Department of Metallurgical and Materials Engineering
Curriculum of UG programme in Materials Engineering

1. Introduction

Addressing continuously evolving demands for materials in the emerging areas such as, energy, aerospace, defence, healthcare, transport, etc. requires engineers with thorough understanding and knowledge of the materials. To cater to this requirement, the Department of Metallurgical and Materials Engineering at IIT Jodhpur envisions to impart high-quality education in the areas of Materials Engineering. The B.Tech. program in Materials Engineering offers a broad-based academic curriculum designed to attract highly motivated students interested in the emerging area of Materials and the program is committed to impart high-quality education in designing, processing and development, characterization and evaluation of advanced materials, and process metallurgy, so that the students can contribute to the Materials innovation.

The B.Tech. program in Materials Engineering educates and trains students to understand the scientific principles that govern the relationships among extraction, processing, structure, properties, and performance of materials. The undergraduate Materials Engineering curriculum encompasses four major streams-

1. Structural materials
2. Functional materials
3. Computational materials engineering
4. Process metallurgy.

The proposed UG curriculum consists of foundational courses, and core and electives from all four major streams. The foundational courses form the base of the program and enables the student to take program core and program elective courses from the four major streams. With such a broad curriculum with sufficient subject depth for an undergraduate program, the B.Tech. program aims to provide students with a solid academic foundation to address the needs in materials area and encourages them to pursue research in the new and emerging areas. In the curriculum, an emphasis is given to the emerging areas in materials engineering such as computational materials engineering, energy materials, and advanced structural materials. Additionally, to enable the students to pursue their interest in one of the four major streams, the program structure allows students to specialize in one of the above mentioned streams of Materials Engineering. The students can obtain a Departmental Specialization after completing additional 20 credits beyond the regular B.Tech. program requirement. This ensures depth along with sufficient breadth in the curriculum. This curriculum is expected to equip the students with relevant experimental and computational skillsets relevant to the industry and will enable the graduates to innovate and address present day materials challenges to meet the future needs of the country.

2. Objective of the program

1. To impart education on the core concepts in Materials Engineering along with providing sufficient breadth of knowledge in the traditional as well as emerging areas of materials engineering
2. To train students on experimental techniques for studying materials engineering
3. To provide students sufficient analytical and computational skills to address materials engineering needs

4. To introduce an early sense of attitude towards technology development and its lifecycle

5. To inculcate an attitude towards the commitment to engineering ethics, continued learning, and professional development

6. To enable students to optionally specialise in one of the four areas of focus:
   a. Structural materials
   b. Functional materials
   c. Computational materials engineering
   d. Process metallurgy.

3. Expected Graduate Attribute

- Overall understanding of atomic structure, crystal structure and imperfections in materials
- Ability to understand the physical and chemical phenomena or process through thermodynamic and kinetic principles
- Ability to understand the relation between electronic band structure and electrical, optical and magnetic properties of materials
- Broad knowledge on processing of materials and fabrication components following various processing and manufacturing techniques, and basic skills to characterize the microstructure
- Ability to correlate processing-structure-property-performance of materials and their processing
- Knowledge about the process of extraction of ferrous and non-ferrous metals from ore
- Ability to use various simulation tools to design materials and predict material behaviour for a better understanding of materials
- Ability to design and execute technical projects
- Skills to communicate engineering concepts and ideas to peers
- Appreciation and adherence to professional ethics

4. Learning Outcome

- Ability to apply principles of thermodynamics and kinetics to understand, design and process advanced materials
- Ability to use computational and analytical modelling techniques to predict various properties of materials
- Ability to use materials testing and characterization techniques to validate structure-property-performance correlation in materials at various length scales

- Understanding of electronic structure of materials and ability to correlate electronic structure with transport properties of materials
- Knowledge of processing parameters for the extraction of ferrous and non-ferrous metals, and knowledge to comprehend the process cycle to convert raw material to a final product
- Ability to understand materials processing and process scale up

5. Topic clouds

The major topics from the individual courses are presented here in the form of a topic cloud.

Computational Materials Engineering

Modelling, Boundary value problem, Diffusion type problem, Wave Propagation Problem, Finite Difference, Computation, Molecular dynamics, Atomistic simulations, Calculation of Phase diagram, Thermodynamic Database, Solidification simulation, Alloy Design, Modelling, Machine learning, Feature identification, Informatics, Finite Element Analysis, Stiffness Matrix, Galerkin method, Displacement formulation, Stress analysis

Structural Materials

Defects in Solids, Plastic Deformation, Strengthening Mechanisms, Mechanical Properties, Failure of Materials, Steels, Processing, Physical Metallurgy, Microstructure, Properties, Corrosion, Oxidation, Polymers, Processing, Rheology, Composites, Fibre-Matrix interface, laminae and laminates, Ceramics, Refractories, Glasses, Sintering, Coatings, Abrasives, 3D printing, Materials for 3D Printing Process, Additive manufacturing, Casting techniques, gating design, casting defects, Fusion welding, Solid state welding, Microstructure and Properties of weld zone

Foundational and Core topics

Physics, Chemistry, Mathematics, Biology, Signals and systems, Machine learning, Numerical Methods, Differential Equations, Computation, Data structure, algorithm, Thermodynamics, Mechanics, Structure of Materials, Physical Metallurgy, Polymers, Corrosion, Materials Selection, Phase Diagram, Functional Properties, Diffusion, Mass Transfer, Heat Transfer, Fluid Flow, Nucleation and Growth, Solidification, Diffraction, Microscopy, Spectroscopy, Thermal Analysis, Materials Processing

Functional Materials

Band structure, Density of States, Semiconductors, Dopants, metal-oxides, organics, electronic devices, semiconductor processing, Battery Materials, Fuel cells, Hydrogen Storage, Solar cells, Supercapacitors, Thermoelectrics, Carbon based materials, Shape memory alloys, smart materials, functionally graded materials, self-healing materials, bio-medical sensing, electrostrictive and magnetostrictive materials, smart textiles, Nanomaterials, Biomaterials, Tissue materials, Implants, Coatings, Thin films, Deposition, Processing, functional Properties

Process Metallurgy

Transport processes, Metal-Slag interaction, Continuous Casting, Hydrometallurgy, Pyrometallurgy, Electrometallurgy, Metal extraction, Refining, Mineral processing, comminution and screening, separation, concentration, Chemical Kinetics, Chemical control, Diffusion control, Rate controlling step, Ladle metallurgy, Degassing, Ingot defects, Process phenomena, Metal-slag interaction, Energy and Mass Balance, Process control, Leaching, Phase stability diagram, Metal recovery processes, Metal utilization, Electrochemistry, Electrodeposition, Electrowinning

6. Unique skillsets targeted

Computational approaches, which will enable

(i) Designing of materials and components for engineering applications
(ii) Prediction of properties of materials
(iii) Designing of industrial processes

Experimental techniques for

(i) Materials testing and characterization
(ii) Performance evaluation and enhancement

7. Mapping of Topic clouds with proposed courses

Table 1. Mapping of topic clouds with proposed courses

Area	Topics	Category (Core/ Elective)	Course
Foundations of Materials Engineering	Numerical Methods, Differential Equations, Computation	Institute Engineering Core (IE)	Scientific Computation
	Reversible and irreversible process, Laws of thermodynamics, Intensive and Extensive properties, State variable and Path variable	Institute Engineering Core (IE)	Thermodynamics
	Supervised learning, Unsupervised learning, Classification, Artificial neural network	Institute Engineering Core (IE)	Introduction to Machine Learning
	Deformation and Strain, Stress, Linear elasticity, Combined loading, Energy methods, Buckling	Program Core (PC)	Mechanics of Solids
	Condensed matter, Functional properties, Soft matter, Surfaces and Interfaces	Institute Program linked Science core (LS)	Introduction to Condensed Matter Physics
	Data structure, algorithm, searching and sorting, hashing	Institute Engineering Core (IE)	Data Structure and Algorithm
	Structure of Materials, Physical Metallurgy, Polymers, Corrosion, Materials Selection	Institute Engineering Core (IE)	Materials Science and Engineering
	Phase equilibria, Thermodynamics of Solutions, Phase diagram, Reaction Thermodynamics	Program Core (PC)	Materials at Equilibrium
	Nucleation and growth, Phase diagram, Thermodynamics and kinetics of Phase transformation, Diffusion, Solidification, Heat treatment	Program Core (PC)	Phase Transformations
	Characterization, Diffraction, Microscopy, Spectroscopy, Thermal Analysis	Program Core (PC)	Materials Characterization
	Casting, Solidification, Forming, Joining, Additive manufacturing	Program Core (PC)	Materials processing and Manufacturing

Structural Materials	Defects in solids, Plastic Deformation, Strengthening Mechanisms, Failure of Materials, Failure prevention	Program Core (PC)	Mechanical Behaviour of Materials
	Steels, Processing, Physical Metallurgy, Microstructure, Strengthening, Properties	Program Elective (PE)	Processing-Microstructure and Properties of Steels
	Electrochemistry, Corrosion, Forms of Corrosion, Corrosion induced failure, Oxidation, Corrosion Prevention	Program Elective (PE)	Degradation of Materials
	Structure of Polymers, Defects, Polymerization, Processing, Rheology, Characterization	Program Elective (PE)	Polymeric Materials and Processing
	Matrix, Reinforcements, Fibre-Matrix interface, Processing, laminae and laminates, Properties, Nanocomposites	Program Elective (PE)	Composites
	Oxide and non-oxide Ceramics, Refractories, Glasses, Sintering, Coatings, Abrasives	Program Elective (PE)	Ceramics and Glass
	3D printing, Materials for 3D Printing Process, Additive manufacturing, Materials processing	Program Elective (PE)	3D Printing: Material Processing and Properties
	Casting techniques, solidification, Heat flow, fluid flow, gating design, casting defects	Program Elective (PE)	Casting and Solidification
	Joining, Fusion welding, Solid state welding, Microstructure of weld zone, Mechanical Properties of weld zone	Program Elective (PE)	Metallurgy of Joining
	Creep, Oxidation and Hot Corrosion, Super Alloys	Program Elective (PE)	High Temperature Materials
Functional Materials	Band structure, Density of States, Semiconductors, Dopants, metal-oxides, organics, carbon nanotubes, electronic devices	Program Core (PC)	Electronic Materials
	Battery Materials, Fuel cells, Hydrogen Storage, Solar cells, Supercapacitors, Thermoelectrics, Carbon based materials	Program Core (PC)	Materials for Energy Conversion and Storage
	Shape memory alloys, smart polymers, smart ceramics, functionally graded materials, self-healing materials, bio-medical sensing, electrostrictive and magnetostrictive materials, smart composites, smart textiles	Program Core (PC)	Smart Materials (both structure property and electronic property of materials components)
	Semiconductors processing, Synthesis and processing of 2D Materials	Program Elective (PE)	Synthesis and Processing of Semiconductors and 2D Materials
	Electrodes and Electrolytes, Electrochemical Cell, Primary and secondary batteries, Thermodynamics and Kinetics	Program Elective (PE)	Battery Materials
	Nanomaterials, Synthesis, Processing, Characterization, Properties of materials	Program Elective (PE)	Nanoscience (from Department of Chemistry)

	Biomaterials, Biocompatibility, Biodegradability, Tissue materials, Implants	Program Elective (PE)	Biomaterials Engineering (Jointly with BSBE)
	Coatings, Thin films, Deposition, Processing, Properties	Program Elective (PE)	Surface Engineering (PE)
Computational Materials Engineering	Boundary value problem, Partial Differential Equation, Diffusion type problem, Finite Difference method, Molecular dynamics, Atomistic simulations	Program Core (PC)	Computational Modelling of Materials
	Thermodynamic parameters, Calculation of Phase diagram, Thermodynamic Database, Solidification simulation, Alloy Design	Program Elective (PE)	Computational Thermodynamics (PE)
	Total energy calculations, Electronic and Phonon Band Structure Calculations	Program Elective (PE)	First Principles Calculations
	Conserved and Non-Conserved Order Parameter, Phase Transitions, Microstructure Evolution	Program Elective (PE)	Phase Field Modelling
	Scientific Data, feature identification, Supervised learning, Materials Design, Model verification	Program Elective (PE)	Machine Learning for Materials Design (PE)
	Finite Element Analysis, Stiffness Matrix, Galerkin method, Displacement formulation, Stress analysis	Program Elective (PE)	Finite Element Methods and Applications (PE)
Process Metallurgy	Transport processes, Metal-Slag interaction, Ladle and tundish metallurgy, Continuous Casting	Program Core (PC)	Iron and Steel Making
	Hydrometallurgy, Pyrometallurgy, Electrometallurgy, Metal extraction, Refining	Program Core (PC)	Extraction of Nonferrous Metals
	Mineral processing, comminution and screening, separation, concentration	Program Elective (PE)	Mineral Beneficiation
	Chemical Kinetics, Transport processes, Chemical control, Diffusion control, Rate controlling step	Program Elective (PE)	Kinetics of Metallurgical Processes
	Degassing, Ladle metallurgy, Ingot defects, Continuous casting	Program Elective (PE)	Secondary and Special Steelmaking
	Process phenomena, Metal-slag interaction, Energy and Mass Balance, Process control	Program Elective (PE)	Process Metallurgy Principles
	Leaching, Phase stability diagram, Metal recovery processes, Metal utilization	Program Elective (PE)	Hydrometallurgy
	Electrochemistry, Electrodeposition, Electrowinning	Program Elective (PE)	Electrometallurgy

8. Course categories and credit distribution in the proposed B.Tech. programmes

Table 2. Course categories and credit distribution in the proposed B.Tech. programmes

S.N.	Course Type	Course Category	Regular B.Tech.		Double B.Tech.	
			Credit	Total	Credit	Total
1	Institute Core (I)	Engineering (IE)	**34**	**69**	**34**	**59**
		Science (IS)	16		**16**	
		Humanities (IH)	12		9	
2	Programme Linked (L)	Science (LS)	7		0	
3	Programme Core (P)	Programme Compulsory (PC)	**50**	**71**	**50**	**71**
		Programme Electives (PE)	**18**		18	
		B.Tech. Project (PP)	3		3	
4	Open (O)	Open Electives (OE)	10	**10**	0	**0**
5	Engineering Science (E)	Engineering Science Core	0	**0**	**22**	**22**
		Engineering Science Elective (EE)	0	**0**	**8**	**8**
			Total Graded	**150**		**160**
6	Non-Graded (N)	Humanities (NH)	6	**15**	6	**15**
		Engineering (NE)	3		3	
		Design/Practical Experience (ND)	6		6	
		Total Graded + Non-Graded		**165**		**175**

9. Credit Structure of B.Tech. Programmes

Table 3. Credit Structure for B.Tech. Programmes

Type	L-T-P	Distribution of contact and beyond contact hours			Total Credits (TC=TH/3)
		Contact Hours (CH)	Beyond Contact Hours (BCH)	Total Hours (TH)	
1 hour of Lecture	1-0-0	1 hr	2 hr	3 hr	1
1 hour of Tutorial	0-1-0	1 hr	2 hr	3hr	1
1 hour of Lab/Project	0-0-1	1 hr	0.5 hr	1.5 hr	0.5

#Contact hour for project refers to the involvement of students in the laboratory, discussion, etc.

10. List of Programme Compulsory Courses

Table 4. Programme Compulsory Courses for Materials Engineering

Sr. No	Course Name	LTP	Contact Hours	Credit
1	Mechanics of Solids	3-1-0	4	4
2	Data Structure and Algorithms	3-0-2	5	4
3	Materials at Equilibrium	3-1-0	4	4
4	Electronic Materials	3-0-0	3	3
5	Mechanical Behaviour of Materials	3-0-0	3	3
6	Phase Transformations	3-0-0	3	3
7	Iron and Steel Making	3-0-0	3	3
8	Materials Characterization	3-0-0	3	3
9	Computational Modelling of Materials	3-0-0	3	3
10	Materials Processing and Manufacturing	3-0-0	3	3
11	Materials for Energy Conversion and Storage	3-0-0	3	3
12	Extraction of Nonferrous Metals	3-0-0	3	3
13	Smart Materials	3-0-0	3	3
14	Electronic Materials Lab	0-0-3	3	1.5
15	Physical Metallurgy Lab	0-0-3	3	1.5
16	Materials Characterization Lab	0-0-2	2	1
17	Computational Modelling of Materials Lab	0-0-2	2	1
18	Materials Processing and Manufacturing Lab	0-0-3	3	1.5
19	Energy Materials Lab	0-0-3	3	1.5
			Total	**50**

11. Stream-wise Programme Elective Courses

Table 6. Stream-wise Programme Electives Courses

Stream	**SN**	**Courses**	**L-T_P**	**Credit**	**Course Level**
Structural Materials	1	Processing-Microstructure and Properties of Steels	3-0-0	3	400
	2	Degradation and Failure of Materials	3-0-0	3	400
	3	Composites	3-0-0	3	400
	4	Polymeric Materials and Processing	3-0-0	3	400
	5	Ceramics and Glass	3-0-2	4	400
	6	Casting and Solidification	3-0-0	3	600
	7	Metallurgy of Joining	3-0-0	3	600
	8	High Temperature Materials	3-0-0	3	700
	9	Digital Fabrication (Offered by ME)	3-0-0	3	300
	10	Smart Manufacturing (Offered by ME)	2-0-2	3	300
	11	Additive Manufacturing (Offered by ME)	3-0-0	3	600
	12	Computer Aided Design (Offered by ME)	3-0-2	4	400
	13	Design of Machine Elements (Offered by ME)	3-0-2	4	300
Functional Materials	1	Battery Materials	3-0-0	3	400
	2	3D Printing: Material Processing and Properties	3-0-0	3	400
	3	Lithium ion Batteries	2-0-2	3	400
	4	Surface Engineering	3-0-0	3	600

	5	Synthesis and Processing of Semiconductors and 2D materials	3-0-0	3	400
	6	Functional Ceramics	3-0-0	3	400
	7	Magnetism and Magnetic Materials	3-0-0	3	400
	8	Nanoscience (Offered by Chemistry)	3-0-0	3	400
	9	Biomaterials Engineering	3-0-0	3	400
	10	Cell-Material Interaction (BSBE)	3-0-0	3	400
	11	Tissue Engineering (BSBE)	3-0-0	3	400
	12	Interfacial Engineering in Soft Matter (CHE)	3-0-0	3	400
	13	Quantum Mechanics (PHY)	3-0-0	3	600
	14	Advanced Condensed Matter Physics (PHY)	3-0-0	3	700
	15	Energy Harvesting Technologies (PHY)	3-0-0	3	700
	16	Physics of Solar Cells (PHY)	3-0-0	3	700
Computational Materials Engineering	1	Computational Thermodynamics	2-0-2	3	400
	2	Modelling of Metallurgical Processes	3-0-0	3	700
	2	Machine Learning for Materials Design	2-0-2	3	700
	4	First-Principles Calculations	3-0-2	4	700
	5	Phase field modelling	3-0-0	3	700
	6	Industry 4.0: Applications in Metallurgical and Materials Engineering	2-0-0	2	700
	7	Introduction to Internet of Things (Offered by EE)	1-0-0	1	700
	8	Finite Element Methods (Offered by ME)	3-0-0	3	600
	9	Artificial Intelligence (CSE)	3-0-0	3	300
	10	Deep Learning (CSE)	3-0-3	4.5	400
	11	Optimization (Offered by MA)	3-0-0	3	400
Process Metallurgy	1	Mineral Beneficiation	3-0-0	3	400
	2	Kinetics of Metallurgical Processes	3-0-0	3	400
	3	Principles of Process Metallurgy	3-0-0	3	400
	4	Hydrometallurgy	3-0-0	3	400
	5	Electrometallurgy	3-0-0	3	400
	6	Secondary and Special Steelmaking	3-0-0	3	600
	7	Processing of Rare Earth and Radioactive Materials (CH)	3-0-0	3	400
	8	Computational Fluid Dynamics (Offered by CH)	3-0-2	4	700
Special Topics	1	Special Topics in Materials Engineering	3-0-0	3	400/600

Specialization to be proposed by the department

The students can obtain a Departmental Specialization after completing additional 20 credits beyond the regular B.Tech. program credit requirement. From the 20 credits, 8 credits must be taken from core areas of that specialization and 12 credits should be taken from the electives within that specialization. 4 elective credits (out of 12) may be taken as elective project, which will allow the student to pursue his/her B.Tech. project in the area of his/her specialization. Therefore, after proper planning, a student opting for specialization may earn 7 (4 specialization elective project + 3 regular B.Tech. project) credits for B.Tech. project. The specializations will enable the students to pursue their area of interest and will ensure depth in the curriculum.

Table 7. Specializations List

S. No.	Name of Specializations	Credit requirement

		Core	Elective
1	Structural Materials	8 credits	12 credits
2	Functional Materials	8 credits	12 credits
3	Computational Materials Engineering	8 credits	12 credits
4	Process Metallurgy	8 credits	12 credits

Table 8. Specialization concept notes

1	**Structural Materials** Structural materials encompass a wide variety of materials whose primary purpose is to support or transmit load. Structural materials are used in applications such as transportation (aircraft and automobiles), construction (buildings and roads), or in components used for body protection (helmets and body armor), energy production (turbine blades), or other smaller structures such as those used in microelectronics. Structural materials can be metallic, ceramic, polymeric or a composite. The objective of offering this specialization to encourage students to pursue emerging area of Materials design, processing, and structure-property correlation for advanced materials for lightweight structures subjected to severe environments such as high temperature, wear, high stress and strain rates, etc. to name a few. The advancement in the microstructural characterization has enabled investigation of materials properties at different length scales which played a key role in solving the sudden material failure issues in the industry domain. Apart from structural investigation, structural materials stream provides knowledge of correlating these microstructural features with the mechanical, physical and electronic properties of the material. This can be achieved by thorough understanding of different materials processing and manufacturing techniques at lab as well as industry scales. Therefore, the specialization will provide in-depth education required for designing advanced structural materials and processing conditions as per the demand of the respective industry to obtain the usable products in a cost-effective manner. Detailed curriculum for this specialization will be proposed later.
2	**Functional Materials** Functional materials represent an ever-growing set of advanced materials, whose properties e.g. shape, electrical conductivity, mechanical properties, color etc. could be tuned by an external stimulus - thermal, electrical, mechanical, light etc. These materials are characterized by one or multiple native properties of their own, e.g. ferroelectricity, thermoelectricity, piezoelectricity, magnetism, energy storage functions, magneto and electrostrictive materials and could be found in all classes of materials - ceramics, metals, polymers and organic molecules. Practically all modern-day applications ranging from computers, memory devices, displays, advanced sensors and MEMS based devices to batteries and shape memory alloys are a result of the advances in the functional properties of materials. With the ever-increasing demand for higher performing, more energy efficient and device miniaturization the functional properties of materials remains the most active areas of research not just in Materials Science but also cross disciplinary. With the advent of 5G and demand for IoT and AI based technologies and building towards a more sustainable world there is an ever-increasing demand for materials with hitherto unexplored novel functionalities. The specialization on "Functional Materials" is being designed to impart the students with different facets of the functional properties of materials and their real-world applications along with a strong emphasis on

	the basics of the underlying phenomena. The functional properties of materials are continuously evolving in a very dynamic world and hence demands a continuously evolving nature of the curricula. Owing to the importance of Functional Materials in today's world we would like to introduce a specialization on Functional Materials in our B.Tech program. A detailed curriculum will be proposed later.
3	**Computational Materials Engineering** Computational Modeling approaches provide insights into Materials aspects at atomic, micro, macro length scales and aid in better understanding of Materials and processes. Developments in the hardware front are making the computing power more affordable and developments in the theoretical approaches are broadening the capabilities of Modelling approaches. As a result, computational modeling is playing a key role in Materials design and discovery. The Computational Materials Engineering (CME) approach combines all available modelling techniques for improving existing metallurgical processes or properties of a structural material or a functional material. In this respect, the CME forms a horizontal for different specializations of Materials Engineering. Traditional science-based modeling techniques such as first-principles calculations, molecular dynamics, phase field methods, finite element methods, finite difference methods, Calphad methods, etc. have evolved to give results within acceptable accuracy of the experimental results. Recently, Materials Scientists started using data analysis-based techniques in Materials design and discovery. The emerging data-based techniques have potential to accelerate the Material Discovery and improve the Materials Processing. The objective of the CME is to combine the traditional science-based techniques with emerging data based techniques for improving Materials design and discovery. The CME concept is still in infancy and requires continuous efforts from all the stakeholders involved to bring it to the state-of-the-art stage. In this direction, we would like to start a B.Tech. program in Materials Engineering with a specialization in CME. Detailed curriculum for this specialization will be proposed later.
4	**Process Metallurgy** Process metallurgy is a specialization concerned with extracting metals from their ores, and the development, production, and use of metallic materials. Process metallurgy practitioners design complex metallurgical reactors using principles of physics, thermodynamics, reaction kinetics, and transport phenomena. Designing of such metallurgical reactors also requires skills in high-temperature experimentation and computer simulation techniques. In the years to come, extraction of metal will be extremely difficult due to the decreasing ore grade and strict laws to regulate the environmental impact of metallurgical emissions. In fact, the future trend in extractive metallurgy is to recover metals, even in parts-per-million levels, from wastes such as used catalysts and more importantly the ever-increasing volume of electronic wastes. A process metallurgy expert acquires multifaceted skills and hence the careers of process metallurgists may not be restricted to steel, copper, or aluminum plants. In fact, they can also design materials processing operations such as casting, powder metallurgy, and heat treatment. Semiconductor and waste processing facilities could also provide job openings. Experts in a computer simulation with a sound knowledge of transport phenomena have job opportunities spanning across other engineering branches too. Detailed curriculum for this specialization will be proposed later.

12. Curriculum of B.Tech. Materials Engineering

Table 9. Curriculum of B.Tech. in Materials Engineering

Cat	*Course*	*LTP*	*CH*	*NC*	*GC*	*Cat*	*Course*	*LTP*	*CH*	*NC*	*GC*
	I Semester						**II Semester**				
IE	Engineering Mechanics	2-1-0	3	-	3	IE	Introduction to Electrical Engineering	3-0-2	5	-	4
IS	Chemistry	3-0-0	3	-	3	IE	Introduction to Computer Science	3-0-2	5	-	4
IS	Physics	3-0-0	3	-	3	IE	Introduction to Bioengineering	3-0-2	5	-	4
IS	Chemistry Lab	0-0-2	2	-	1						
IS	Physics Lab	0-0-2	2	-	1						
IS	Mathematics I	3-1-0	4	-	4	IS	Mathematics II	3-1-0	4	-	4
IE	Engineering Visualization	0-0-2	2	-	1	IE	Engineering Realization	0-0-2	2	-	1
NE	Engineering Design I	0-0-2	2	1	-	NE	Engineering Design II	0-0-2	2	1	-
NH	Communication Skill I	0-0-2	2	1	-	NH	Communication Skill II	0-0-2	2	1	-
NH	Social Connect and responsibilities I	0-0-1	1	0.5	-	NH	Social Connect and responsibilities II	0-0-1	1	0.5	-
NH	Performing Arts I /Sports I	0-0-1	1	0.5	-	NH	Performing Arts II/Sports II	0-0-1	1	0.5	-
	Total	**11-2-12**	**25**	**3**	**16**		**Total**	**12-1-14**	**27**	**3**	**17**
	III Semester						**IV Semester**				
LS	Scientific Computations	3-1-0	4	-	4	IE	Materials Science & Engineering Fractal 1: Physical Metallurgy Fractal 2: Polymers Fractal 3: Corrosion	3 × 1-0-0	3	-	3
IE	Thermodynamics	3-1-0	4	-	4	PC	Data Structure and Algorithm	3-0-2	5		4
PC	Mechanics of Solids	3-1-0	4	-	4	PC	Materials at Equilibrium	3-1-0	4		4
IE	Introduction to Machine Learning	3-0-2	5	-	4	PC	Materials for Energy Conversion and Storage	3-0-0	3		3
LS	Condensed Matter Physics	3-0-0	3	-	3	IE	Signals and Systems	3-1-0	4	-	4
NE	Intro. To Profession	0-0-2	2	1		IH	Humanities I	3-0-0	3	-	3
	Total	**15-3-4**	**22**	**1**	**19**		**Total**	**15-1-4**	**23**	**-**	**21**
	V Semester						**VI Semester**				
PC	Electronic Materials	3-0-0	3		3	PC	Computational Modelling of Materials	3-0-0	3		3
PC	Mechanical Behavior of Materials	3-0-0	3		3	PC	Materials Processing and Manufacturing	3-0-0	3		3
PC	Phase Transformations	3-0-0	3		3	PC	Extraction of Nonferrous Metals	3-0-0	3		3
PC	Materials Characterization	3-0-0	3		3	PC	Iron and Steel Making	3-0-0	3		3
PC	Electronic Materials Lab	0-0-3	3		1.5	PC	Smart Materials	3-0-0	3		3
PC	Physical Metallurgy Lab	0-0-3	3		1.5	PC	Computational Modelling of Materials Lab	0-0-2	2		1
PC	Energy Materials Lab	0-0-3	3		1.5	PC	Materials Processing and Manufacturing Lab	0-0-3	3		1.5
PC	Materials Characterization Lab	0-0-2	2		1						
IH	Humanities II	3-0-0	3	-	3	PE	Programme/Open Elective	3-0-0	3		3

NH	Professional Ethics I	0-1-0		1	-	NH	Professional Ethics II	0-1-0		1	-
	Total	**15-1-11**	**26**	**1**	**20.5**		**Total**	**18-1-5**	**24**	**1**	**20.5**
	VII Semester						**VIII Semester**				
PP	B. Tech. Project	0-0-6	6	-	3	IH	Humanities IV	3-0-0	3	-	3
PE/OE	Programme/Open Electives	10-0-0	10	-	10	PE/OE	Programme/Open Electives	15-0-0	15	-	15
IH	Humanities III	3-0-0	3	-	3						
IS	Environmental Science	2-0-0	2	-	2						
	Total	**15-0-6**	**21**	**-**	**18**		**Total**	**18-0-0**	**18**	**-**	**18**
									Total of graded and Non-Graded Credit	**9**	**150**
									Non-Graded Design Credits	**6**	**-**
									Grand Total	**15**	**165**

14. Detailed Course Content
of
Programme Compulsory Courses

14. Detailed Course Content

Program Compulsory Courses

Course Title	**Materials at Equilibrium**	Number	MTL2XX0
Department	Metallurgical and Materials Engineering	L–T–P [C]	3–1–0 [4]
Offered for	B.Tech. (MT)	Type	Program Compulsory (PC)
Pre-requisite			

Objectives

1. Provide a basis for describing and understanding the stability of various forms of matter.
2. Provide a basis for predicting the properties of an equilibrated system as a function of its content and characteristics.

Learning Outcomes

3. Establish the conditions for stability of a material and derive its properties.
4. Control the evolution of microstructures with respect to different parameters.

Course Content

Phase equilibria [8 lectures]: Criteria for equilibrium, Maxwell relations, One component system, variation of free energy with temperature and pressure, equilibrium between condensed phases (solid-liquid, solid-solid), equilibrium between a vapor phase and a condensed phase

Behavior of gases and liquids [6 lectures]: Ideal and non-ideal gases, activity, fugacity, Partial molar quantities, Raoult's law and Henry's law

Solution thermodynamics [8 lectures]: Gibbs Duhem equation, Gibbs free energy of formation of a solution (ideal, non-ideal), configurational entropy, Regular solution model, statistical model of solutions

Gibbs Free Energy Composition and Phase Diagrams (binary) [8 lectures]: Gibbs free energy and thermodynamic activity, standard state, criterion for phase stability, Gibbs free energy composition diagrams, activity-composition diagrams, Application of regular solution model to phase diagrams

Reactions involving gases [6 lectures]: Reaction equilibrium a gas mixture and the equilibrium constant, effect of pressure and temperature on the equilibrium constant

Reactions involving a condensed phase and a gas phase [6 lectures]: Standard Gibbs free energy variation with temperature, Ellingham diagrams, effect of phase transformations

Text Books

1. Gaskell, D.R. and Laughlin, D.E., (2018), *Introduction to Thermodynamics of Materials*, 6th Edition CRC Press

References

1. Hillert, M., (2008), *Phase Equilibria, Phase Diagrams and Phase Transformations Their Thermodynamic Basis,* Second edition, Cambridge University Press
2. Dehoff, R., (2006), Thermodynamics in Materials Science, 2nd Edition, CRC Press

Online Course Material

3. Ceder, G., and Anton Van der Ven, A., *3.20 Materials at Equilibrium (SMA 5111).* Fall 2003. Massachusetts Institute of Technology: MIT OpenCourseWare, https://ocw.mit.edu. License: Creative Commons BY-NC-SA.

Title	**Electronic Materials**	Number	MTL3XX0
Department	Metallurgical & Materials Engineering	L-T-P [C]	3-0-0 [3]
Offered for	B.Tech. (MT)	Type	Program Compulsory (PC)
Prerequisite			

Objectives

The Instructor will:

1. Introduce and discuss about different electronic materials, devices and processes.
2. Motivate students to learn more about advanced electronic devices and technologies

Learning Outcomes

The students are expected to gain:

1. Basics of electronic structures of different materials.
2. Understanding the physics of electronic materials and devices.

Contents

Physics of Electronic Materials [12 lectures]: Introduction, electronic structures, basics of quantum mechanics, energy band theory, Free Electron Bands, Band structure in metals and semiconductors, Development of band gap, Fermi energy levels, Fermi surface, density of states and charge transport

Semiconductor Materials [8 lectures]: Intrinsic Semiconductors: carrier concentration, mobility, temperature dependence; Extrinsic semiconductors: Dopant types and materials, Donors and Acceptors, temperature dependence of number of carriers, Effective mass, Compound Semiconductors

Electronic devices [4 lectures]: p-n junctions, metal-semiconductor contacts, metal-insulator-semiconductor capacitors, bipolar junction transistors, junction field-effect transistors, MOSFETs and logics.

Other electronic materials [8 lectures]: III-V and II-VI semiconductors, metal oxides, organics, carbon nanotubes and 2D semiconductors.

Optical properties of materials & Applications [10 lectures]: Optical properties of materials: optical constants, index of refraction, absorbance, reflectivity, transmissivity, Hagen-Rubens relation; atomistic theory, harmonic oscillators. Quantum mechanical treatment of the optical properties: absorption, optical spectra of materials. Applications of the optical properties of materials: Kramers-Kronig analysis, reflection spectra, Lasers, light-emitting diodes, integrated optoelectronics, waveguides, modulators, switches.

Textbook

1. Streetman,B.G., Banerjee,S. (2001) *Solid state electronic devices*, Prentice-Hall of India.
2. R.E. Hummel, Electronic Properties of Materials, Springer-Verlag, 3rd edition, 2001.

Reference Books

1. Sze,S. M., Ng,K.K. (2006) *Physics of semiconductor devices*, John Wiley & sons.

Online Course Material

1. Parasuraman Swaminathan, Electronic materials, devices and fabrication, NPTEL Course Material, Department of Metallurgical and Materials Engineering, IIT Madras, https://nptel.ac.in/courses/113/106/113106062/

Title	**Mechanical Behavior of Materials**	**Number**	MTL3XX0
Department	Metallurgical and Materials Engineering	L-T-P [C]	3–0–0 [3]
Offered for	B.Tech. (MT)	Type	Program Compulsory (PC)
Pre-requisite	-		

Objectives

1. To provide background on the mechanisms of deformation in engineering materials, and on the evolution of material microstructure when subjected to mechanical stress during materials processing and engineering applications

Learning Outcomes

1. Ability to design materials with improved mechanical properties and identify failure mechanisms in materials for engineering applications
2. To measure important mechanical properties and correlate with the microstructure

Contents

Continuum Theory of Deformation [2 lectures]: Stress and strain tensor, Generalized Hooke's Law, Yield Criteria

Lattice Defects [6 lectures]: Vacancies and interstitials, dislocations: Edge and Screw, stress fields around edge and screw dislocations, strain energy of dislocations, force on dislocation, dislocation-dislocation interaction

Plastic Deformation [8 lectures]: Slip in a perfect lattice, slip by dislocation movement, Critical Resolved Shear stress, cross-slip and climb, deformation of single crystals, dislocations in different crystal structures, twinning

Strengthening Mechanisms [8 lectures]: Grain boundary strengthening, strain hardening, solid-solution hardening, age-hardening, martensite strengthening

Fracture and Toughening Mechanisms [6 lectures]: theoretical fracture strength and Griffith's Law, modes of fracture, fracture toughness, brittle and ductile fracture, toughening mechanisms in metals, ceramics, and polymers

Fatigue and Creep [6 lectures]: Introduction to fatigue, stress and strain-life approach, cyclic stress-strain curve, fatigue crack propagation, high temperature deformation, fatigue-creep interaction

Deformation of Polymers [6 lectures]: Elastic deformation in semi crystalline polymers, nonlinear elastic deformation, shear banding and crazing, stress-strain curves

Text Books

1. Courtney, T. H., (2005), *Mechanical Behaviour of Materials*, 2nd Edition, Waveland Press Inc.
2. Dieter, G.E., (1989), *Mechanical Metallurgy*, SI Metric Edition, McGraw-Hill Book Company.
3. Shetty, M. N., (2013), *Dislocations and Mechanical Behavior of Materials*, Prentice Hall India Learning Private Limited

Reference Books

1. Hertzberg, R.W., (2013), *Deformation and Fracture Mechanics of Engineering Materials,* 5th Edition, Wiley
2. McClintock,F.A., and Argon,A.S., (1966), *Mechanical Behavior of Materials*, Addison-Wesley.

Online Course Material

1. Van Vilet, K., *3.22* Mechanical Behavior of Materials, Spring 2008. Massachusetts Institute of Technology: MIT OpenCourseWare, https://ocw.mit.edu/courses/materials-science-and-engineering/3-22-mechanical-behavior-of-materials-spring-2008/

Title	**Phase Transformations**	Number	MTL3XX0
Department	Metallurgical and Materials Engineering	L-T-P [C]	3-0-0 [3]
Offered for	B.Tech. (MT)	Type	Program Compulsory (PC)
Prerequisite	-		

Objectives

The Instructor will:

1. Explain the importance of phase transformations in solid and liquid state and their applications through experimentation

Learning Outcomes

The students are expected to have the ability to:

1. Understand the microstructure evolution during the phase transformation
2. Understand the variation of properties with the microstructure evolution towards developing heat treatment-microstructure-property relationship

Contents

Thermodynamics and Kinetics [6 Lectures]: free energy, order of transformation, driving force, homogeneous and heterogeneous nucleation, growth kinetics, coarsening, precipitation
Phase Transformation during Solidification [4 Lectures]: Eutectic and Peritectic Transformation
Heat-Treatment of Ferrous and Nonferrous Metals [6 Lectures]: Annealing, Normalizing, Hardening and Tempering, Precipitation Hardening
Interfaces [4 Lectures]: atomic mechanisms of diffusion, activation energy, interfacial free energy, types of interface (coherent, semi-coherent and incoherent interfaces), interface migration
Diffusional Phase Transformations in Solids [14 Lectures]: austenite, transformation of austenite, TTT diagram, eutectoid transformation, pearlite and bainite transformation, order-disorder transformation, precipitation hardening, spinodal decomposition and massive transformation
Diffusionless Phase Transformations in Solids [8 Lectures]: Martensite transformation: characteristics and nature, morphology, crystallography, theory of nucleation and growth, and pre-martensite phenomena, martensitic transformation in steel. Martensite in non-Ferrous systems-thermoelastic martensite and shape memory effect.

Textbooks

1. Raghavan,V., (1987), *Solid State Phase Transformations*, 1st edition, Prentice Hall India,.
2. Porter,D.A., Easterling,K.E., and Sherif,M.Y., (2009), *Phase Transformation in Metals and Alloys*, 3rd edition, CRC Press,
3. Abbaschian,R., Abbaschian,L., and Reed-Hill,R.E., (2009), *Physical Metallurgy Principles*, 4th edition, Cengate Learning,
4. Rajan,T.V., Sharma,C.P., and Sharma,A., (2011), *Heat Treatment: Principles and Techniques*, 2nd edition, Prentice Hall India

Reference Books

1. Khachaturyan,A.G., *Theory of Structural Transformations in Solids*, 1st edition, Dover publications, 2008.
2. Avner, S.H., *Introduction to Physical Metallurgy*, 2nd edition, McGraw Hill Education, 2017

Online Course Material

1. Gururajan,M.P., *Phase Transformations and Heat Treatment*, NPTEL Course Material, Department of Metallurgical Engineering and Materials Science, Indian Institute of Technology Bombay, http://nptel.ac.in/courses/113101003/

Title	**Iron and Steel Making**	**Number**	MTL3XX0
Department	Metallurgical and Materials Engineering	L-T-P [C]	3–0–0 [3]
Offered for	B.Tech. (MT)	Type	Program Compulsory (PC)
Pre-requisite			

Objectives

1. Explain principles of thermodynamics and process metallurgy involved in traditional and advanced iron and steel making processes

Learning Outcomes

1. Understand the basics of process metallurgy involved in iron and steel making processes
2. Be cognizant of advanced iron making and steel making processes in industries

Contents

Introduction to Iron Making and steelmaking [10 lectures]: concept of integrated steel plant, different types of ironmaking processes, agglomeration techniques, basic thermodynamics, kinetics and transport phenomena in iron and steelmaking processes

Transport Processes in Blast Furnace [8 lectures]: temperature, burden distribution, and aerodynamics of blast furnace, physical and chemical; processes in upper and lower zones of blast furnace

Alternative Iron Making Processes [8 lectures]: direct reduction process-DRI, HBI, smelting reduction process-Corex, Romelt, HiSmelt, Finex etc.

Modern Steelmaking Processes [10 lectures]: basic oxygen furnace steelmaking, Electric Arc Furnace, and induction furnace steelmaking

Secondary Steelmaking Processes [6 lectures]: deoxidation, ladle and tundish Metallurgy, continuous casting, casting defects

Text Books

1. Ghosh,A., and Chatterji,A., (2008), *Ironmaking and Steelmaking: Theory and Practice*, Prentice-Hall (India)
2. Turkdogan,E.T., (1997), *A Text Book of Steelmaking*, Academic Press, London Shetty, M. N., (2013), *Dislocations and Mechanical Behavior of Materials*, Prentice Hall India Learning Private Limited
3. Chatterjee,A., (1994), *Beyond the Blast Furnace,* CRC Press

Self-Learning Materials

1. Ghosh,A., (2000), *Secondary Steelmaking*, CRC Press, Boca Raton

Online Course Material

1. Muzumdar,D., and Koria,S.C., Steelmaking, NPTEL Course Material, Department of Material Science and Engineering, Indian Institute of Technology Kanpur, http://nptel.ac.in/courses/113104013/

2. Gupta,G.S., Iron Making, NPTEL Course Material, Department of Materials Engineering, Indian Institute of Science Bangalore, http://nptel.ac.in/courses/113108079/

Title	**Materials Characterization**	Number	MTL3XX0
Department	Metallurgical and Materials Engineering	L-T-P [C]	3-0-0 [3]
Offered for	B.Tech. Program	Type	Program Compulsory (PC)
Prerequisite	-		

Objectives

The Instructor will:

1. Explain the principle of the instruments and methods for characterizing different materials and their properties

Learning Outcomes

The students are expected to have the ability to:

1. Know the basic working principles of various instruments and use the same while performing experiments
2. Choose the characterization methods based on the requirement and performance

Contents

Light Optical Microscopy [6 Lectures]: polarization microscopy, phase contrast microscopy, DIC Microscopy and confocal microscopy

Diffraction Techniques [6 Lectures]: X-Ray Diffraction, Electron Diffraction

Electron Microscopies [8 Lectures]: Scanning electron microscopy (SEM) & transmission electron microscopy (TEM)

Scanning Probe Microscopy [6 Lectures]: scanning tunnelling microscopy (STM) & atomic force microscopy (AFM)

Spectroscopic Characterization [6 Lectures]: UV-VIS-NIR, optical emission, XRF, FTIR, and Raman spectroscopy

Surface Characterization [6 Lectures]: Auger electron spectroscopy, X-ray photoelectron spectroscopy

Thermal Analysis [4 Lectures]: thermal mechanical analysis (TMA), differential scanning calorimetry (DSC), thermal gravimetric analysis (TGA), differential thermal analysis (DTA)

Textbook

1. Zhang,S., Li,L. and Kumar,A., (2008), *Materials Characterization Techniques*, , CRC Press
2. Cullity, B.D., Stock, S.R., (2014), *Elements of X-Ray Diffraction*, 3rd Edition, Pearson Education Limited

Reference Books

1. Evans,C., Brundle.R. and Wilson, (1992), *Encyclopaedia of Materials Characterization: Surfaces, Interfaces, Thin Films (Materials Characterization Series),* Butterworth-Heinemann,
2. Kaufmann,E.N., (2012), *Characterization of Materials, 3 Volume Set, 2nd Edition,* Wiley
3. Egerton,R., (2016), *Physical Principles of Electron Microscopy: An Introduction to TEM, SEM and AEM,* 2nd ed. Springer
4. Hwang,J-Y, Monteiro,S.N., Bai,C., Carpenter,J.S., Cai,M., Firrao,D., Kim,B-G., (2012), *Characterization of Minerals, Metals and Materials,* Wiley

Online Course Materials

1. Shankaran,S., *Materials Characterization*, NPTEL Course Material, Department of Metallurgical & Materials Engineering, Indian Institute of Technology Madras, http://nptel.ac.in/courses/113106034/
2. Alagarsamy,P., *Characterization of Materials*, NPTEL Course Material, Department of Physics, Indian Institute of Technology, Guwahati, http://nptel.ac.in/courses/115103030/
3. Biswas,K. and Gurao,N.P., NPTEL Course Material, *Advanced Characterization Techniques*, Department of Materials Science and Engineering, Indian Institute of Technology, Kanpur, http://nptel.ac.in/courses/113104004/

4. Barbastathis,G., Smith,H. and Berggren,K., *Submicrometer and Nanometer Technology*. Spring 2006. Massachusetts Institute of Technology: MIT OpenCourseWare, https://ocw.mit.edu. License: Creative Commons BY-NC-SA

Course Title	**Computational Modelling of Materials**	Number	MTL3XX0
Department	Metallurgical and Materials Engineering	L–T–P [C]	3–0–0 [3]
Offered for	B.Tech. (MT)	Type	Program Compulsory (PC)
Pre-requisite	-		

Objectives

1. Introduce modelling in the context of Materials Engineering
2. Introduce the theory behind the first-principles calculations
3. Create awareness of the opportunities and limitations of Molecular dynamics simulations

Learning Outcomes

1. Ability to formulate model and solve initial value and boundary value problems
2. Understand the working principles of the first-principles calculations and molecular dynamics
3. Simulate materials using the first-principles calculations and molecular dynamics

Course Content

Introduction to Modelling in Materials [14 lectures]: Types of linear PDEs, Modelling Diffusion type problems-Derivation of Heat Equation, Boundary Conditions, Separation of Variables, Infinite diffusion problem by integral transform, 1-D wave equation-Boundary conditions, Steady state problems, Numerical solutions-Finite Difference Method

Molecular Dynamics [14 lectures]: Molecular dynamics: Applications, basic concepts, potential energy functions, integration algorithms, temperature control, boundary conditions, neighbour lists, initialization, equilibrium, geometry optimization, static properties, dynamical properties, analysis of results, visualisation

First Principle Calculations-2 [14 lectures]: Notation & Mathematics: Dirac notation, Fourier transformation, Function and functional, Quantum mechanics: Schrodinger equation, Born-Oppenheimer approximation, Mean-field methods, Kohn-Sham method: Density functional theory, Hohenberg-Kohn theorems, Kohn-Sham method, Exchange correlation functional, Structure relaxation, Smearing methods, Electronic band structure, Fermi-Dirac distribution

Text Books

1. Rappaz, M., Bellet, M., Deville, M., *Numerical Modeling in Materials Science and Engineering,* Springer Science & Business Media, 2010.
2. Frenkel, D., Smit, B., *Understanding Molecular Simulation: From Algorithms to Applications*, 2nd Edition, Elsevier 2001.
3. Lee, J. G., *Computational Materials Science: An Introduction,* 2nd edition, CRC Press, 2016.

References

1. Sholl, D. S., and Steckel, J. A., *Density Functional Theory: A Practical Introduction*, 1st Edition, Wiley, 2009.
2. Parr, R.G., and Yang, W., *Density-Functional Theory of Atoms and Molecules*, 1st Edition, Oxford Science Publications, 1994.
3. Lesar, R., *Introduction to Compuational Materials Science*

Online Course Material

1. Ceder, G. and Marzari, N., 3.320 *Atomistic Computer Modeling of Materials* (SMA 5107). Spring 2005. Massachusetts Institute of Technology: MIT OpenCourseWare, https://ocw.mit.edu. License: Creative Commons BY-NC-SA

Title	**Materials Processing and Manufacturing**	Number	MTL3XX0
Department	Metallurgical and Materials Engineering	L-T-P [C]	3-0-0 [3]
Offered for	B.Tech. (MT)	Type	Program Compulsory (PC)
Prerequisite	-		

Objectives

The Instructor will:

1. Introduce the various industrially relevant materials processing and manufacturing techniques

Learning Outcomes

The students are expected to have the ability to:

1. Understand the microstructure evolution during the phase transformation
2. Understand the variation of properties with the microstructure evolution towards developing heat treatment-microstructure-property relationship

Contents

Bulk Processing of Materials [14 lectures]: Thermodynamics of solidification, pure metal solidification, Alloy Solidification: Constitutional undercooling, dendritic growth. Structure of casting and ingots, Types of casting, Heat transfer, Joining- Welding and its types, Brazing and Soldering, Microstructural mechanisms associated with metals joining operations, Powder Metallurgy, Additive manufacturing of metals.

Bulk Metal Forming Techniques [14 lectures]: Rolling- Analysis of rolling, hot and cold rolling, microstructural changes during rolling, rolling defects, rolling mill; Forging- open and closed die forging; lubricated and non-lubricated extrusion.; wire-drawing- die design and materials, optimal die angle, sheet metal forming- bending, stretching and deep drawing, anisotropy parameter, forming limit diagram, microstructural changes

Processing of Ceramics and Polymers [14 lectures]: Ceramic processing: Powder preparations, solid state reactions, Sintering, Colloidal processing, Co-precipitation method, Sol-Gel process, Porous ceramics and ceramic fibres. Polymer processing: Mixing and compounding, extrusion process, moulding processes, thermoforming, roller and blade coating, textile/fiber spinning technology, Additive manufacturing of polymers and ceramics.

Textbooks

1. Flemings,M.C., (1974), *Solidification Processing*, Mcgraw-Hill Book Company
2. Dieter,G.E., (1986), *Mechanical Metallurgy*, 3rd Edition, McGraw Hill Book Company
3. El-Kareh, B., Fundamentals of semiconductor processing technology, 3rd Edition, 1995, Springer US

Reference Books

1. Chalmers,B., (1967), *Principles of Solidification*, Wiley
2. Stefanescu,D.M., (2015), Science *and Engineering of Casting Solidification*, 3rd edition, Springer
3. Hosford, W.F., Caddell, R.M., (2014), Metal Forming: Mechanics and Metallurgy, 4th Edition, Cambridge University Press

Online Course Material

1. Shekhar, S., Fundamentals of Materials Processing (Part–1), NPTEL Course Material, Department of Materials Science and Engineering, Indian Institute of Technology Kanpur, https://nptel.ac.in/courses/113/104/113104073/

2. Shekhar, S., Fundamentals of Materials Processing (Part–2), NPTEL Course Material, Department of Materials Science and Engineering, Indian Institute of Technology Kanpur, https://nptel.ac.in/courses/113/104/113104075/

Title	**Materials for Energy Conversion and Storage**	Number	MTL4XX0
Department	Metallurgical and Materials Engineering	L-T-P [C]	3-0-0 [3]
Offered for	B.Tech. (MT)	Type	Program Elective (PE)
Prerequisite	-		

Objectives

The course outlines in a nutshell:

1. Different modes of energy conversion and storage
2. Development of materials with time and different applications, scale, energy and power density

Learning Outcomes

The students are expected to gain knowledge on:

1. Structure processing property performance relationship of the energy materials developed over time.
2. Different modes of energy conversion and storage with respect to scale, cost, energy and power density

Contents

Introduction [2 lectures]: Classification, Overview of Electrical (static), Electrochemical, Thermal, Mechanical, Photo-electrochemical (includes biological) energy storage.

Electrical (static) [4 lectures]: Capacitor, Leyden Jar, corona discharge, dielectrics.

Electrochemical conversion and storage [14 lectures]: Introduction to Electrolytic capacitor, Electrochemical cell (Battery), Supercapacitor, primary and secondary batteries, Li-ion battery, fuel cells.

Photo-electrochemical conversion [4 lectures]: Photo-electric effect, artificial photo synthesis, semiconductor based solar cells, dye-synthesized solar cells.

Thermal conversion and storage [8 lectures]: Solar thermal energy conversion, sterling engines, Molten salt technology, eutectic mixtures, Phase-change materials, thermoelectric materials.

Mechanical storage [6 lectures]: Pumped storage, gravity batteries, Compressing air storage, flywheels.

Carbon Materials for Energy conversion and storage [4 lectures]: Hybridization and carbon allotropes overview, Synthesis and characterization of carbon allotropes, Functionalization of carbon materials, Carbon nanomaterials for energy conversion and storage.

Textbook

1. Cheong K.Y., Impellizzeri,G and Fraga,M.A., (2018), *Emerging Materials for Energy Conversion and Storage* 1st Edition, Elsevier

Reference Book

1. Rosen, M.A., (2012) *Energy Storage*, Nova

Online Course Materials

1. Prof. Bazant M., MITopencourseware: Electrochemical Energy Systems, MIT Course Number 10.626 / 10.426, https://ocw.mit.edu/courses/chemical-engineering/10-626-electrochemical-energy-systems-spring-2014/
2. Prof. Pal K., Selection Of Nanomaterials For Energy Harvesting And Storage Application, NPTEL Course Material, Mechanical Engineering, Indian Institute of Technology Roorkee, https://nptel.ac.in/courses/112/107/112107283/

Title	**Extraction of Nonferrous Metals**	**Number**	MTL3XX0
Department	Metallurgical and Materials Engineering	L-T-P [C]	3–0–0 [3]
Offered for	B.Tech. (MT)	Type	Program Compulsory (PC)
Pre-requisite	-		

Objectives

Explain principles of thermodynamics and process metallurgy involved in traditional and advanced processes of nonferrous metal extraction

Learning Outcomes

1. Understand the basics of extractive metallurgy involved in nonferrous metal extraction processes

Contents

Early developments in metal extraction [2 lectures]: Nonferrous metals in Indian history, uses of nonferrous metals, Sources of nonferrous metals

Principles of metals extraction [4 lectures]: Thermodynamic principles, homogeneous and heterogeneous reactions, Ellingham diagram, kinetic principles, principles of electro-chemistry

General methods of extraction [10 lectures]: Pyrometallurgy – calcination, roasting and smelting, Hydrometallurgy – leaching, solvent extraction, ion exchange, precipitation, and electrometallurgy – electrolysis and electro-refining)

General methods of refining [4 lectures]: Basic approaches, preparation of pure compounds, purification of crude metal produced in bulk

Extraction of metals from oxide sources [6 lectures]: Basic approaches and special features of specific extraction processes, extraction of metals such as magnesium, aluminum, tin and ferro-alloying elements, production of ferro alloys.

Extraction of metals from Sulphide Ores [6 lectures]: Pyro-metallurgy and hydrometallurgy of sulphides, production of metals such as copper, lead, zinc, nickel etc.

Extraction of metals from Halides [6 lectures]: Extraction of metals from halides: Production of halides and refining methods, Methods of extraction of metals such as titanium, rare earths, uranium, thorium, plutonium, beryllium, zirconium etc.

Production of precious metals [2 lectures]: Methods applied for gold, silver and Pt group of metals

Waste Utilization [2 lectures]: Secondary metals and utilization of wastes, Energy and environmental issues in nonferrous metals extraction

Text Books

1. Ray, H.S., Sridhar, R. and Abraham, K.P. Extraction of nonferrous metals, Affiliated East West Press Pvt Ltd., New Delhi (2007)
2. Dennis, W.H., Extractive Metallurgy, Philosophical Library, New York (1965)

Self-Learning Materials

1. Ray, H.S., and Ghosh, A., Principles of extractive metallurgy, Wiley Eastern Ltd., New Delhi, 1991

Online Course Material

1. Ray, H.S., Non-ferrous Extractive Metallurgy, NPTEL Course Material, Department of Materials and Metallurgical Engineering, Indian Institute of Technology Kharagpur, https://nptel.ac.in/courses/113/105/113105021/

Title	**Smart Materials**	Number	MTL4XX0
Department	Metallurgical and Materials Engineering	L-T-P [C]	3-0-0 [3]
Offered for	B.Tech. Materials Engineering	Type	Compulsory
Prerequisite	Nil		

Objectives

The Instructor will:

1. Introduce the family of smart materials along with their mechanisms, design and applications
2. Provide appreciation to utilize smart materials in context of smart engineering structure

Learning Outcomes

The students are expected to gain:

1. Basic understanding of intelligent materials and their utilization
2. Methodology of newer materials development towards specific applications

Contents

Introduction [6 lectures]: Basic definitions, classification of smart materials, modification of material structures, stimuli for reversible shape and structural transformation

Shape Memory Alloys (SMA) [8 Lectures]: Shape memory and superelasticity effects, Microstructural mechanisms, Range of SMA, phases and crystal structure, Processing (training), bonding and joining, High temperature SMA, Magnetic SMA, Giant magnetostrictive material, Thin films, Applications

Polymeric Smart Materials [14 lectures]: Functionally graded polymer blend, Smart performances; Electro-conductive polymers, Electro-chromatic Sol-Gel, Smart drug delivery systems, Bio-medical sensing, Self-healing materials, Nanoparticles, Porous particles, Smart widows, Flip-chip under-fill, Magneto-rheological fluids, Thermo-responsive polymers, Information materials and adaptive architecture, Application in forensic science

Ceramic Smart Materials [6 lectures]: Piezoelectric and electrostrictive ceramics, Non-contact ultrasonic material testing and analysis, Hydrothermal synthesis of smart ceramics, Intelligent control of phase assemblage, crystal size and morphology

Smart Composites [4 lectures]: Design and characterization of magnetostrictive composites, Carbon nanomaterials based yarns and nanocomposites, Structural health monitoring and self-healing, Active fiber composites

Smart Textiles [2 lectures]: Smart textile for medicine and health care, Textile based electronic components

Integration of Smart Materials and Smart Structures [2 lectures]: Varying smart materials and multifunctions, Biotelemetry study, Structure design concepts, Applications

Laboratory Experiments

NA

Textbook

1. Schwartz M. (Ed.) (2009) *Smart Materials*, CRC Press, Taylor and Francis Group
2. Hou X. (Ed.) (2016), Design, Fabrication, Properties and Applications of Smart and Advanced Materials, CRC Press
3. Elhajjar et al. (Eds.) (2014) Smart Composites Mechanics and Design, LLC, Taylor and Francis Group

Reference Books

1. Guardia, M., Esteve-Turrillas F.A. (Eds.) (2019) Handbook of Smart Materials in Analytical Chemistry, Vol. 1, Wiley

Online Course Material

1. Bhattacharya B, Smart Materials and Intelligent System Design (Video); IIT Kanpur, 2018, https://nptel.ac.in/courses/112104251/#

2. Bhat K.N. et al., Micro and Smart Systems, IISc Bangalore. NPTEL 2012, https://nptel.ac.in/courses/112108092/

Title	**Electronic Materials Lab**	Number	MTL3XX0
Department	Metallurgical & Materials Engineering	L-T-P [C]	0-0-3 [1.5]
Offered for	B.Tech. (MT)	Type	Program Compulsory (PC)
Prerequisite			

Objectives

The objective of the course is to introduce the students to different types of electrical and electronic property characterization and instrumentation.

Learning Outcomes

Upon successful completion of the course students will get a first-hand knowledge of device fabrication and then measure and analyse the functional properties of the materials.

Laboratory Experiments

1. Impedance Spectroscopy: Impedance Measurements as a function of temperature
2. Measurement of Dielectric and Ferroelectric properties of Materials
3. Piezoelectric Effect: Measurement of piezoelectric constants
4. Preparation of structures using photolithography
5. Deposition of metallic electrodes using thermal evaporation method
6. Semiconducting thin films using solution/printing processes
7. Measuring electrical resistance and sheet resistance of semiconductors
8. Effect of temperature on the electrical conductivity of semiconductors
9. Electrical characterization of p-n junction diodes
10. Magnetic Measurements: M-H hysteresis, M vs T measurement
11. Optical Property measurements

Textbook

Specific Laboratory protocols and handouts will be made for different experiments.

Title	**Physical Metallurgy Lab**	**Number**	MTL3XX0
Department	Metallurgical and Materials Engineering	L-T-P [C]	0–0–3 [1.5]
Offered for	B.Tech. (MT)	Type	Program Compulsory (PC)
Pre-requisite	-		

Objectives

To introduce the students to different types of phase transformations in solid and liquid state experiments and to provide hands-on training on various mechanical testing equipment to measure mechanical properties of materials.

Learning Outcomes

The students are expected to have the ability to

1. Apply the knowledge of phase transformation to understand microstructure and mechanical property evolution in materials
2. Measure mechanical properties of materials

Laboratory Experiments

1. Uniaxial monotonic stress-strain response of metals, ceramics, and polymers
2. Hardness via spherical and Vickers indentation and correlation with yield strength
3. Effects of annealing, normalizing, and hardening heat treatments on microstructure and mechanical properties of steels
4. The effects of grain size on yield strength
5. Effects of cold working and subsequent annealing on microstructure and mechanical properties
6. Hardenability of steels using Jominy end quench test
7. Age hardening study of a range of aerospace materials (Al-alloys, Ti-alloys, superalloys)
8. Activation energy and Stored energy calculation for phase transformation
9. Measurement of quasi-static and indentation fracture toughness
10. Measurement of impact fracture toughness using Charpy/Izod impact test
11. Fracture surface interpretation using SEM
12. Creep of a 60%Sn-40%Pb Solder wire at room temperature

Textbook

Specific Laboratory protocols and handouts will be made for different experiments.

Title	**Materials Characterization Lab**	Number	MTL3XX0
Department	Metallurgical and Materials Engineering	L-T-P [C]	0-0-2 [1]
Offered for	B.Tech. Program	Type	Program Compulsory (PC)
Prerequisite	-		

Objectives

Hands on training on instruments and methods for characterizing different materials and their properties

Learning Outcomes

The students are expected to have the ability handle various material characterization tools.

Laboratory Experiments

1. Quantitative metallogrphic analysis of metals, ceramics, polymers and composites
2. Electropolishing of aluminium alloys
3. Grain refinement studies using polarization microscope
4. Crystal structure determination using X-ray Diffraction analysis
5. Crystallite size measurement using X-ray Diffraction analysis
6. Indexing of selected area diffraction pattern
7. Specific heat and enthalpy calculation using DSC analysis
8. Phase transformation during solidification using thermal analysis
9. FTIR analysis of ceramic materials
10. UV-Visible spectroscopy analysis of thin films

Textbook

Specific Laboratory protocols and handouts will be made for different experiments.

Course Title	**Computational Modeling of Materials Lab**	Number	MT3LXX0
Department	Metallurgical and Materials Engineering	L–T–P [C]	0–0–2 [1]
Offered for	B.Tech. 3rd Year	Type	Compulsory
Pre-requisite			

Objectives

1. Hands-on training in running simulations.

Learning Outcomes

1. Simulate materials using numerical methods, molecular dynamics, first-principles calculations

Course Content

Numerical modelling Exercises
1. One-Dimensional Transient Heat Conduction: Numerical implementation
2. Diffusion equation: finite difference method
3. 1D-wave equation

Molecular dynamics Exercises
1. Calculate the energy in different crystal lattice structures
2. Determination of coefficient of thermal expansion
3. Application of tensile load and visualize the results
4. Determination of bulk modulus

First-principles calculations Exercises
1. Preparation of input files and visualisation of structures
2. Optimisation of simulation parameters.
3. Determination of equilibrium lattice parameter
4. Structure optimisation using a variable-cell method

Text Books

1. Rappaz, M., Bellet, M., Deville, M., *Numerical Modeling in Materials Science and Engineering,* Springer Science & Business Media, 2010.
2. Frenkel, D., Smit, B., *Understanding Molecular Simulation: From Algorithms to Applications*, 2nd Edition, Elsevier 2001.
3. Lee, J. G., *Computational Materials Science: An Introduction,* 2nd edition, CRC Press, 2016.

References

1. Sholl, D. S., and Steckel, J. A., *Density Functional Theory: A Practical Introduction*, 1st Edition, Wiley, 2009.
2. Parr, R.G., and Yang, W., *Density-Functional Theory of Atoms and Molecules*, 1st Edition, Oxford Science Publications, 1994.

Online Course Material

1. Ceder, G. and Marzari, N., 3.320 *Atomistic Computer Modeling of Materials* (SMA 5107). Spring 2005. Massachusetts Institute of Technology: MIT OpenCourseWare, https://ocw.mit.edu. License: Creative Commons BY-NC-SA

Title	**Materials Processing and Manufacturing Lab**	Number	MTL3XX0
Department	Metallurgical and Materials Engineering	L-T-P [C]	0-0-3 [1.5]
Offered for	B.Tech. (MT)	Type	Program Compulsory (PC)
Prerequisite	-		

Objectives

Hands on training on various industrially relevant materials processing and manufacturing techniques

Learning Outcomes

The students are expected to have the ability to handle various material processing and manufacturing equipment.

Laboratory Experiments

1. Injection molding of polymers
2. Blade coating of polymers
3. Sol-gel processing of ceramics
4. Sintering of ceramics
5. Melting and Casting of Aluminum Alloys
6. Welding of steels
7. Welding of Aluminum alloys
8. Additive manufacturing of polymers
9. Additive manufacturing of ceramics

Textbook

Specific Laboratory protocols and handouts will be made for different experiments.

Title	**Energy Materials Lab**	Number	MTL4XX0
Department	Metallurgical and Materials Engineering	L-T-P [C]	0-0-3 [1.5]
Offered for	B.Tech. (MT)	Type	Program Elective (PE)
Prerequisite	-		

Objectives

The course outlines in a nutshell:

1. Different modes of energy conversion and storage
2. Development of materials with time and different applications, scale, energy and power density

Learning Outcomes

The students are expected to gain knowledge on:

1. Structure processing property performance relationship of the energy materials developed over time.
2. Different modes of energy conversion and storage with respect to scale, cost, energy and power density

Laboratory Experiments

1. Demonstration of static electricity storage with electrostatic generator, Corona effect, Energy storage in Leyden jar. Fabrication of a capacitor
2. Charging and discharging of a capacitor, Measuring the capacitance of a Capacitor, Role of capacitor in voltage stabilizing/regulating, filtering
3. Fabrication and operation of a Lead-acid battery, Charge discharge voltammetry/EIS characteristics of Lead-acid battery
4. Fabrication and operation of a Lithium-ion battery, half-cell and full cell configuration, Charge discharge/voltammetry/EIS characteristics of Lithium-ion battery
5. Degradation test for lithium ion batteries, Use of different cathodes, Cell fabrication and dismantling, observation of structural changes, effect of temperature
6. Battery aging and self-discharge of lead-acid and lithium ion battery, battery for electric vehicles
7. Conversion of carbon dioxide into propane through artificial photosynthesis
8. Experimental Evaluation of a Paraffin as Phase Change Material for Thermal Energy Storage
9. Modelling and validation of a flywheel energy storage, modelling of gravity assisted storage systems (can be taken before)
10. Synthesis of different forms of carbon nanomaterials for capacitor, artificial photosynthesis devices and electrodes for batteries, observation of different morphologies and structural reversibility (demonstration experiment, make it simple)

Textbook

Specific Laboratory protocols and handouts will be made for different experiments.

15. Detailed Course Content
of
Programme Elective Courses

15. Detailed Course Content

Program Elective Courses

Title	**Processing-Microstructure and Properties of Steels**	Number	MT4XXX
Department	Metallurgical and Materials Engineering	L-T-P [C]	3-0-0 [3]
Offered for	B.Tech. (MT)	Type	Program Elective (PE)
Prerequisite	None		

Objectives

The Instructor will:

1. Describe the processing-structure-property relationship of steels used in engineering applications

Learning Outcomes

The students are expected to have the ability to:

1. Design the processing routes to obtain steel microstructures that will provide customizable properties to the component for specific engineering applications

Contents

Processing of Steels [6 lectures]: Melting and casting, Steel refining by ESR and VIM, and VAR, heat treatment of steels, thermo-mechanical processing of steels, sheet metal forming and welding of steels

Physical Metallurgy of Steels [12 lectures]: Effects of alloying elements on Fe-C phase diagram, structure and transformation kinetics of pearlite, interphase precipitation, divorced pearlite, Martensite-crystal structure, transformation kinetics, morphology, Bainite-Bainite start temperature, upper and lower bainite, bainitic microstructure, Widmanstattaen ferrite, acicular and equiaxed ferrite

Low Carbon Steels [8 lectures]: types of low carbon steels, hot-rolled ferrite-pearlite steels, processing by hot rolling, cold-rolling and annealing, interstitial free steel, HSLA steel, Dual-phase (DP) steel, TRIP steels, applications

Medium and High Carbon Steels [8 lectures]: microalloyed steel-microstructure and mechanical properties, rail steels, patenting-pearlite formation in high strength steel wire, drawing of pearlitic high carbon steel wires, hardening and tempering process, temper embrittlement, tool steels, applications

Stainless Steels [4 lectures]: alloy design for stainless steels, austenitic, ferritic and martensitic stainless steels, precipitation hardened and duplex stainless steels, applications

Surface Hardened Steels [4 lectures]: carburizing, Nitriding, carbo-nitriding, induction hardening, flame hardening

Textbooks

1. Krauss,G., (2005), *Steels: Processing, Structure, and Performance*, 2nd Edition, ASM International

Reference Books

1. Bhadeshia,H.K.D.H, Honycombe,R.W.K, (2017), *Steels: Microstructures and Properties*, 4th Edition, Butterworth-Heinemann

Title	**Degradation and Failure of Materials**	Number	MTL4XX0
Department	Metallurgical and Materials Engineering	L-T-P [C]	3-0-0
Offered for	B.Tech. (MT)	Type	Program Elective (PE)
Prerequisite	-		

Objectives

The instructor will explain

1. About materials degradation due to different types of corrosion, their mechanisms and inhibition.
2. Failures resulting due to corrosion and corrosion prevention

Learning Outcomes

The students are expected to gain:

1. Basic understanding on the possibility, outcome and rate of corrosion.
2. Knowledge on selection of corrosion resistant materials even before designing

Contents

Introduction [4 lectures]: Definitions, Different forms of Environmental degradation, Cost of Corrosion, Electrochemical Nature, Aims

Thermodynamics of Corrosion [10 lectures]: Process at Interface, Free Energy and Electrochemical Potential, EMF Series, Nernst Relationship, Important Reactions, Cell Potential, Reference Electrodes, Pourbaix diagram and its important in metal corrosion, Calculation of Pourbaix diagram for Al, Cu, Ni and Fe.

Kinetics of Corrosion [10 lectures]: Current Density and Corrosion Rate, Corrosion Rate Expressions, Exchange Current Density, Polarization, Activation, Concentration and Resistance polarization, Mixed potential theory.

Types of Corrosion and Failures [8 lectures]: Major forms of corrosion and failures originating due to corrosion, Hydrogen embrittlement, Corrosion fatigue

Corrosion testing and protection [6 lectures]: Corrosion experiments - Potentiodynamic test - Galvanostatic test - Linear Polarization-Immersion test - Salt fog test. Electrochemical ways: Sacrificial anode, Impressed current cathodic protection, Anodic protection, Environmental control over corrosion - Coating – Inhibitor.

Oxidation of Metals and Alloys [4 lectures]: Pilling Bedworth Ratio - Thermodynamics of oxidation: Ellingham diagram, of oxidation - Effect of doping on the oxidation behaviour.

Laboratory Experiments

NA

Textbook

1. Fontana M. G. (1987) Corrosion Engineering, 3rd Edition, McGraw Hill Book Company

Reference Books

1. Zaki A. (2006) Principles of Corrosion Engineering and Corrosion Control, Elsevier Science & Technology Books.

Online Course Material

1. Mondal K., Corrosion - Part I and II, NPTEL Course Material, Metallurgy & Material Science, Indian Institute of Technology Kanpur, https://nptel.ac.in/courses/113104082/, https://nptel.ac.in/courses/113/104/113104089/

Title	**Composites**	**Number**	MT3XX0
Department	Metallurgical and Materials Engineering	L-T-P [C]	3–0–0 [3]
Offered for	B.Tech. (MT)	Type	Program Elective (PE)
Pre-requisite	-		

Objectives

The main objective of this course is

1. To introduce structure and processing of composites
2. To and uses of composites

Learning Outcomes

The students are expected to

1. Classification and application of different composite materials and their processing techniques
2. Acquire understanding about the structure property relationship of different types of composites

Contents

Introduction and Classification of Composites [6 lectures]: Composites, matrix*:* metal matrix composites, polymer matrix composites, ceramic matrix composites, fiber reinforcements: fiber types, particulate reinforcements, nanocomposites

Design and Manufacturing of Composites [14 lectures]: Selection of matrix and reinforcement- Reinforcement with Aligned Continuous Fibers and Discontinuous fibers, wettability and role of interface; Manufacturing- Hand and Prepeg layup, Bag molding, Autoclave Processing, Compression Molding, Resin Transfer Molding, Pultrusion; Metal-Matrix Composites- Solid state and Liquid State processing; Ceramic-Matrix Composites- Solid state, sol-gel, co-precipitation and hydrothermal techniques

Tailoring Composite Materials [6 lectures]: by component selection, by interface modification, surface modification, microstructure control

Basic Mechanics of Composites [8 lectures]: Fiber-Matrix interface- theories of adhesion, glass fiber-polyester resin interface, measurement of bond strength, Elastic properties-unidirectional lamiae, elastic properties of short fiber composite materials, strength of a unidirectional laminae, fiber pull out, longitudinal and transverse tensile and compressive strength, in-plane shear strength

Properties and Applications of Composites [8 lectures]: Monotonic properties, fatigue and creep properties of composites, *Applications of Composites*- Materials for Lightweight Structures, Materials for civil infrastructure, Materials for Aerospace components- propeller blades, turbine blades, space applications

Textbook

1. Clyne, T. W. and Hull, D., (2019) *An Introduction to Composite Materials*, 3rd edition, Cambridge University Press.
2. Balasubramanian, M., (2013), Composite Materials and Processing, 1st Edition, CRC Press

Reference Book

1. Matthews F. L. and Rawlings R. D. (1999) *Composite Materials*, 1st edition, Woodhead Publishing.

Online Course Material

1. Prof. Nachiketa Tewari, Introduction To Composites, Aerospace Engineering, Indian Institute of Technology Kanpur, https://nptel.ac.in/courses/112/104/112104229/

Title	**Polymeric Materials and Processing**	Number	MTL4XX0
Department	Metallurgical and Materials Engineering	L-T-P [C]	3-0-0 [3]
Offered for	B.Tech. (MT)	Type	Program Elective (PE)
Prerequisite	-		

Objectives

The Instructor will:

1. Provide background on basics of processing, structure and properties of polymers of engineering applications

Learning Outcomes

The students are expected to gain:

1. Basic understanding of structure-property relationship in polymers
2. Knowledge about synthesis, and processing of polymers for engineering applications

Contents

Structure of Polymers [14 lectures]: Basics definitions, molar mass averages, Tacticity and isomerism, Amorphous and semi-crystalline polymers, free volume theory, crystal structure and its determination, degree of crystallinity, melting and crystallization, defects in crystalline polymers, polymer blends, block-copolymers, elastomers (**Offered by Chemical Engineering**)

Synthesis and Processing of Polymers [14 lectures]: Polymerization conditions and polymer reactions; Melt Processing, Extrusion, Injection Molding, Thermosets and Thermoforming; Plastics Technology: Molding, Extrusion, multipolymer systems and composites, additives and compounding; Elastomer Technology: vulcanization, elastomer compounding (**Offered by MT**)

Polymer Rheology and Mechanical Behavior [4 lectures]: Viscous flow, Storage and Loss modulus, visco-elasticity - creep, stress relaxation, kinetic theory of rubber elasticity (**Offered by MT**)

Characterization of Polymers [10 lectures]: Measurement of molecular weight and size: end group analysis, thermal analysis, colligative property measurement, dynamic light scattering, gel permeation chromatography, X-ray scattering, Spectroscopic methods (**Offered by MT**)

Laboratory Experiments

NA

Textbook

1. Young R.J. and Lovell P.A. (2011) *Introduction to Polymers*, 3rd Edition, CRC Press

Reference Books

1. Chanda M. (2006) *Introduction to Polymer Science & Chemistry*, CRC Press
2. Baird,D.G, Collias,D.I., (2014), *Polymer Processing*, Wiley

Online Course Material

1. Adhikari B, Science & Technology of Polymers, NPTEL Course Material, Department of Metallurgy & Material Science, Indian Institute of Technology Kharagpur, https://nptel.ac.in/courses/113105028/

Title	**Ceramics and Glass**	**Number**	MT4XX
Department	Metallurgical and Materials Engineering	L-T-P [C]	3–0–2 [4]
Offered for	B.Tech. (MT)	Type	Program Elective (PE)
Pre-requisite	-		

Objectives

The main objective of this course is to

1. Impart and introduce the basic concepts and uses of ceramics and glass.

Learning Outcomes

Upon successful completion of the course the student

1. Would have the knowledge of basic science and technology involved in ceramic materials and glass.
2. Be cognizant of various processing techniques involved in the creation of products.

Contents

Ceramic Compounds & Materials [8 lectures]: Chemistry of ceramics, crystal structure and bonding in ceramic materials, defect chemistry in ceramics, Polymorphism, Ceramic raw materials (Clay, Silicate, Zirconia), Mechanical and Thermal properties of ceramics

Sintering and Microstructure of Ceramics [6 lectures]: Thermodynamics and kinetics, Mass Transport, Solid phase sintering, Liquid phase sintering, Sintering additives, Pressure sintering

Ceramic Processing [8 lectures]: Ceramic Powder Characterization, Rheological behaviour of slurries, Particle packing, Forming Processes: Dry pressing, Semi dry pressing, Plastic forming method: extrusion and injection molding, Sol-gel processing, Casting methods: slip casting, tape casting, Drying and Firing process

Non-oxide Ceramics [2 lectures]: Silicon nitride, Aluminum nitride, Silicon carbide, Boron carbide

Industrial Applications of Ceramics [9 lectures]: Refractories, Abrasives, Whitewares, Cement, Ceramic Coatings, Nuclear Ceramics, Bio Ceramics

Glass [9 lectures]: Structure of glass, Thermodynamics and Kinetics of Glass, Physics of glass, Thermal & Mechanical properties, Coloring, Glass production, Glass-Ceramics

Laboratory Experiments

1. Chemical Analysis of Raw materials
2. Characterization of Ceramic powder: Tap density, Particle Size Analysis
3. Thermal analysis of ceramic powders using DTA / TGA / DTGA
4. Ceramic powder preparation:
5. Measurement of Green Strength and Green Density of Ceramics
6. Sintering of Ceramics: Measurement of sintering density, microstructure and phase analysis
7. Casting and Forming Lab
8. Preparation of Soda-Lime-Silica glass with different colouring oxides, e.g. CoO, FeO etc.
9. Preparation of Boro-silicate glass with alkali & alkaline earth oxides.

Text Books

1. Kingery,W.D., Bowen, H.K., and Uhlmann, D.R., Introduction to Ceramics, John Wiley & Sons
2. Barsoum,M.W., Fundamentals of Ceramics, CRC Press
3. Shelby,J.E., (2005) Introduction to Glass Science and TechnologyThe Royal Society of Chemistry

Self-Learning Materials

1. Reed,J.S., Introduction to the principles of ceramic processing
4. Tooley,F.V., Hand Book of Glass Manufacture – Vol. I & II, Ogden Publishing Co., NY

Online Course Material

1. Juejun Hu, Amorphous Materials, DMSE MIT, MIT OCW, https://ocw.mit.edu/courses/materials-science-and-engineering/3-071-amorphous-materials-fall-2015/index.htm

Title	**Casting and Solidification**	Number	MT6XX0
Department	**Metallurgical and Materials Engineering**	L-T-P [C]	3-0-0 [3]
Offered for	**B.Tech. (MT)**	Type	Program Elective (PE)
Prerequisite	**None**		

Objectives

The Instructor will:

1. Impart fundamental understanding of various casting processes and the theory of solidification
2. Discuss design methodology and process parameters involve in obtaining defect free casting.

Learning Outcomes

The students are expected to have the ability to:

1. Understand of solidification of metals and alloys and correlating with various casting processes

Contents

Conventional and Special Casting Techniques [14 Lecture]: Casting Terminology, Types of pattern and allowances, Applications and Challenges; Expendable and Permanent Mould Casting Processes. Special casting techniques: investment casting, rheocasting and thixocasting, squeeze casting, high and low pressure die casting, continuous casting.

Solidification of metals and alloys [14 Lecture]: Heat flow, plain front solidification, cellular solidification, constitutional undercooling, formation of dendrites, eutectic solidification, monotectic solidification.

Gating design and casting defects [14 Lecture]: Fluid flow, gating and riser design, Adams' and Caine's riser design, fluidity. Casting defects: classification, remedial measures, quality assessment.

Textbooks

Flemings,M.C., *Solidification Processing* (1974), Mcgraw-Hill Book Company

Campbell,J., (2015), *Complete casting Handbook: Metal Casting Processes, Metallurgy, Techniques and Design*, Butterworth-Heinmann

Reference Books

1. Heine R. W, Loper C. R., and Rosenthal P. C., (2008), Principles of Metal Casting, Tata McGraw Hill
2. Davies, G. J., (1973) *Solidification and Casting*, Wiley,
3. Stefanescu, D. M., Science *and Engineering of Casting Solidification*, (2015), 3rd edition, Springer

Online Course Materials

1. Karunakar, D.B., *Metal Casting*, NPTEL Course Material, Department of Mechanical and Industrial Engineering, Indian Institute of Technology Roorkee, http://nptel.ac.in/courses/ 112107083/

Title	**Metallurgy of Joining**	Number	MT6XX0
Department	Metallurgical and Materials Engineering	L-T-P [C]	3–0–0 [3]
Offered for	B.Tech. (MT) Program	Type	Program Elective (PE)
Prerequisite	-		

Objectives

The Instructor will:

1. introduce the basics of materials joining techniques and the associated metallurgy of welds

Learning Outcomes

The students are expected to have the ability to:

1. Understand the importance of the materials joining in structural applications.
2. Study the fundamentals of welding microstructures and properties

Contents

Materials Joining basics [6 lectures]: Materials joining basics, type of joints, Types of welding techniques, heat input and joining efficiency, importance of welding in structural applications

Fusion welding [8 lectures]: Important welding techniques such as submerged arc welding, flux core arc welding, tungsten inert gas welding, Metal inert gas welding, plasma arc welding, electron beam welding, laser beam welding.

Solid state welding [8 lectures]: Important welding techniques like Diffusion bonding, friction welding, friction stir welding, adhesive joining, ultrasonic welding, forge welding

Metallurgy of fusion welding [8 lectures]: Fusion zone, partially melted zone, heat affected zone, residual stresses in welding, epitaxial growth during welding, heat transfer in welding

Metallurgy of solid state welding [6 lectures]: materials plasticization, bonding interfaces, effect of processing parameters, heat input in welding

Case Studies [6 lectures]: fusion welding of Al alloys, Friction stir welding of Mg alloys, Laser beam welding of Al alloys and steel

Textbook

1. Kou S., (2003), *Welding Metallurgy*, 2rd Edition, Jhon Willey and Sons, New Jersey, United States
2. Lippold J.C., (2015) Welding Metallurgy and Weldability, Jhon Willey and Sons, New Jersey, United States

Reference Books

1. Reeser M.A., (2017), Welding complete: Techniques, project plans and instructions, cool springs press, MA USA.

Title	**Battery Materials**	Number	MTL4XX0
Department	Metallurgical and Materials Engineering	L-T-P [C]	3-0-0 [3]
Offered for	B.Tech. (MT)	Type	Program Elective (PE)
Prerequisite	Thermodynamics, Corrosion		

Objectives

Through this course the instructor

1. Will provide an insight of development of battery materials

Learning Outcomes

The students are expected to gain knowledge on:

1. Cycling behaviour of the batteries.
2. Development of different types of batteries demanding on application, Merits and demerits of each batteries.
3. Materials developed so far and future goals to be achieved.

Contents

Introduction to Electrochemistry [8 lectures]: Chemical and Electrochemical Reactions, Components of electrochemical cells, Operation of a Cell, Self-Discharge, Theoretical Cell Voltage, Capacity, and Energy, Specific Energy and Energy Density, Thermodynamic Background, Variation of the Voltage with Discharging and Recharging, Cycling Behaviour.

Battery Characteristics, Performance, Design, Selection & Standardization [2 lectures]: General Characteristics and Factors Affecting Battery Performance, Battery Design and Construction, Selection and Application of Batteries, Battery Standardization

History and evolution of Batteries [6 lectures]: Primary Batteries, voltaic pile, Daniell cell, Zinc-Carbon Batteries, Alkaline-Manganese Dioxide Batteries, Secondary Batteries, Lead-Acid Batteries, Nickel-Iron Batteries, Nickel-Cadmium Batteries, Nickel-Zinc Batteries, Nickel-Hydrogen Batteries, Nickel-Metal Hydride Batteries, Lithium-Ion Batteries.

Development of Negative Electrodes [8 lectures]: The lead electrode, Aluminium and Magnesium electrode, Zinc and Cadmium Electrode in Aqueous Systems, Metal Hydride Electrodes, Negative Electrodes in Lithium Cells

Development of Positive Electrodes [8 lectures]: Manganese Dioxide/ The "Nickel" Electrode / Lead oxide electrode/ Oxygen electrode Electrodes in Aqueous Systems.

Development of Electrolytes [10 lectures]: Liquid Electrolytes, General Considerations Regarding the Stability of Electrolytes Vs. Alkali Metals, Elevated Temperature Electrolytes for Alkali Metals, Electrolyte Stability Windows and Their Extension, Composite Structures That Combine Stability Regimes, Solid Electrolytes.

Laboratory Experiments

NA

Textbook

1. Huggins R. A. (2009) *Advanced Batteries: Materials Science Aspects*, 1st Edition, Springer

Reference Books

2. Linden D. and Reddy T. B. (2002) *Handbook of Batteries, 3rd Edition*, The McGraw-Hill Companies

Online Course Material

Title	**3-D Printing: Material Processing and Properties**	Number	MTL4XX0
Department	Metallurgical and Materials Engineering	L-T-P [C]	3-0-0 [3]
Offered for	B.Tech. Materials Engineering	Type	PE
Prerequisite	Nil		

Objectives

The Instructor will introduce:

1. Importance of 3-D printing of materials for various range of applications
2. Process control and product quality evaluation through application of basics

Learning Outcomes

The students are expected to gain:

1. Insight of the evolutionary technology for rapid and cost effective growth of products
2. Aptitude to translate the knowledge into novel components with industrialization competitiveness

Contents

Introduction [5 lectures]: 3-D printing small but multipurpose product inspiration, Science fiction to innovation, Multidisciplinary terminology, Current system configurations, Construction, Classification

Hardware – software – material Interdependence [5 lectures]: Essence of hardware, software and materials, Impact on systems engineering in various industries, Processing philosophy

Raw Materials [4 lectures]: Forms and sources of raw materials, Processing methods and characteristic properties, Material specifications based industries and processing technology e.g. aerospace, medicine

3-D Printing Processes [2 lectures]: Process flow and basics of stages involved, Process control, Upgrading options, 3-D product design, evaluation, justification and integration (DEJI) model

Additive Manufacturing of Metallic Systems [5 lectures]: Light metals and alloys, Superalloys, Intermetallic compounds, Shape memory alloys, porous metals, Rare earth permanent magnets

Thermo-mechanical Effects [2 lectures]*:* Phase transformation, Microstructure evolution, Variation in properties, Thermo-mechanical modeling of microstructure evolution and mechanical properties

3-D Printing of Polymers and Hydrogels [5 lectures]: Natural polymers, Synthetic polymers, Design considerations and guidelines, Mechanics modeling, AM of tooling for mass production processes, 3-D bioprinting hardware, Reactive inkjet printing of nylon materials, Stimuli responsive hydrogels, Biopolymer hydrogel biolinks

3-D Printing of Ceramics and composites [5 lectures]: Processing technology and options, Laminated object manufacturing, Laser Engineered net shaping, Bio-active ceramics and bio-active glasses, Engineering ceramics, Green-tape-based AM, Complex ceramic architecture, Metal matrix composites, Ceramic matrix composites, Polymer matrix composites and their variants, Nano-composites

Special Purpose 3-D Printing [5 lectures]: Functionally grades materials, Bio-medical applications, Biomematic design model, Frugal design sustainability, Smart material- DNA origami, 4-D printing, Reconstructive surgery, Patient specific 3-D printing, Hydrogen storage material, Printed and hybrid electronics enabled by digital AM technologies, Reverse Engineering

Post-processing and Inspection techniques [2 lectures]: Post processing problems and requirements, Rectification

Student Presentation & Discussion [2 lectures]: Concept for developing prototype object, Methodology, Examining novelty and market acceptability, Translation to business idea

Laboratory Experiments

NA

Textbooks

1. Gibson, I., et al (Eds.) (2015), *Additive Manufacturing Technology: 3D printing, Rapid Prototyping, and Direct Digital Manufacturing*, 2nd Ed., Springer
2. Maniruzzaman, M.. (Ed.), (2019), *3D and 4D Printing in Bio-medical Applications: Process-Engineering and Additive Manufacturing*, Wiley- VCH Verlag GmbH & Co.

Reference Books

1. Declan, M.D.. (2019), *Polymer Based Additive Manufacturing- Biomedical Applications*, Springer Nature.
2. Gu, D., (2015), *Laser Additive Manufacture of High-Performance Materials*, Springer Verlag

Online Course Material

1. Ramkumar, J., 2018, *NOC: Rapid Manufacturing*, Department of Mechanical Engineering; IIT Kanpur, https://nptel.ac.in/courses/112/104/112104265/

Title	**Lithium ion batteries**	Number	MTL4XX
Department	Metallurgical and Materials Engineering	L-T-P [C]	2-0-2 [3]
Offered for	B.Tech. (MT)	Type	PE
Prerequisite	Thermodynamics		

Objectives
The theoretical and practical limits of battery technology can be a barrier to meeting some performance requirements. Through this course the instructor will provide a thorough insight of development of battery materials with future goals to be achieved.

Learning Outcomes
The students are expected to gain knowledge on:
1. Cycling behaviour of the batteries.
2. Development of different types of batteries demanding on application, Merits and demerits of each batteries.
3. Materials developed so far and future goals to be achieved.

Contents
Introduction: *[4 lectures]* Components of Li ion electrochemical cells, Operation of a Li ion Cell, Reconstitution and Insertion Reactions, Theoretical Cell Voltage, Capacity, and Energy, Cycling Behaviour, Experimental Methods to Evaluate the Critical Properties of Electrodes and Electrolytes, Use of DC and AC Methods to Determine the Electronic and Ionic Components of the Conductivity in Solid Electrolytes and Mixed Conductors, Influence of Impedances to the Transport of Ionic and Atomic Species within the Cell, Self-Discharge, Joule Heating to Due to Self-Discharge in Electrochemical Cells.

Negative Electrodes in Lithium ion Cells: *[8 lectures]* Elemental Lithium Electrodes, drawbacks, Lithium–Carbon Alloys, Metallic Lithium Alloys, Mixed-Conductor Matrix Electrodes, Convertible Reactant Electrodes, Electrochemical Behaviour, structural reversibility, Amorphization, Decrepitation, Modification of the Micro and Nanostructure of the Electrode, Electrodes for aqueous systems.

Positive Electrodes in Lithium ion Cells: *[8 lectures]* Insertion Reaction, Reconstitution Reaction, Electrodes, Materials with Layered Structures, Materials with the Spinel Structure, Materials with the Olivine Structure, Liquid Positive Electrode Reactants: The Li/SO_2 System, The $Li/SOCl_2$ System, Electrodes for aqueous systems, Hybrid Ion Cells, The Oxygen Evolution Problem.

Electrolytes in Lithium ion Cells: [8 lectures] Lithium-Conducting Inorganic Molten Salts, Lower Temperature Alkali Halide Molten Salts, Ambient Temperature Organic Solvent Liquid Electrolytes/Ionic liquids, Interaction of Organic Solvent Electrolytes with Graphite, Electrolyte Additives, Solid Electrolytes, Lithium Ion Conductors: Perovskite and Garnet Structure, Relation Between the Potential and the Oxygen Pressure in Lithium Systems, Electrolyte Stability Windows and Their Extension, Two Solid Electrolytes in Series, Implications for the Safety of Lithium Cells.

Laboratory Experiments

1. Introduction to LIBs, different parts of LIB, different size and shapes, applications
2. Synthesis of graphite and metal-alloys based negative electrodes for LIB
3. Synthesis of oxide, phosphate and silicate based positive electrodes for LIB
4. Fabrication of lithium half cells and full cells
5. Cycle behaviour, charge/discharge characteristics and performance analysis of LIB
6. Voltammetry study and analysis of electrochemical behaviour through impedance spectroscopy
7. Exploration of degradation mechanism of oxide and phosphate-based LIBs
8. Aging and self-discharge characteristics of oxide and phosphate-based LIB

9. Short-circuit and thermal runaway failure of oxide and phosphate-based LIB
10. Thermal imaging and calorific study of parasitic reactions
11. Battery management system, balancing and development of smart charger for LIBs

Textbook

1. Masaki Yoshio M., Brodd R. J. and Kozawa A. (2010) *Lithium-Ion Batteries: Science and Technologies*, Springer
2. Toll M. (2017) *DIY Lithium Batteries: How to Build Your Own Battery Packs*, Toll Publishing

Reference Books

1. Huggins R. A. (2009) *Advanced Batteries: Materials Science Aspects*, 1st Edition, Springer
2. Linden D. and Reddy T. B. (2002) *Handbook of Batteries, 3rd Edition*, The McGraw-Hill Companies

Online Course Material

1. Dr. WALKER W. Q., Short course on lithium-ion batteries: fundamental concepts, heating mechanisms and simulation techniques, Nasa Johnson space center, Structural engineering division, Thermal design branch.

2. Prof. Bazant M., MITopencourseware: Electrochemical Energy Systems, MIT Course Number 10.626 / 10.426, https://ocw.mit.edu/courses/chemical-engineering/10-626-electrochemical-energy-systems-spring-2014/

3. Prof. Maiti H.S., Advanced ceramics for strategic applications, NPTEL, Metallurgy and Materials Science, https://nptel.ac.in/courses/113/105/113105015/

Title	**Surface Engineering**	Number	MTL6XX0
Department	Metallurgical and Materials Engineering	L-T-P [C]	3–0–0 [3]
Offered for	B. Tech. (MT)	Type	Program Elective (PE)
Prerequisite	None		

Objectives

The Instructor will:

1. Provide knowledge on the importance of surface engineering in materials protection and design
2. Introduce various advanced surface engineering techniques available in the industry

Learning Outcomes

The students are expected to have the ability to:

1. Understand the basics of various advanced surface engineering techniques
2. Understand the limitations of standard materials and how they can be improved with surface engineering
3. Identify the surface treatment best suited to a specific application

Contents

Fundamentals of surface engineering [10 Lectures]: definition, scope, classification, and general principles, surface dependent properties and failures, Surface and surface energy: Structure and types of interfaces. Protection from wear and corrosion by surface engineering. Enhancing the performance of thermal protection systems, biocompatibility, and other functional properties of materials by surface engineering.

Surface engineering Techniques [24 Lectures]: Surface engineering by energy beams: Laser assisted microstructural modification –Laser assisted compositional modification – surface cladding. Electron beam assisted modification and joining. Ion beam assisted microstructure and compositional modification. Surface engineering by spray techniques: Principle and scope of applications of Flame spraying, Plasma coating, HVOF, cold spray. Characterization of surface microstructure and properties (name of the techniques and brief operating principle). Evaporation - Thermal / Electron beam, Sputter deposition of thin films & coatings – DC & RF, Sputter deposition of thin films & coatings –Chemical vapor deposition and PECVD, Plasma and ion beam assisted surface modification, Surface modification by Ion implantation and Ion beam mixing.

Characterization of surfaces [8 Lectures]: Measurement of coatings thickness, porosity & adhesion of surface coatings, Measurement of residual stress & stability, Surface microscopy, topography and Spectroscopic analysis of modified surfaces.

Textbooks

1. Davis,J.R, (2001), *Surface Engineering for Corrosion and Wear Resistance*, ASM International,.
2. Budinski K., (1990), *Surface Engineering for Wear Resistance*, Prentice Hall.

Reference Book

1. Ernest, R., *Friction and Wear of Materials*, (1995), John Wiley and Sons, New York.
2. *Surface Engineering*, (2001) ASM Metals Handbook, Vol. 5, Ohio

Self-Learning Material

1. Kallol, M. and Sandeep. S., *Heat Treatment and Surface Hardening – I* NPTEL Course Material, Department of Mechanical and Industrial Engineering, Indian Institute of Technology Kanpur, https://nptel.ac.in/courses/113104074/
2. Kaushik P., *Surface Engineering of Nanomaterials,* NPTEL Course Material, Department of Mechanical and Industrial Engineering, Indian Institute of Technology Kanpur, https://nptel.ac.in/courses/113107075/

Title	**Synthesis and Processing of Semiconductors and 2D materials**	Number	MTL3XX0
Department	Metallurgical & Materials Engineering	L-T-P [C]	3-0-0
Offered for	B.Tech. (MT)	Type	Program Compulsory (PC)
Prerequisite			

Objectives

The Instructor will:

1. Introduce different synthesis and fabrication techniques used for semiconductor device fabrication.
2. Introduce different synthesis techniques used for 2D materials

Learning Outcomes

After completion of the course students will be have a basic understanding of different semiconductor device fabrication techniques as well as gain knowledge how to synthesize various 2D materials

Contents

General Introduction (1 Lecture)

Semiconductor processing [17 Lectures]: Silicon Wafer Fabrication Physical vapour deposition methods: e-beam, pulsed laser and ion beam evaporation, Glow, Discharge and Plasma, Sputtering–mechanisms and yield, DC and RF sputtering, Chemical vapour deposition: Sol-gel, Spin Coating, Atomic Layer deposition, CVD, PECVD, MOCVD, solution processing techniques, (printing, spin coating, chemical bath depositions, etc.). Semiconductor Integration with Functional oxides and Challenges in fabrication

2D Materials Processing [Lectures 13]: Different types of 2D materials, Strategies and challenges of 2D materials synthesis: micromechanical exfoliation, ultrasonic exfoliation, hydrothermal method, topochemical transformation, chemical vapor deposition, Top Down vs Bottom up, Production of graphene and 2-d materials: Comparison of production methods, Scotch-tape method (micromechanical cleavage), Chemical vapour deposition, Solution-exfoliation 1 – graphene and other 2-d materials, Solution-exfoliation 2 – graphene oxide, Decomposition of silicon carbide, Production of graphene nano-ribbons, Synthesis of hexagonal boron nitride, and transition metal dichalcogenides, to new and emerging materials such as black phosphorus, silicene, and germanene.

Lithography and Etching [Lectures 6]: Pattern Formation, Optical Lithography, Resists, Wet Chemical Etching, Reactive Ion Etching, Ion implantation doping

Metallization and Polishing [Lectures 2]

Cleanroom & Contamination [Lectures 3]: Cleanroom standards, Contamination and yield, Environment, safety and health

Textbook

1. Ohring, M., (2002), The materials science of Thin films, 2nd Edition, Academic Press Ltd.

2. Chopra, K. L., (1969), Thin Film Phenomena, McGraw-Hill Book Company

Reference Books

1. Editor Gogotsi, Y., (2019), 2D Metal Carbides and Nitrides (MXenes): Structure, Properties and Applications, Springer

2. Shinohara, H., Tiwari, A., (2015), Graphene: an introduction to the fundamentals and industrial applications. John Wiley & Sons

Online Course Material

2. Parasuraman Swaminathan, Electronic materials, devices and fabrication, NPTEL Course Material, Department of Metallurgical and Materials Engineering, IIT Madras, https://nptel.ac.in/courses/113/106/113106062/

Title	**Biomaterials Engineering**	Number	BSBE 4XX0
Department	Bioscience and Bioengineering	L-T-P [C]	3–0–0 [3]
Offered for	B. Tech. (MT)	Type	Program Elective (PE)
Prerequisite	None		

Objectives
The Instructor will:
1. Provide an insight on the fundamental concepts of biomaterials engineering.
2. Give an overview of techniques for characterizations of different types of biomaterials for various applications.

Learning Outcomes
The students will have the ability to:
1. Analyze the suitability of the material to be used as a biomaterial.
2. Compare the performance of different biomaterials.
2. Design a strategy for modification of biomaterials for a specific application.

Contents
Fundamental of Biomaterials [14 Lectures]: Introduction to biomaterials, types of biomaterials, processing of biomaterials, surface properties and surface modification of biomaterials, physicochemical characterization of biomaterials. **(by MM department)**

Biological Properties of Biomaterials [14 Lectures]: Concepts of biocompatibility, immune-compatibility, hemocompatibility and biodegradability, Bioconjugations, Biomineralization, Biological characterization of biomaterials **(by BSBE)**

Applications of Biomaterials [14 Lectures]: Biomimetic and stealth biomaterials, types and applications of implants, biomaterials for drug delivery systems, biomaterials for tissue engineering, regulatory affairs **(by BSBE)**

Text Books
1. Basu,B., (2017), *Biomaterials Science and Tissue Engineering*, First edition, Cambridge University Press

Reference Books
1. Shelly, E., Elbert, S, Zhang, G., (2020), *Biomaterials Science: An Introduction to Materials in Medicine, Edited by William R Wagner, Michael J. Yaszemski,* 4th edition, Academic Press Inc.

Self-Learning Material
1. https://nptel.ac.in/courses/113/104/113104009/

Title	**Functional Ceramics**	Number	MTL4XX0
Department	Department of Metallurgical and Materials Engineering	L-T-P [C]	3-0-0 [3]
Offered for	BTech/PhD	Type	PE
Prerequisite	Semiconductor Devices		

Objectives
The instructor will:
1. Provide in-depth knowledge into the electronic, magnetic, and optical properties of ceramic materials systems and their properties

Learning Outcomes
On successful completion of the course, the students would be:
a) Know the relationships between ceramic structure (electronic, microstructural, and defect structure) and the wide variety of properties they display.
b) Learn how these variety of phenomena can be exploited in useful applications like sensors, and piezoelectric transducers
c) Access Current day research topics on electronic magnetic and optical materials.

Contents
General Introduction [1 Lecture]

Crystallography and Bonding [6 Lectures]: Structures, Bonding in Ceramics Structure formation rules in Oxides, Important structures in Oxides.

Defects [5 Lecture hours]: Defects in ceramics and defect chemistry, Defects diffusion and equilibrium

Electrical conductivity [5 Lectures]: Conduction Mechanisms in Ceramics, Resistors, varistors and thermistors

Dielectrics, ferro- and piezo-electrics [16 Lectures]: Capacitor Materials, Dielectric Breakdown, High and low permittivity materials, Microwave and tunable dielectrics, Ferroelectric memories, Piezoelectric materials: PZT, $BaTiO_3$, Morphotropic Phase boundary, Electrostriction, Pyroelectric materials: Thermal Imaging, IR detection

Magnetic Ceramics [3 Lectures]: General Properties, Magnetic ferrites, Magneto crystalline anisotropy, Magnetostriction, Applications

Electro-optical Properties [3 Lectures]: Electro-optic effect, Non-Linear optics, Birefringence, PLZT material and structure

Material processing [3 Lectures]: Thin film and Bulk processing

Textbook
1. Electroceramics: Materials, Properties and Applications by A. J. Moulson and J. M. Herbert, Chapman and Hall, 2nd Edition, 1990.
2. Kofstad, Per. "Nonstoichiometry, diffusion, and electrical conductivity in binary metal oxides." (1972).

Reference Books
1. Introduction to solid State Physics by Charles Kittel, Wiley Eastern, 5th Edition, 1983
2. Newnham, R. E. (2012). Structure-property relations (Vol. 2). Springer Science & Business Media

Online Course Material

1. Ashish Garg, Electroceramics, NPTEL Course Material, Department of Material Science & Engineering, Indian Institute of Technology Kanpur, https://nptel.ac.in/courses/113/104/113104005/
2. Ashish Garg, Fundamentals and Applications of Dielectric Ceramics, NPTEL Course Material, Department of Material Science & Engineering, Indian Institute of Technology Kanpur, https://nptel.ac.in/courses/113/104/113104090/

Title	**Magnetism and Magnetic Materials**	Number	MTL4XX0
Department		L-T-P [C]	(3-0-0) [3]
Offered for	B.Tech. (MT)	Type	Elective
Prerequisite	Basic knowledge on Quantum Mechanics		

Objectives

The course will provide knowledge of underlying phenomena of magnetism. Emphasis will be on the preparation process & characterisation methods of magnetic materials used for Engineering applications

Learning Outcomes

The students are expected to have the ability of understanding magnetic phenomena, and metallurgical aspect of developing magnetic materials. They will also get an exposure of engineering application of magnetic methods and magnetic materials.

Contents

- Origin of magnetism, Bohr Magnetron, Classification of magnetic materials, Weiss molecular field (4L)
- Magnetism in Metals and Insulators, Exchange Interaction, Magnetic Anisotropy and Magnetostriction, (6L)
- Domain and Domain Walls, Magnetic Hysteresis and Barkhausen Emissions, Techniques for Characterisation of Magnetic Materials, Superconductor and Superconducting Magnets, Structure Property Relations (8L),
- Soft Magnetic Materials: Nickel Iron Alloys, Cobalt-Iron alloys, Electrical steel (CRNO, CRGO and amorphous), Amorphous & Nanostructured magnetic alloys. (6L)
- Hard Magnetic Materials: Alnico, NdFeB, SmCo (6L)
- Soft & Hard Ferrites, Magnetic Shape Memory and Magnetocaloric Materials (6L),
- Application of Magnetism and Magnetic Materials (2L)

Text/Reference Book:

(i) Chih-Wen Chen, Magnetism and Metallurgy of Soft magnetic Materials, Dover Publications, INC. New York, ISBN 0-486-64997

(ii) B.D. Cullity, Introduction to Magnetic Materials, Addison-Wesley publishing company, California, London,

(iii) D. C. Jiles, Introduction to Magnetism and Magnetic Materials, Chapman & Hill, London, 1991.

(iv) S. Chikazumi, Physics of Ferromagnetism, Oxford University Press 1997, Reprinted in 2002, ISBN: 0-19-851776-9

Title	**Computational Thermodynamics**	Number	MTL6XX0
Department	Metallurgical and Materials Engineering	L-T-P [C]	2–0–2 [3]
Offered for	B.Tech (MT)	Type	Program Elective (PE)
Prerequisite			

Objectives

1. Understanding the correlation between the phase diagram and chemical thermodynamics for alloy design.

Learning Outcomes

1. Ability to construct multicomponent phase diagrams using computational thermodynamic approach.

Contents

1. *Thermodynamics of Solution [7 Lectures]:* Thermochemistry of solutions. Evolution of phase diagrams - quasichemical theory, Sub regular solution model.
2. *Calculation of thermodynamic parameters [7 Lectures]:* First principle calculation, Semi-empirical- Miedema approach. Calorimetric measurement, electrochemical measurement,
3. *Calculation of multicomponent phase diagram [14 Lectures]:* Redlitch-kister polynomial, Muggianu and kohler extrapolation. Crystallography in thermodynamics, Order and disorder structure, antisite defect and vacancies. Compound energy formalism. Modeling of Interstitial and substitutional phases, stoichiometric and non-stoichiometric compounds.

Lab Experiments

1. Construction of equilibrium and non-equilibrium phase diagram,
2. Vertical section phase diagram and Property diagram for multi-component alloys,
3. Scheil and equilibrium solidification simulation,
4. Liquidus projections and monovariant reactions in ternary phase equilibria,
5. Creation of user defined thermodynamic database.

Textbooks

1. Saunders and Miodownik, (1998), *CALPHAD (Calculation of Phase Diagrams): A Comprehensive Guide,* 1st Edition, Pergamman Press,
2. Lukas,H., Suzana,G., Fries, B.S., (2007), *Computational Thermodynamics: The Calphad Method,* Cambridge University Press,

Self-Learning Material

1. Porter, D.A., Easterling, K. E., and Sherif, M.Y., (2009), *Phase Transformation in Metals and Alloys*, 3rd Edition, CRC Press

Online Course Materials

1. Murty, B.S., Advanced Metallurgical Thermodynamics, NPTEL Course Material, Department of Metallurgical and Materials Engineering, Indian Institute of Technology Madras, https://nptel.ac.in/courses/113106031/.

Title	**Mineral Beneficiation**	Number	MTL4XX0
Department	Metallurgical and Materials Engineering	L-T-P [C]	3–0–0 [3]
Offered for	B.Tech. (MT)	Type	Program Elective (PE)
Prerequisite	-		

Objectives
The Instructor will:
Introduce the principles of physical separation methods, simulation, and instrumentation related to mineral processing

Learning Outcomes
The students are expected to have the ability to:
Ability to engineer selective mineral processing based on material and environment conditions

Contents
Introduction to Mineral Geology [2 lectures]: Geological formation of minerals. Classification and identification of minerals

Introduction to Mineral Beneficiation [4 lectures]: Mineral Beneficiation Plant, Materials handling, Sampling, Sizing of ore particles- sieve analysis and testing, particle size distribution

Comminution and Screening [10 lectures]: Liberalization of dissimilar minerals, Degree of liberalization, comminution- fracture, laws of comminution, crushing – Primary and secondary crusher, crushing operation, Ginding- Ball milling, Wet and Dry Grinding, Chemical Comminution-leaching, dissolution, Screening- types, factors affecting rate of screening, screening efficiency

Separation and Concentration of ores [14 lectures]: Classification mechanical sorting, Gravity separation or concentration- Float and sink, heavy medium separation, Jigging, Flowing film concentration, Froth Floatation-floating reagents, types of floatation, Surface properties and selective flotation of ores, floatation for Sulphide ores, flocculation, Magnetic and Electrical Separation

Solid-Liquid Separation [4 lectures]: Settling of solids in fluids, Solid-Liquid separation-Dewatering, Mechanical Dewatering of Slurries and Liquid-Liquid processing methods, Filtering

Applications and Examples *[8 lectures]:* Mineral beneficiation of Zn, Cu, Fe, Pb ores, Heap leaching of Au, *Mineral Processing of special materials (from brine and mineral resources), rare earths, vanadium, etc.*

Textbooks

1. Wills,B.A. and Napier-Munn,T.J., (2006), Mineral *Processing Technology*, Elsevier Science & Technology Books, 7th Edition
2. Subbarao,D.V., (2011), *Mineral Beneficiation: A Concise Basic Course*, CRC Press

Reference Books

1. Drzymala, J., (2007), Mineral Processing: foundations of theory and practice of minerallurgy, Wroclaw University of Technology
2. German,R.M., (2005), *Powder Metallurgy & Particulate Materials Processing*, Metal Powder Industry

Online Course Materials

1. Majmuder, A., *Introduction to Mineral Processing*, NPTEL Course Material, Department of Mining Engineering, Indian Institute of Technology Kharagpur, http://nptel.ac.in/courses/105105171/

Title	**Kinetics of Metallurgical Processes**	Number	MTL4XX0
Department	Metallurgical and Materials Engineering	L-T-P [C]	3-0-0 [3]
Offered for	B.Tech. (MT)	Type	Program Elective
Prerequisite	-		

Objectives

This course aims to cover:

1. Various kinetic aspects of metallurgical processes encountered in during metal extraction

Learning Outcomes

The students will be able to:

1. Identify the rate controlling mechanism for a metallurgical process

Contents

Introduction and Kinetics of Homogeneous Reaction [6 lectures]: Scope of metallurgical kinetics, rate processes, rate of reaction, Rate equation, molecularity and order of reactions; reaction mechanism, temperature dependence of reaction rate-Arrhenius equation and activation energy

Interpretation of Batch Reaction Data [8 lectures]: Irreversible first order, second order, and third order reaction, zero-order reaction, overall order of reaction from half-life, homogeneous catalyzed reactions, irreversible reactions in series, General and first order reversible reactions

Chemically Controlled Reactions [8 lectures]: Reaction steps and rate controlling step, reaction between a solid and a fluid, interfacial reaction control-kinetic law, reduction of Hematite by CO or H_2, Examples of leaching reaction- Ammonia leaching and acid leaching of Chalcopyrite, Chemisorption, Total internal reaction

Diffusion through product layer [8 lectures]: Reaction of a flat plate and of a spherical solid, Diffusion through porous solid, Example: packed bed, leaching of Sulphide minerals

Fluid Phase mass transfer [12 lectures]: Mass Transfer Across a Boundary Layer, Mass Transfer at Solid–Fluid Interface, Dissolution of a Solid in a Liquid, Electrochemical Mechanism in Leaching, Smelting reduction process-reduction of FeO in slag, reaction between two fluids-mass transfer across two fluid interface, slag-metal reaction, mass-transfer as a rate controlling step

Laboratory Experiments

NA

Textbook

1. Ray, H.S., Ray, S.K., (2018), *Kinetics of Metallurgical Processes*, 1st Edition, Springer
2. Ghosh, A., Ghosh, S., (2014), *Textbook of Metallurgical Kinetics,* PHI Learning Private Limited

Reference Books

1. Levenspiel, O., (2006), *Chemical Reaction Engineering*, 3rd Edition, John Wiley and Sons.
2. Wilkinson, D.S., (2000), *Mass Transport in Solids and Fluids*, Cambridge Univeristy Press

Online Course Material

1. Prof. B. Mandal, Chemical Reaction Engineering-I, NPTEL Course Material, Department of Chemical Engineering, Indian Institute of Technology Guwahati, https://nptel.ac.in/courses/103/103/103103153/

Title	**Principles of Process Metallurgy**	Number	MT4XX0
Department	Metallurgical and Materials Engineering	L-T-P [C]	3-0-0 [3]
Offered for	B.Tech. (MT)	Type	Program Elective (PE)
Prerequisite	None		

Objectives

The Instructor will:

1. Introduce methods for the calculation of mass and energy balance for various metal extraction processes
2. Expose the students to various process control and transport phenomena for various metal extraction processes

Learning Outcomes

The students are expected to have the ability to:

1. Apply the principles of thermodynamics and transport phenomena to understand and control metallurgical processes
2. Relate the basic phenomena and process output through mass and energy calculations

Contents

Metal-slag interactions [6 Lectures]: Thermo-physical properties of metals and slags, slag-metal equilibrium calculations, application of slag capacity during metal refining

Process phenomena [6 Lectures]: bubble formation, foaming, gas-liquid reactions, reactions between liquid phases

Process control in metallurgical processes [6 Lectures]: Iron making, converter steel making, electric arc furnace, secondary steel making

Mass and Energy balance in Iron and Steel Making [8 Lectures]: Materials Balance in Iron making, Blast furnace stoichiometry, Enthalpy balance in blast furnace. Material and heat balance in converting. Material and heat balance in steel making by L.D converters and open-hearth furnace.

Mass and energy balance in calcination and roasting [8 Lectures]: Calcination - Principles of calcination, Materials and heat balance in calcinations. Roasting - Introduction, Sources of energy, Determination of calorific value of gaseous fuel, Amount of air, Materials balance calculation in roasting. Basics of heat balance in roasting. Calculation Procedure for Roasting Temperature.

Mass and energy balance in non-ferrous smelting [8 Lectures] Matte smelting, Industrial copper smelting. Material balance and heat balance problems in matte smelting. Reduction smelting, Material balance in zinc and lead smelting, Material and heat balance in Imperial Smelting Process.

Textbooks

1. Sano N., Lu W., Riboud P., (1997), *Advanced Physical Chemistry for Process Metallurgy*, Academic Press,
2. Shamsuddin M., (2016), *Physical Chemistry of Metallurgical Processes*, John Wiley & Sons.
3. Alan Fine H, Gordon H. Geiger, (1998), *Handbook on Material and Energy Balance Calculations in Metallurgical Processes*, 2nd Revised Edition, Wiley.

Self-Learning Materials

1. Ray, H.S., and Ghosh, A., (1991), *Principles of extractive metallurgy*, Wiley Eastern Ltd., New Delhi

Online Course Materials

1. Muzumdar, D., and Koria, S.C., *Steel Making*, NPTEL Course Material, Department of Material Science and Engineering, Indian Institute of Technology Kanpur, http://nptel.ac.in/courses/113104013/
2. Ray, H.S., Non-ferrous Extractive Metallurgy, NPTEL Course Material, Department of Materials and Metallurgical Engineering, Indian Institute of Technology Kharagpur, https://nptel.ac.in/courses/113/105/113105021/

Title	**Hydrometallurgy**	Number	MTL4XX0
Department	Metallurgical and Materials Engineering	L-T-P [C]	3-0-0 [3]
Offered for	B.Tech. (MT)	Type	Program Elective (PE)
Prerequisite	-		

Objectives

This course aims to cover:

1. Thermodynamic and kinetic aspects of leaching as a hydrometallurgical technique of metal extraction
2. Purification of leach liquors by ion exchange, solvent extraction, adsorption using active carbon, selective precipitation operations, and solid-liquid separation techniques.
3. Several practical leaching processes for nonferrous metal extraction and processing.

Learning Outcomes

The students will be able to:

1. Understand the thermodynamics and kinetics of leaching and how it impacts the design of a hydrometallurgical process.
2. Discuss the concepts and design of separation and purification of leach liquors including solvent extraction; ion exchange; precipitation; crystallisation; and membrane treatment.
3. Explain the concepts and design of metal recovery processes

Contents

Introduction and Chemical fundamentals of hydrometallurgy [8 lectures]: Mineral Deposition, lean ore, Aqueous Processing and Utilization of Metals, Chemical Potential, Equilibrium, Solubility Product, Relationships Amongst K, pK, pKa, and pH

Speciation and phase diagram [8 lectures]: Speciation (Ion Distribution) Diagrams, Metal-Ligand Speciation Diagrams, Phase Stability Diagrams

Rate processes [14 lectures]: Chemical/Electrochemical/Biochemical Reaction Kinetics, Reaction Kinetics, Mass Transport, Combined Mass Transport and Reaction Kinetics, Models for Reactions Involving Particles, Crystallization Kinetics

Metal extraction: [12 lectures]: Separation of dissolved metals, metal recovery processes, metal utilization

Laboratory Experiments

NA

Textbook

1. Free,M.L., (2013) *Hydrometallurgy: Fundamentals and Applications*, 1st Edition, John Wiley & Sons, Inc., Hoboken, New Jersey

Reference Books

1. Havlik, T., (2008) *Hydrometallurgy: Principles and Applications*, CRC Press Woodhead Publishing

Online Course Material

1. Prof. H.S. Ray, Non-ferrous Extractive Metallurgy, NPTEL Course Material, Metallurgy & Material Science, Indian Institute of Technology Kharagpur, https://nptel.ac.in/courses/113105021/

Title	**Electrometallurgy**	Number	MTL4XX0
Department	Metallurgical and Materials Engineering	L-T-P [C]	3-0-0 [3]
Offered for	B.Tech. (MT)	Type	Program Elective (PE)
Prerequisite	-		

Objectives

The aims to cover

1. The principles and applications of aqueous electrochemistry in extractive metallurgy.
2. Analysis of the thermodynamic and electro-chemical kinetic phenomena in aqueous and non-aqueous electrowinning and electrorefining of metals.

Learning Outcomes

The student should be able to:

1. Have knowledge and understanding of the existing electrometallurgical processes,
2. Analyze, conceive and conceptually design novel electrometallurgical processes

Contents

Introduction, Definitions, Principles and Concepts [8 lectures]: Electrodes and electrochemical reactions, cell and circuit, The Nernst equation and energy producing cells, Electrolysis, Faraday's law, Electro-crystallization.

Surface Morphology of Metal Electrodeposits [10 lectures]: Thin Compact Surface Metal Films, Thick Compact Metal Electrodeposits, Nucleation rate and deposition overpotential, Deposition from simple/ complex salt solutions with/without the presence of adsorbed additives, Disperse (Spongy, Dendritic, Powdered, Granular, Whisker) Deposits.

The Current Distribution in Electrochemical Cells [10 lectures]: Two equal plane parallel electrodes arrangement, Ohmic resistance of the cell, The edge effect, Cell voltage-current density dependencies, Determination of the current density distribution, Cells with Low Anode Polarisation, Corner Weakness Phenomena in Electroforming, Electrodeposition at a periodically changing rate.

Applications [14 lectures]: Electrowinning (zinc and aluminium), Electrorefining (copper), Optimum conditions for electroplating (metals/alloys/composites) from aqueous/non-aqueous/molten salt solutions, Electropolishing, Electro-machining, Electrochemical Oxidation of Metals.

Laboratory Experiments

NA

Textbook

1. Popov K. I., Djokic S. S. and Grgur B. N. (2002) *Fundamental aspects of electrometallurgy*, Kluwer academic publishers, New York.

Reference Books

1. Free M., Moats M., Houlachi G., Asselin E., Allanore A., Yurko J., Wang S (2012) *Electrometallurgy 2012*, John Wiley & Sons, Inc., Hoboken, New Jersey.

Online Course Material

1. Prof. H.S. Ray, Non-ferrous Extractive Metallurgy, NPTEL Course Material, Metallurgy & Material Science, Indian Institute of Technology Kharagpur, https://nptel.ac.in/courses/113105021/

Title	**Secondary and Special Steel Making**	Number	MTL6XX0
Department	Metallurgical and Materials Engineering	L-T-P [C]	3–0–0 [3]
Offered for	B. Tech. (MT)	Type	Program Elective (PE)
Prerequisite	-		

Objectives

The Instructor will:

1. Provide knowledge on various secondary steel making process

Learning Outcomes

1. Expose students to advanced methods of making super clean steel

Contents

Melt cleanliness and Degassing [14 Lectures]: The concept of cleanliness of steels, non-metallic inclusions, dissolved gases. Tramp & residual elements in steels and their effect on steel properties. Transport Phenomena during taping of Liquid Steel- Estimation of Gas absorption during tapping. Importance of Slag free tapping. Thermodynamic and kinetics of degassing of steel melts. Operation of degassing reactors viz. DH, RH, tank degassers etc., Re-melting refining technologies. Vacuum Degassing process.

Ladle Metallurgy [14 Lectures]: Thermodynamics & Kinetics of Deoxidation. Types & selection of Deoxidizers, Metallurgical & Thermodynamic conditions for Good Desulphurization and synthetic slag. Wire Injection Techniques for increased efficiency of Deoxidation &Desulphurization. Limitations of primary steel making, unit operations and unit processes in ladle metallurgy. Ladle furnaces design and operation, injection metallurgy.

Casting and Special steel making process [14 Lectures]: Ingot casting of steel, Segregation, Ingot Defects. Continuous Casting: Heat Transfer and Solidification, bloom, Billet, Slab and Thin strip Caster, primary and Secondary Cooling, Process parameters of the caster. Special steel making processes viz. AOD, VOD continuous steel making etc. Principles of Electroslag remelting (ESR) & Vacuum Arc Remelting (VAR). Advantages over traditional Secondary Steel Making vs Costs involved.

Text Books

1. Ghosh, A., (2000), *Secondary Steel Making: Principles & Applications*, First edition, CRC Press.

Reference Books

1. Ghosh, A., Chatterjee, A., (2012), *Iron and Steel Making – Theory & Practice*, PHI Leasing Private Ltd.
2. Mazumdar, D., (2015), *A First Course in Iron and Steel Making*, Universities Press(India) Pvt. Ltd.

Self-Learning Material

1. Mazumdar. D and Koria S.C., *Steel Making*, NPTEL Course Material, Department of Metallurgical Engineering and Materials Science, Indian Institute of Technology Kanpur, https://nptel.ac.in/courses/113104059/