abide by legislative rules and regulations, as well as contractual duties related to sustainable development, in order to protect occupational health, safety, and the environment in the organization.

Introduction: Sustainable Development Goals (SDGs) and their concept, environmental concerns in mining, metallurgy, ceramics, and polymers operational standards, safeguarding and managing resources.

Industrial waste in materials industries: Industrial wastes from metals, ceramics, plastics and rubber based industries - Identification, characterization and classification. Handling, transportation and storage. Disposal: equipment and processing methods; legal procedures. Recover, recycle, and recycle. Impact of beneficiation process.

Industrial safety: Concept of safety, safety by design, safety inspection, accident prevention, Heinrich theory of accident prevention, cost of accident, safety performance monitoring. Safety against fire, chemicals, and acids: detection, prevention, and protection.

Health hazards: Common industrial hazards and remedies, engineering controls and personal protective controls, hazard identification and risk assessment- FMEA and HAZOP, QRA. Temporary and cumulative effects in Occupation diseases - silicosis, asbestosis, pneumoconiosis, aluminosis, gas poisoning. Game theory approach to deal pollution.

Safety management: Safety guidelines and procedures in the materials sector. Case studies on the mining, blast furnace, iron and steel industries, foundries, hot and cold processing of metals, and blast furnaces. Handling powders and raw ingredients for ceramics. Issues about the health and safety of raw materials used in sanitary napkins, glass, refractory, and cement. Prevention and awareness of associated hazards and illnesses.

Text Books:

1. M.H. Fulekar, B. Pathak, R.K. Kale, Environment and sustainable development, Springer, 2014.

2. D. Petersen, Techniques for safety management - A systems approach, ASSE 1998.

Reference books:

1. S.P. Mahajan, Pollution control in process industries, Tata McGraw Hill Publishing Company, New Delhi, 1993.
2. J. Nagaraj, Industrial safety and pollution control handbook, National safety council, 1992.
3. Michael Karmis, Mine Health and Safety Management, SME, Littleton Co., 2001.
4. N.V. Krishnan, Safety in Industry, Jaico Publishing House, 1996, Mine Health and Safety Management SME, Littleton, CO, USA, 2001.

INDIAN INSTITUTE OF TECHNOLOGY PATNA

Department of Metallurgical and Materials Engineering

MM4122 Glass Science and Technology
(3-0-0) 3 credits

Course learning objectives (Complies with PLO 1)
- To know about the critical role glass plays in day-to-day life
- To understand the state-of-art modern and updated Industrial glass production techniques
- To understand the thermodynamics and kinetics of glass formation and how it influences the structure and property

Course learning outcomes
Upon completion of this course, the student will be:
- Familiar with different types of glass and it's application
- Familiar with industrial glass making and able to solve industrial problems regarding glass processing
- Able to understand the properties of glass and how it is different from its crystalline counterpart

Glass Science: Nature of the glassy state, Glass formation and the glass transition, Kinetic and thermodynamic criteria for glass formation, glass former, modifier and Intermediate, TTT diagram, phase diagrams in glass manufacture, structural, Thermodynamic, and Kinetic effects on T_g, viscosity of glass, Bridging and Non-Bridging Oxygen.
Types of glasses and their chemical compositions, Physical properties of glasses, density, refractive index, thermal expansion and thermal stresses, thermal endurance of glass, toughening of glasses, strength and fracture behavior of glass and its articles, effect of temperature and composition on the physical properties of glasses, durability and corrosion behavior, colored glass.
Glass Technology: Glass-making raw materials, addition of cullet to the batch, glass-batch formulation, batch materials handling equipment, reactions amongst the constituents of glass, design of glass tank furnace. temperature modelling for appropriate refractory selection, thermal currents, and flow pattern in the glass tank furnace, refining of glass, defects in glass, bubbles and seeds, cords, stresses, and color inhomogeneity and their remedies, annealing of glasses, measurement of stress/ strain in glass, Float glass, Container glass, Glass Fibre, and fiberglass.
Glass-ceramics: Nucleation and crystal growth in glasses, nucleation through micro miscibility, nucleating agents, properties and applications of glass-ceramics.

Text Books:
1. Glass Science and Technology, D.R. Uhlmann, N.J. Kredl (ed), Vol. 1&2, Academic Press, 1990.
2. Chemistry of Glasses: Amal Paul, Chapman Hall, 1990.

Reference Books:
1. Fundamentals of Ceramics: M.W. Barsoum, McGraw Hill, 1997.
2. Introduction to Ceramics, 2nd Ed., W. David Kingery, H.K. Bowen, Donald R. Uhlmann, Wiley,1976.
3. Hand book of Glass Manufacture: F.V.Tooley, Vol 1 & 2, Ashlee Pub. Co, 1984.

INDIAN INSTITUTE OF TECHNOLOGY PATNA

Department of Metallurgical and Materials Engineering

MM4123 Semiconductor Materials and Devices
(3-0-0) 3 credits

Course learning objectives (Complies with PLOs 2 and 3)

- To discuss the working and applications of basic semiconductor devices
- To impart a fundamental knowledge of device fabrication relevant to the semiconductor industry.
- To enable the students to understand working principle of semiconductor devices such as transistors, diodes, solar cells, and light-emitting devices.

Course learning outcomes

Upon completion of this course, the student will be able to:

- Grasp the basics concepts of semiconductor materials such as the energy bands, band gap, charge carrier concentration, transport phenomenon of charge carriers.
- Describe the fabrication of semiconductors devices
- Demonstrate the applications of various semiconducting devices such as p-n and Schottky junctions, BJTs and FETs, LEDs and solar cells

Fundamental of Semiconductors: Energy band theory, Sommerfield free electron theory for metals, Brillouin Zone Theory, density of states, Quasi-Fermi levels, Maxwell-Boltzmann distribution, Fermi-Dirac statistics, intrinsic semiconductor, n-type/p-type semiconductor, transport phenomenon of charge carriers, Energy bands in solids, band structure, band diagram of few important semiconductors (Si, Ge, GaAs, GaN), engineering of doping, surface energy of solids, effective mass, Brillouin zone, direct and indirect gaps semiconductor and photovoltaic effect.

Fabrication of Semiconductors and devices: Production of single crystal of semiconducting materials, Semiconductor Grade Silicon, metallurgical grade silicon, Lithography, DC/RF magnetron sputtering.

Devices and characterizations: Heterostructure p-n junctions, Schottky junctions, Ohmic contacts: Metal-semiconductor junctions, Schottky and Ohmic contacts, Metal-Semiconductor contacts, Metal-insulator-semiconductor structures, tunnel diodes, Gunneffect, p-i-n structures, Zener diode, Bipolar transistors, principle of operation of MOSFETs, characteristics of MOSFET, source-drain/transfer characteristics of MOSFET, introduction to JFETs, MESFETs, and MODFETs. carrier statistics under illumination condition, generation and recombination of carriers, emitting diodes (LED), LEDs, laser-diodes and solar cells, Current-voltage characteristics, capacitance-voltage (CV) and impedance measurements.

Textbooks:

1. Semiconductor Devices: Physics and Technology Hardcover – by Simon M. Sze (Author), Ming-Kwei Lee, 2012.
2. An Introduction to Semiconductor Devices- D. Neamen, McGraw-Hill Education, 2005.
3. Physics of Semiconductor Devices -S.M. Sze and K. K. Ng, Wiley- Interscience, 3rd edition, 2006.

Reference books:

1. Semiconductor Physics: An Introduction. K. Seeger, Springer-Verlag, Berlin, 9^{th} Ed., 2004.
2. Electronic Materials and Devices: David K. Ferry, Jonathan P. Bird, Wiley, 2001.

3. Introduction to the Electronic Properties of Materials: David C. Jiles, 2^{nd} Ed., CRC Press, 2001.

INDIAN INSTITUTE OF TECHNOLOGY PATNA

Department of Metallurgical and Materials Engineering

MM4124 Thin Films
(3-0-0) 3 credits

Course Learning Objectives (Complies with PLOs 1 and 3)

- Understand about the various physical and chemical deposition methods
- Understand and analyse the characteristics of thin films using different instrumentation technique.
- Able to understand different types of nucleation theories, growth mechanisms of thin films

Course Learning Outcome

Upon completing of this course, the student will be able to:

- Identify various techniques of thin film depositions
- Classify and distinguish different types of thin film and their properties with relevant industrial applications
- Understand the nucleation and growth of various thin films during processing

Basics of surface: Concept of Surface Energy, Surface Thermodynamics, Surface Tension and Surface Energy, Broken Bond Model for Surface Energy of Crystalline Solids (BCC and FCC), Mechanisms for Reduction of Surface Energies, Surface Relaxation, Restructuring and Adsorption.

Vacuum components for thin films: Importance of High Vacuum for making thin films, Details of Vacuum Pumps (**e.g**. Rotary Turbo-molecular and Diffusion Pump), Pressure Gauge regular maintenance for vacuum conditions.

Thin film deposition techniques: Physical vapour deposition methods (Glow discharge, RF, Magnetron sputtering), Evaporation (Vacuum, electron beam, ion beam evaporation), Chemical Vapour Deposition Methods (Metal-Organic, Plasma Enhanced, Photochemical etc.), Plasma Technology for Thin Films, Molecular Beam Epitaxy atomic layer deposition.

Solution based chemical Techniques: Spray pyrolysis, Electrodeposition, Electroless deposition and plating for large area industrial coating, Sol-gel (spin coating and dip coating) and Langmuir Blodgett techniques for polymer and soft molecules.

Fundamental physical and chemical processes: Nucleation and Growth of Thin Films, Structure Zone Model, 3-D island layer by layer growth, thin film Microstructure, orientation and their influence on final properties.

Characterization of thin films: In situ characterizations, techniques for physical and structural characterization (thickness, phase, composition, morphology etc.), Highlights of measurements for various functional and chemical properties of thin films.

Applications of thin films: Hard Mechanical Thin Coatings, Thin films for Transistors and Semiconductors, Applications of Organic Thin Fims.

Textbooks:

1. Milton Ohring, The Materials Science of Thin Films, Academic Press-Sanden, 1992
2. Vacuum deposition of thin films, L. Holland, Chapman and Hall.
3. Thin films phenomena, K.L. Chopra, McGraw Hill, Yew York.

Reference Books:

1. Thin Film Materials: Stress, Defect Formation and Surface Evolution, L. B. Freund, S. Suresh, Cambridge University Press, 2004
2. Thin Film Processes II, Werner Kern, editor: John Vossen, Academic Press, 2012
3. Thin-Film Deposition: Principles and Practice, Donald L. Smith, McGraw Hill Professional, 1995

MM4125 Heat Treatment of Steel
(3-0-0) 3 credits

Course learning objectives (Complies with PLOs 1, 2 and 3)

- To understand the time-temperature sequence for altering the microstructure with/without application of stress
- To understand the engineering of various heat treatment processes and their impact on material properties

Course learning outcomes

Upon completion of the course, the student will be able to:

- Appreciate the guiding factor of heat treatment which would influence the properties in a desired way
- Acquire insights into the relationship among process, property and microstructure

Introduction to heat treatment: Objective of heat treatment; thermodynamics of phase transformation; Iron carbon phase diagram and their limitations; Austenitic, bainitic and martensitic transformations. Various types of heat treatment furnaces; TTT Diagram: types and application of TTT Diagrams (Austempering, Patenting and Martempering); CCT Diagram; Annealing (stress-relieving annealing, spheroidization, homogenising, etc.), Normalising, Hardening (objective, methods, quenching mediums, internal stresses and austenitizing temperature, defects in the process), Tempering (objective, stages, effects of addition of carbon and other alloying elements). Tempering of numerous alloy steels.
Thermo-mechanical treatment of steels: Principles, Ausforming; Isoforming; Embrittlement during tempering, hardenability and factors affecting the properties.
Hardening (case and surface)**:** Nitriding, Carburising, and Carbonitriding, Laser hardening, and Induction hardening.
Engineering steels: Heat treatment and their effect on industrial steels including stainless steels, tool steels, maraging steels, dual phase steels, bearing steels, spring, and HSLA steel.

Text Books:

1. Heat Treatment of Metals: B. Zakharov, CBS Publishers, 1998.
2. Principles of Heat Treatment of Steels, F.M.B. Fernandes and T. Ericsson, ASM Handbook, 1991.
3. Heat Treatment of Metals: Vijendra Singh, Standard Publishers Distributors, 2009.

Reference Books:

1. Principles of the Heat Treatment of Plain Carbon and Low Alloy Steels: C.R. Brooks, ASM International, 1996.
2. Steels: Processing, Structure and Performance: G. Krauss, 2nd Ed., ASM International, 2015.
3. The Physical Metallurgy of Steels: W.C. Leslie, McGraw-Hill, 1981.

MM4126 Creep, Fatigue and Fracture
(3-0-0) 3 credits

Course learning objectives (Complies with PLOs 1, 3 and 5)

- Gain a thorough understanding of creep, fatigue, and fracture mechanisms in engineering materials.
- To understand and predict how materials fail under various loading conditions and the deformation behaviour of metallic materials at high temperatures

Course learning outcomes

Upon completion of course the students will be able to

- Differentiate between creep, fatigue, and fracture and explain the mechanisms by which they occur in different materials.
- Design components that consider creep, fatigue, and fracture resistance for safe and reliable operation.

Creep: Stress-strain curve, concept of homologous temperature, effect of temperature on dislocation motion. Creep curve, structural changes during creep, constitutive equations. Mechanism of creep deformation, dislocation creep, diffusion creep. Deformation mechanism maps, superplasticity in metals and ceramics, grain boundary sliding, rupture

Fatigue: Cyclic stress-strain, low cycle fatigue, Coffin-Manson relation, S-N curve, stress intensity factor, notch sensitivity, fatigue crack initiation mechanism, Paris law, factors affecting fatigue life, thermal fatigue, fatigue protection methods, fretting. Creep-fatigue interaction. Case studies.

Fracture: basic models of fracture, Griffith theory, stress concentration factor, ductile fracture, brittle fracture, ductile to brittle transition, modes of fracture, hydrogen embrittlement. Fracture in structural and bio-implant components, fracture under rapid loading rates. Stress corrosion cracking, Fractography. Case studies.

Text Books:

1. Mechanical Behavior of Materials: Thomas H. Courtney, 2nd Ed., Waveland Press Inc., 2005.
2. Mechanical Metallurgy: G.E. Dieter, 3rd Ed., McGraw Hill, 2017.
3. Deformation and Fracture Mechanics: R.W. Hertzberg, R.P. Vinci, J.L. Hertzberg, 5th Ed., Wiley, 2012.

Reference Books:

1. Metal Fatigue in Engineering: R.I. Stephens, A. Fatemi, R.R. Stephens, H.O. Fuchs, 2nd Ed., Wiley, 2000.
2. Creep of Engineering Materials: I. Finnie, W. R. Heller, McGraw Hill, 1999.

MM4221 Smart Polymers
(3-0-0) 3 credits

Course learning objectives (Complies with PLOs 1 and 3)
- To introduce the basic concepts of synthesis & processing of smart polymers
- To develop an understanding of different types and properties of smart polymers
- To impart knowledge of smart polymers applications

Course learning outcomes
Upon completion of this course, the students will be conversant with
- Fundamentals and processing of smart polymers
- Environmentally responsive polymers (i.e. temperature, pH, light etc.), Self-healing polymers, Shape memory polymers, Enzyme-responsive polymers, magnetically responsive polymer
- Application of smart polymers (i.e. drug delivery, medical devices, bio-technology, textile, optical storage)

Introduction: Overview, types and applications of smart polymer.

Temperature-responsive polymers: Basic concepts of temperature-responsive polymers in aqueous solution, Key forms of temperature-responsive polymers in aqueous solution, selected programs of thermo-responsive polymers.

pH-responsive polymers: Key varieties and characteristics of pH-responsive polymers, various architectures of pH-responsive polymers, Synthesis of pH-responsive polymers, Different methodologies for the preparation of pH-responsive polymers and Applications.

Photo-responsive polymers: Key types and properties of photo-responsive polymers Chromophores and their light-induced molecular response, and Applications.

Magnetically responsive polymer gels and elastomers: synthesis of magnetically responsive polymer gels and elastomeric materials, Magnetic properties of filler-loaded polymers, Elastic behaviour of magnetic gels and elastomers, The swelling equilibrium under a uniform magnetic field, Kinetics of shape change, Polymer gels in a non-uniform electric or magnetic field and Applications.

Enzyme-responsive polymers: Enzyme-responsive materials: rationale, definition and history, Preparation of enzyme-responsive polymers, Characterisation of enzyme-responsive polymers, Key varieties and characteristics of enzyme-responsive polymers and Applications.

Shape memory polymers: Characterizing shape memory effects in polymeric materials, Categorizing shape memory polymers based on their stimulus type and polymer structure, Applications.

Smart polymer hydrogels: Synthesis, key categories, characteristics, and uses for hydrogels made of smart polymers.

Self-healing polymer systems: Different forms of self-healing, Self-healing and recovery of functionality in materials.

Applications of smart polymers: Drug delivery using smart polymer nanocarriers, smart polymers in medical equipment for minimally invasive surgery, diagnosis, and other uses, Smart polymers for textile applications, for food packaging applications, for optical data storage and for bio-separation and other biotechnology applications.

Text books:

1. Maria Rosa Aguilar, Julio San Román, Smart Polymers and Their Applications, Woodhead Publishing Limited/Elsevier, 2019.
2. José Miguel García, Félix Clemente García, José Antonio Reglero Ruiz, Saúl Vallejos and Miriam Trigo-López, Smart Polymers Principles and Applications, De Gruyter, 2022.

Reference Books:

1. Asit Baran Samui, Smart Polymers Basics and Applications, Taylor and Francis Group, 2022.
2. Igor Galaev, Bo Mattiasson, Smart Polymers Applications in Biotechnology and Biomedicine, Routledge/ Taylor and Francis Group, 2019.

INDIAN INSTITUTE OF TECHNOLOGY PATNA

Department of Metallurgical and Materials Engineering

MM4222 Energy Materials
(3-0-0) 3 credits

Course learning objectives (Complies with PLOs 2, 3 and 5)

- To understand the challenges and issues related to energy-efficient technology
- Describes how advanced materials make possible efficient energy harvesting, energy conversion and energy storage technologies
- Explain energy-related material issues including design, synthesis, characterization, and performance for energy device applications
- Discuss materials enabling energy-efficient transportation and housing

Course learning outcomes

Upon completion of this course, the student will be able to:

- Understand theories for optoelectronics, photovoltaics, electrocatalysis and batteries.
- Demonstrate knowledge of materials design, synthesis, and modification for energy related applications
- Utilize various materials engineering techniques to enhance the performance of energy applications
- Demonstrate the structure/composition-performance relationship for energy materials

Introduction: Optoelectronic, Photovoltaic technologies, Energy Efficient Lighting
Energy harvesting technologies/materials: organic and inorganic solar cells, nuclear materials, material for wind energy and thermoelectric
Energy conversion technologies/devices: e.g., polymer and solid oxide fuel cells, light emitting diodes, engines, and turbines
Energy storage technologies: batteries, introduction to electrochemical energy storage and conversion, lithium ion batteries, basic components in Lithium – ion batteries: electrodes, electrolytes, and current collectors, characteristics of commercial lithium ion cells, Sodium ion rechargeable cell, introduction to battery pack design, advanced materials and technologies for supercapacitors, Li – Air batteries, Li – Sulphur batteries, rare-earth Li resources and recycling of Li ion battery, Other types of batteries, hydrogen storage, phase change materials. Supercapacitor
Energy-efficient materials: transportation, housing. Materials selection

Textbooks:

1. Handbook of Photovoltaics Science and Technology, By Antonio Luque and Steven Hegedus
2. Physics of solar cells: from basic principles to advanced concepts, By Peter Würfel and Uli Würfel

Reference books:

1. Organic photovoltaics: materials, device physics, and manufacturing technologies, By Christoph J. Brabec, Vladimir Dyakonov, Ullrich Scherf
2. Principles of Solar Cells, LEDs and Diodes: The Role of the PN Junction, By Adrian Kitai

INDIAN INSTITUTE OF TECHNOLOGY PATNA

Department of Metallurgical and Materials Engineering

MM4223 Electroceramics
(3-0-0) 3 credits

Course learning objectives (Complies with PLOs 1 and 3)

- To demonstrate the fundamentals of functional (electronic, magnetic, optical, dielectric etc.)
- To illustrate process, structure, property correlations of wide range of functional ceramic materials

Course learning outcomes

- Classify various classes of electroceramic materials and describe their structure and properties
- Relate the phase, chemical composition and microstructure of electroceramics to the particular conductive, dielectric, ferroelectric, piezoelectric and pyroelectric, electro-optic and magnetic properties

Ceramic Capacitors: Multi-layer ceramic capacitors, Importance of $BaTIO_3$ as a capacitor material, Improvement of dielectric constant, effect of doping.

Electronic and Ionic conducting ceramics: Highly conducting ceramics, non-stoichiometric and valence-controlled semiconductors. Grain boundaries effects, NTC and PTC thermistors, Superionic ceramic conductors (AgI, β-Alumina).

Piezoelectric, Ferroelectric and Electro-optic Ceramics: Ferroelectric ceramic materials, chronology of ferroelectric ceramics, ferroelectric hysteresis and poling, Relaxor ferroelectrics, General characteristics of piezoelectric materials, Piezoelectric constants. Electro optic effect, linear, quadratic and memory devices, importance of morphotropic phase boundary, Pyroelectric Materials, Electro-optic Ceramics.

Magnetic Ceramics: Soft and hard ferrites, their applications. Ni-Zn ferrites, Mn-Zn ferrites, mixed garnets and Hexagonal Ferrites. Effect of composition, processing and microstructure on the magnetic properties. Processing and applications of magnetic ceramics.

Text Books:

1. Electroceramics: Materials, Properties, Applications: A.J. Moulson and J.M. Herbert, 2nd Ed., Chapman & Hall, Springer, 2003.
2. Fundamentals of Ceramics: Michel W. Barsoum, McGraw Hill, 1997.
3. Ceramic Materials for Electronics: R.C. Buchanan (ed.), Marcel Dekker, 1991.
4. Electronic Ceramics: L.M. Levison (ed.), Marcel Dekker, 1988.

Reference Books:

1. Ferroelectric Materials and Their Applications: Y.H. Xu, North-Holland, Elsevier, 1991.
2. Piezoelectric Ceramics: Principles and Applications: APC International, Ltd, 2002.
3. Ferroelectric Devices: Kenji Uchino, Marcel Dekker, 2000.

MM4224 Biomaterials
(3-0-0) 3 credits

Course learning objectives (Complies with PLOs 1 and 5)

- To identify the major types of materials that are used in the body and their major modes of failure and apply material property fundamentals to analyze the performance of a material in vivo and translate material properties from test data to material performance.
- To understand common use of biomaterials as metals, ceramics and polymers and its chemical structure, properties, and morphology.
- To understand the interaction between biomaterial and tissue for short term and long-term implantations

Course learning outcomes

Upon completion of this course, the student will be able to:

- Understand the multidisciplinary nature of biomaterials as a field of study and define design criteria for a material with relationship to their clinical application
- Understand how to analyse the interaction of materials with the human body and what biocompatibility is in relation to specific materials
- Analyse issues relevant to property retention for materials when implanted in the human body and be capable of reading, comprehending and communicating the content of technical articles on biomaterials research and applications

Introduction: Definition and scope of biomaterials, Classification of bio-ceramic materials. Alumina and zirconia in surgical implants and their coatings. Bioactive glasses and glass ceramics with their clinical applications. Synthesis and characteristics of dense and porous hydroxyapatite and calcium phosphate ceramics. Resorbable bioceramics. Characterization of bio-ceramics.

Structure-property relationship of biological materials: structure of proteins, polysaccharides, structure-property relationship of hard tissues cell, bone, teeth and connective tissues. Structure, properties and functional behaviour of bio-materials. Tissues response to implants (biocompatibility, wound healing process), body response to implants, blood compatibility.

Application: Classification of bioceramic materials for medical applications, Carbon as an implant. Regulation of medical devices, Cell culture of bio ceramics, network connectivity and hemolysis, Preparation of bio ceramics and characterization of bioactivity.

Bio-polymers: Polysaccharide based polymers, gelatinization, starch based blends, biodegradation of starch based polymers, production of lactic acid and polylactide, properties and applications of polylactides, introduction to polyhydroxyalkanoates and their derivatives, applications, chitin & chitosan and its derivatives as biopolymers, biopolymer films, biodegradable mulching, advantages and disadvantages, chemical sensors, biosensors, functionalized biopolymer coatings and films.

Applications of biopolymers: Food Packaging, functional properties, safety and environmental aspects, shelf life, films and coatings in food applications, applications of biopolymers for organ transplant, different biopolymers used for organ transplant e.g. dental cement, orthopedic, skin, artificial kidney etc., applications of biopolymers in tissue engineering, regeneration,

Targeted drug delivery: Introduction to drug delivery, polymers in controlled and targeted drug delivery, dressing strips, polymer drug vessels, core shell and nanogels.
Application based and material based classification of biomaterials. Drug delivery, Callipers, biosensors, implants.

Text books:

1. An Introduction to Bioceramics: Larry L. Hench, June Wilson, World Scientific, 1993.
2. Biomaterials: An Introduction: Park Joon, R. S. Lakes, Springer, 2007.
3. Biopolymers-New Materials for Sustainable films and Coatings: David Plackett, John Wiley & Sons Ltd., 2011
4. Biopolymers from Renewable resources: David Kaplan, Springer, 1998

Reference books:

1. Bioceramics and their Clinical Applications: T. Kokubo, Woodhead Publishing, 2008.
2. Biopolymers: R. M. Johnson, L. Y. Mwaikambo, N. Tucker, Rapra Technology, 2003.
3. Hand Book of Bioplastics & Biocomposites for Engineering Applications: Srikanth Pillai, Wiley, 2011.
4. Biopolymers: Steinbuechel Alexander, Vol. 1-10, Wiley, 2003.
5. Polymers from Renewable Resources: Biopolymers and Biocatalysis: Carmen Scholz, Richard A. Gross American Chemical Society, 2001.

INDIAN INSTITUTE OF TECHNOLOGY PATNA

Department of Metallurgical and Materials Engineering

MM4225 Crystallographic Texture and Analysis
(3-0-0) 3 credits

Course learning objectives (Complies with PLOs 2 and 3)

- To understand the concept of crystallographic texture and its importance in material properties
- To gain knowledge of various techniques used to characterize crystallographic texture in polycrystalline materials.
- To learn the interpretation of texture data and relate it to the microstructure and deformation behaviour of materials.

Course learning outcomes

Upon completion of this course, the student will be able to:

- Explain the connection between crystallographic texture, microstructure, and mechanical properties of materials.
- Analyse and interpret texture data using relevant software or tools
- Apply the understanding of texture to predict and improve material performance in various engineering applications.

Concept of texture: Crystal orientation, sample coordinate system, crystal coordinate system, stereographic projections, pole figure, construction of pole figures, reading pole figures and inverse pole figures.
Orientation distribution functions, Bunge convention, Euler angles, Euler space, two-dimensional representation of ODF, and identification of standard texture components in Euler space.

Texture measurement: Bulk and local texture measurements, electron diffraction using SEM and TEM, Kikuchi lines and indexing, Hough transformation, orientation imaging microscopy, X-ray and neutron diffraction measurement. Transmission EBSD.

Texture during material processing: Deformation, annealing and recrystallization texture. Solidification and transformation texture. Texture in thin films and coatings. Influence of texture on mechanical properties.

Case studies: Texture control in electrical steel, aluminium alloys, shape memory alloys, magnetic materials.

Text Books:

1. Introduction to Texture Analysis: Macrotexture, Microtexture and orientation mapping: V. Randle and O. Engler, 2nd Ed., CRC Press, 2009.
2. Recrystallization and Related Annealing Phenomenon: F.J. Humphreys, M. Hatherly, 2nd Ed., Pergamon Press, 2004.

Reference Books:

1. An Introduction to Textures in Metals: M. Hatherly and W.B. Hutchinson, The Institute of Metals, 1979.
2. DST-SERC School Lectures on Texture.

INDIAN INSTITUTE OF TECHNOLOGY PATNA

Department of Metallurgical and Materials Engineering

MM4226 Furnace and Refractories
(3-0-0) 3 credits

Course learning objectives (Complies with PLO 3)

- To be able to explain the composition, classification and properties of refractories
- To be able to evaluate mechanical properties, thermal behaviour and slag resistance of refractory materials
- To be able to evaluate the design, performance, and lifetime of refractories for industrial applications

Course learning outcomes

Upon completion of this course, the student will be able to:

- Demonstrate a clear understanding of the types of refractories used for different industries
- Interpret the information on chemical and mineral compositions, thermal conductivity, and micro-structural examinations and other characterization carried out on refractory bricks
- Evaluate the industrial application of various refractory materials, their design, performance and testing methods

Furnaces: Fundamentals of furnace design, thermodynamics of fuel combustion, chemical reaction and enthalpy evolution, importance of heat balance, Sankey and virtue diagrams, temperature of flame, electric furnaces, advance furnaces, different heat loss in furnaces, choice of insulation, waste heat management through recuperation and regeneration, fuel economy and thermal efficiency of furnaces, principles of temperature and atmosphere control

Various types of furnaces utilized in metallurgy/ ceramic industries, blast furnaces, open-hearth furnaces, Bessemer converters, LD converters, coke-oven batteries, tunnel kilns, chamber furnaces, glass tank furnaces, rotary kilns.

Refractories: Composition, physical and chemical properties of raw materials; Principles of manufacturing of firebricks, silica, alumina, mullite, magnesite, chrome-magnesite, dolomite, magnesia, forsterite and insulating bricks along with relevant phase diagrams, spinel, borides, carbides, nitride, and carbon refractories

Application of refractories in a blast furnace, open hearth furnace, Bessemer and L.D. converter, copper, aluminum, cement, lime, and glass industry. monolithic refractories, use of monolithic over shaped refractories.

Testing of refractories: Bulk density, porosity, fusion point, cold crushing strength, creep resistance, pyrometric cone equivalent and refractories under load, hot modulus of rupture, abrasion resistance, thermal conductivity, thermal expansion and spalling, corrosion, and reaction of refractories.

Text Books:

1. Industrial ceramics: Felix Singer, Sonja S. Singer, Chapman & Hall, Springer, 1963.
2. Refractories: F.H. Norton, Cbls\Ceramic book and Literature, 1985.
3. Industrial and Process Furnaces: P. Mullinger and B. Jenkins, Butterworth Heinemann, Elsevier, 2013.

Reference Books:

1. Fundamentals of Materials for Energy and Environmental Sustainability: G. David and C. David, Cambridge University Press, 2011.
2. The Technology of Ceramics and Refractories: Petr Petrovich Budnikov, M.I.T. Press, 1964.

INDIAN INSTITUTE OF TECHNOLOGY PATNA

Department of Metallurgical and Materials Engineering

MM4227 Composite Science and Technology
(3-0-0) 3 credits

Course learning objectives (Complies with PLOs 1 and 3)

- To disseminate details regarding the various kinds of composites, their requirements, and their benefits.
- To disseminate knowledge on how various composites are prepared.
- To provide knowledge on the characteristics, uses, and testing of various composites.

Course learning outcomes

Upon completion of this course, the students will be

- Able to choose appropriate composites for specific applications.
- Able to comprehend about the many techniques used in the manufacturing of composite materials
- Able to select suitable testing procedures for composite analysis.

Metal matrix composites (MMCs): Overview, significant of metallic matrices, Characteristics and uses of MMCs. Processing of metal matrix composites: liquid state processing: melt stirring, compocasting (rheocasting), squeeze casting, liquid infiltration under gas pressure; solid state processing: diffusion bonding, powder metallurgy; Deposition: in-situ processes, spray co-deposition, and other deposition methods including CVD and PVD. Interface reactions.

Ceramic matrix composites (CMCs): Introduction; processing and structure of monolithic materials – technical ceramics, glass-ceramics. Processing of ceramics: conventional mixing and pressing – cold pressing and sintering, hot pressing; Reaction bonding processes, techniques involving slurries, liquid state processing – matrix transfer moulding, liquid infiltration, sol-gel processing; Carbon-carbon composites - porous carbon-carbon composites, dense carbon-carbon composites. Properties and applications of CMCs; Glass-ceramic matrix composites; Processing, properties and applications of alumina matrix composites - SiC whisker reinforced, zirconia toughened alumina; Vapour deposition techniques like CVD, CVI, liquid phase sintering, Lanxide process and in situ processes.

Polymer matrix composites (PMCs): Thermoset matrices–polyesters, epoxides, phenolics, vinyl esters, polyimides and cyanate esters, thermoplastic matrices and rubber matrices. Fibers: Glass, carbon, kevlar, natural fibers and surface treatment- sizing/coupling agents. Interfaces: Wettability, the type of bonding at the interface, its crystallographic character, and the ideal interfacial bond strength. Processing: Sheet molding compounds, bulk molding compounds, hand layup process, spray layup process, resin transfer molding, pressure bag molding, vacuum bag molding, autoclave molding, filament winding and pultrusion. Properties and applications of PMCs.

Testing of composites: Destructive and non-destructive testing of composites

Analysis of composites: Micro-mechanics, macro-mechanics and failure theories.

Text books:

1. Chawla. K.K., Composite Materials - Science and Engineering, Springer, 2001.

2. Jones, R.M., Mechanics of Composite Materials, Taylor and Francis, 1999.
3. P. K. Mallick, Composites Engineering Handbook Part-1&2, CRC Press (2016).

Reference Books:

1. Lubin, G., Handbook of Composites, Van Nostrand Reinhold Co., 1982.
2. Eckold, G., Design and Manufacture of Composite Structures, Wood head Publishing Ltd., 1994.
3. F. R. Jones (Ed.), Handbook of Polymer-Fibre Composites, Longman Group (1994).
4. K. Friedrich, S. Fakirov, Z. Zhang (Eds.), Polymer Composites – from Nano to Macro scale, Springer (2005).

INDIAN INSTITUTE OF TECHNOLOGY PATNA

Department of Metallurgical and Materials Engineering

MM2290 Structure and Properties of Materials (IDE I)
(3-0-0) 3 credits

Course learning objectives (Complies with PLO 1)

- To provide an introductory level understanding of material structure (microstructure) on different length scales
- To understand how specific material properties and behaviours are determined by the associated structure

Course learning outcomes

On completion of the course the students will be able to

- Differentiate between different types of materials and their structures
- Understand the structure dependence of properties and design materials for various engineering applications

Bonding in solids: primary and secondary bonding is solids, bond strength and bond energy.

Basic crystallography: crystalline and amorphous materials. Packing of atoms, coordination number, unit cell, Bravais lattice, simple crystal structures, defects in solids, Miller indices

Classification of materials: engineering materials and their classification, metallic materials, ceramic materials and polymeric materials. Composite materials.

Properties of materials: mechanical, electrical, magnetic and optical properties. Microstructure-property correlation in materials.

Materials selection: introduction to materials selection charts, Ashby maps, materials performance index, processibility and cost.

Text Book:

1. Materials Science and Engineering, an Introduction: William D. Callister, 7th Ed., John Wiley and Sons, 2007
2. Materials Science and Engineering: V. Raghavan, 6th Ed., Prentice Hall India, 2015.

INDIAN INSTITUTE OF TECHNOLOGY PATNA

Department of Metallurgical and Materials Engineering

MM3190 Microscopy and X-ray Diffraction (IDE II)
(3-0-0) 3 credits

Course learning objectives (Complies with PLO 3)
- To understand the availability of various techniques to characterize materials
- To understand the strengths and limitations of different characterization techniques

Course learning outcomes
Upon completion of this course, the student will be able to:
- Understand structure and microstructure of materials
- Choose the appropriate technique to characterise different materials

Introduction: Importance and the need for materials characterization, bonding, crystal structure and system, miller indices, Bravais lattice.
Diffraction: Basics of diffraction and interference of light, Young's double slit experiment, interpretation of diffraction from the single slit and multiple slits.
X-ray Diffraction: Generation of X-rays, X-ray diffraction (XRD), Bragg's Law, Atomic scattering factor, structure factor, indexing of diffraction patterns, selection rules, estimation of peak intensity, phase identification and analysis by XRD, determination of structure and lattice parameters, strain and crystallite size measurements through XRD, effect of temperature on XRD.
Optical Microscopy: Principles of optical microscopy, magnification, Rayleigh criterion, resolution limitation, Airy disk, depth of focus, and field.
Electron diffraction: Wave properties of the electron, electron-matter interactions, ring patterns, spot patterns, and Laue zones.
Scanning Electron Microscopy: Principle, construction, and operation of Scanning Electron Microscope, SE and BSE imaging modes, Elemental analysis using Energy dispersive analysis of X-rays,
Transmission electron microscope: Principle, construction, and working of Transmission Electron Microscope (TEM), the origin of contrast: mass-thickness contrast, electron diffraction pattern, Bright field, and dark field images.
Thermal characterization techniques (DTA, DSC, DTA)

Text Books:
1. Elements of X-Ray Diffraction: B.D. Cullity and S.R. Stock, 3rd Ed., Pearson, 2001.
2. Scanning Electron Microscopy and X-Ray Microanalysis: Joseph Goldstein, Eric Lifshin, Charles E. Lyman, David C. Joy and Patrick Echlin, 3rd Ed., Springer, 2003.

Reference Books:
1. Transmission Electron Microscopy: A Textbook for Materials Science: David B. Williams and C. Barry Carter, Springer, 2009.
2. Structure of Materials: An Introduction to Crystallography, Diffraction and Symmetry, Marc De Graef, Michael E. McHenry; 2nd Ed., Cambridge University Press, 2012.

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Department of Metallurgical and Materials Engineering

MM4190 Nanomaterials (IDE III)
(3-0-0) 3 credits

Course learning objectives (Complies with PLO 3)

- To understand the influence of dimensionality at nanoscale on their properties
- To understand the size and shape-controlled synthesis of nanomaterials and their current and futuristic applications/challenges.
- To visualize the applications of nanomaterials in their routine life

Course learning outcomes:

Upon completion of this course, the student will be able to:

- Appreciate the quantum effects operating at nanoscale on the properties of materials
- Design, synthesize and characterize materials at nanoscale
- Contrast the properties of materials at the nanoscale relative to its bulk counterpart and apply nanomaterials for advanced industrial applications

Overview: Overview of Nanostructures and Nanomaterials; Characteristic length scales of materials. Classification-Natural nanomaterials, artificial nanomaterials, Inorganic nano materials- Metal-based nanoparticles, Metal oxide nanoparticles, Semiconductor Nanoparticles, Ceramic nanomaterial, Composites nanomaterials. 3D, 2D, 1D and 0 Dimensional Nanomaterials. Carbon Nanotubes, Fullerenes, Nanowires, Quantum Dots. Applications of nanostructures, Surfaces and interfaces in nanostructures, Grain boundaries in Nanocrystalline materials, Defects associated with nanomaterials, Micro porous, Mesoporous materials and Macro porous materials.

Fundamentals: Various electron confinements in nanomaterials, concept of quantum well, dots and wires and thermodynamics of nanomaterials

Nanomaterials' manufacturing: Top down approaches: mechanical milling, electrospinning; Lithography, sputtering, the arc discharge method; laser ablation, thermal decompositions. Bottom-up approaches: chemical vapour deposition (CVD), solvothermal and hydrothermal growth; sol–gel method and electrochemical and pyrolysis approaches.

Properties of Nanostructures and Nanomaterials: Surface area, thermal and electrical conductivity, mechanical properties; support for catalysts, Optical and electrical properties, physical and chemical properties of nanomaterials.

Text books:

1. Booker, R., Boysen, E., Nanotechnology, Wiley India Pvt. Ltd. (2008).
2. Rogers, B., Pennathur, S., Adams, J., Nanotechnology, CRS Press (2007).
3. Bandyopadhyay, A.K., Nano Materials, New Age Int., (2007)

Reference books:

1. Dr. Kurt E. Geckeler, Prof. Hiroyuki Nishide, Advanced Nanomaterials: Copyright © 2010 Wiley-VCH Verlag GmbH & Co. KGaA
2. Jingbo Louise Liu, Sajid Bashir Tian-Hao Yan, Advanced Nanomaterials and Their Applications in Renewable Energy.
3. Nanomaterials, Nanotechnologies and Design: An Introduction to Engineers and Architects, D. Michael Ashby, Paulo Ferreira, Daniel L. Schodek, Butterworth-Heinemann, 2009.
4. S. Cambell, The Science & Engineering of Microelectronic Fabrication, Oxford, 1996.