M.Tech. & M.Tech.-Ph.D. dual degree in Materials Engineering

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Introduction

Metallurgical and Materials Engineering is an interdisciplinary branch that deals with converting raw materials into a product by leveraging upon design, extraction, processing, and characterization of materials for aerospace, automotive, energy, electronics, and healthcare applications. The following are the focus areas of the Department: (a) Computational Materials Engineering, (b) Structural Materials, (c) Functional Materials, and (d) Process Metallurgy. Computational Materials Engineering provides understanding of materials from atomistic to macro length scales, and leads to smart and intelligent materials selection, alloy design, discovery of unknown materials as well as improvement of metallurgical processes. The major focus of Structural Materials area is to understand the processing-microstructure-property correlation for designing and processing materials with superior combinations of properties in the finished engineering products. Functional Materials possess one or more native properties that can be triggered by an external stimulus (electric/magnetic fields). Hence these materials are used for a plethora of functional devices ranging from energy harvesting, healthcare, and modern day information technology. Process Metallurgy deals with mineral beneficiation and metal extraction.

The Department offers an M.Tech. program and an M.Tech.-Ph.D. dual degree program in Materials Engineering. Incoming students choose a specialisation from the following two specialisations in the beginning of their first semester: (a) Structural Materials, and (b) Process Metallurgy. The credits required for the M.Tech. degree are distributed among the program core, specialisation core, specialisation electives, program electives, open electives, project, and non-graded compulsory activities. The program core courses are common among all specialisations and cover the core concepts within the discipline of Materials Engineering. The student will take the specialisation core courses and the specialisation elective courses offered in the chosen specialisation and conduct a project within that specialisation. The specialisation core courses provide the essential background of the chosen specialisation and prepare the students for the specialisation electives as per their options exercised. The program elective courses in the program structure are designed to ensure sufficient breadth in Materials Engineering, and these courses must be chosen from the other specialisations within the program. The open elective courses allow students to explore courses from any department.

Objectives

- Provide rigorous academic and research training in advanced areas of Materials Engineering.
- Produce professionals with an in-depth understanding of Materials Engineering, capable of providing solutions to meet future materials challenges.
- Educate students to become academicians, scientists, innovators, and entrepreneurs.

Graduate attributes

- In-depth understanding of thermodynamic and kinetic principles of Materials.

- Knowledge to characterize features at various length scales using experimental and computational approaches.
- Comprehend and intelligently design structure, micro-structure property correlation.
- Skills to effectively communicate scientific findings to peers and the general public.
- Appreciation and adherence to professional ethics.
- Innovative skills to design and execute technical projects.

(a) Structural Materials

- Comprehensive knowledge of transformation in materials, their processing and characterization techniques.
- In-depth understanding of the role of processing parameters on material microstructure.
- In-depth understanding of the role of microstructure and loading conditions on mechanical behavior of materials.

(b) Process Metallurgy

- Knowledge about various ore and mineral dressing techniques for enrichment of metal content.
- Knowledge about pyro-, hydro-, electro- extractive metallurgy principles for metal production.
- Basic understanding of ceramic processing and refractories.

Learning Outcome

Ability to

- Apply thermodynamic and kinetic principles to understand and control materials processes and properties.
- Identify appropriate experimental techniques to characterize materials at various length scales.
- Define a research problem and devise an appropriate methodology for addressing the same.
- Identify normative commitments of technological knowledge, artefacts and familiarity with the manifold responsibilities linked to their profession.
- Critically develop linguistic competence and subject competence in the genres of technical communication.

(a) Structural Materials

- Apply principles of material processing, thermodynamics, and kinetics to improve and customize material properties.
- Ability to design and execute experiments for studying mechanical behavior of materials at various length and time scales and develop models for failure prediction.

(b) Process Metallurgy

- Ability to identify important control parameters of extraction processes.
- Ability to design experiments for assessing the minerals.
- Ability to design processes to enrich the metal content of minerals and ores.

Program structure with courses

Cat.	Course Number	Course Title	L-T-P-D	Credits		Cat.	Course Number	Course Title	L-T-P-D	Credits
I Semester						**II Semester**				
MC	MTL7XX0	Computational Thermodynamics and Kinetics of Materials	3-0-2-0	4		MC	MTL7XX0	Structure and Characterization of Materials	3-0-2-0	4
MC	MTL7XX0	Industry 4.0: Applications in Metallurgical and Materials Engineering	2-0-0-0	2		SC	MTL7XX0	Specialisation Core-2	3-0-0-0	3
SC	MTL7XX0	Specialisation Core - 1	3-0-0-0	3		SC	MTL7XX0	Specialisation Core-3	0-0-2-0	1
SE	MTL7XX0	Specialisation Elective-1	3-0-0-0	3		SE	MTL7XX0	Specialisation Elective-3	3-0-0-0	3
SE	MTL7XX0	Specialisation Elective-2	3-0-0-0	3		SE	MTL7XX0	Specialisation Elective-4	3-0-0-0	3
NH	HSN7XX0	Technical Communication	1-0-0-0	0		NH	HSN7XX0	Innovation and IP Management	1-0-0-0	0
Total				**15**		Total				**14**
III Semester						**IV Semester**				
ME	MTL7XX0	Program Elective-1	3-0-0-0	3		OE		Open Elective-2	3-0-0-0	3
ME	MTL7XX0	Program Elective-2	3-0-0-0	3		MP	MTD7XX0	Project (Stage-II)	0-0-0-11	11
OE		Open Elective-1	3-0-0-0	3		NH	HSN7XX0	Professional Ethics	1-0-0-0	0
MP	MTD7XX0	Project (Stage-I)	0-0-0-5	5						
NH	HSN7XX0	Systems Engineering and Project Management	1-0-0-0	0						
			Total	**14**					Total	**14**

<u>Distribution of Credits (M.Tech.)</u>

S.No.	*Category*	*Category Title*	*Total Credits*
1	MC	Program Core	10
2	SC	Specialisation Core	7
3	SE	Specialisation Elective	12
4	ME	Program Electives	6
5	OE	Open Electives	6
6	MP	Project	16
7	NH	Non-Graded Compulsory	4
		Total (Graded)	**57**
		Total (Graded + Non-graded)	**61**

M.Tech. Program Courses
List of Program Core courses

Course Number	*Course Title*	*L-T-P-D*	*Credits*
MTL7XX0	Computational Thermodynamics and Kinetics of Materials	3-0-2-0	4
MTL7XX0	Structure and Characterization of Materials	3-0-2-0	4
MTL7XX0	Industry 4.0: Applications in Metallurgical and Materials Engineering	2-0-0-0	2

List of Specialisation Core courses
(a) Structural Materials

Course Number	*Course Title*	*L-T-P-D*	*Credits*
MTL7XX0	Advanced Phase Transformations	3-0-0-0	3
MTL7XX0	Plastic Deformation and Microstructure Evolution	3-0-0-0	3
MTL7XX0	Structural Materials Laboratory	0-0-2-0	1

(b) Process Metallurgy

Course Number	*Course Title*	*L-T-P-D*	*Credits*
MTL7XX0	Non-Ferrous Metals Extraction	3-0-0-0	3
MTL7XX0	Ceramic Processing	3-0-0-0	3
MTL7XX0	Process Metallurgy Laboratory	0-0-2-0	1

List of Specialisation Elective courses

List of specialisation elective courses to be offered for M.Tech. students under different specializations:

(a) Structural Materials

Course Number	*Course Title*	*L-T-P-D*	*Credits*
MTL7XX0	Material Aspects in Additive Manufacturing	3-0-0-0	3
MTL7XX0	Dislocations in Materials	3-0-0-0	3
MTL7XX0	Diffusion in Solids	3-0-0-0	3
MTL7XX0	Cellular Materials	3-0-0-0	3
MTL7XX0	Fracture and Fatigue	3-0-0-0	3
MTL7XX0	Thermo Mechanical Processing	3-0-0-0	3
MTL7XX0	Near Net Forming	3-0-0-0	3
MTL7XX0	Light Metals and Alloys	3-0-0-0	3
MTL7XX0	High Entropy Alloys	3-0-0-0	3
MTL7XX0	Solidification of Metals and Alloys	3-0-0-0	3
MTL7XX0	Composite Materials	3-0-0-0	3
MTL7XX0	Continuum Plasticity	3-0-0-0	3
MTL7XX0	High Temperature Materials	3-0-0-0	3
MTL7XX0	Processing of Polymer Matrix Composites	2-0-0-0	2
MTL7XX0	Refractory Materials and Applications	3-0-0-0	3
MTL7XX0	Glass Science and Technology	3-0-0-0	3
MTL7XX0	Alloy Design: Computational Thermodynamic approach	3-0-2-0	4
MTL7XX0	Principles of Continuum Mechanics	3-0-0-0	3
MTL7XX0	Symmetry, Structure and Tensor Properties	3-0-0-0	3
MTL7XX0	Advances in Iron and Steel Making	3-0-0-0	3
Courses from other Departments			
MEL7XX0	Advanced Mechanics of Solids	3-0-0-0	3

MEL7XX0	Probabilistic Methods in Engineering Design	3-0-0-0	3
MEP7XX0	Smart Manufacturing	1-0-2-0	2
MEL7XX0	Finite Element Methods in Engineering	3-0-0-0	3
CHL7XX0	Structure & Property for Polymers	3-0-0-0	3
CHL7XX0	Mechanics of Viscoelastic Materials	3-0-0-0	3

(b) Process Metallurgy

Course Number	***Course Title***	***L-T-P-D***	***Credits***
MTL7XX0	Advances in Iron and Steel Making	3-0-0-0	3
MTL7XX0	Mineral Processing Technology	3-0-0-0	3
MTL7XX0	Mass and Energy Balance in Metallurgical Processes	3-0-0-0	3
MTL7XX0	Modelling of Metallurgical Processes	3-1-0-0	4
MTL7XX0	Refractory Materials and Applications	3-0-0-0	3
MTL7XX0	Clean Coal Technology	3-0-0-0	3
MTL7XX0	Glass Science and Technology	3-0-0-0	3
MTL7XX0	Solidification of Metals and Alloys	3-0-0-0	3
MTL7XX0	Metallurgical Industrial Waste Management	2-0-0-0	2
Courses from Other Departments			
CHL7XX0	Process Engineering and AI Applications	2-0-2-0	3
CHL7XX0	Data Analytics in Process Modelling and Simulation	2-0-2-0	3
CHL7XX0	Advanced Process Control and AI Applications	3-0-0-0	3

Program Elective courses
A student from a given specialisation should opt for Program Elective courses from the other Specialisation courses (core and elective).

Open Elective courses
The open elective courses can be taken from courses offered by any Department.

DETAILED SYLLABUS FOR PROGRAM CORE COURSES

Title	**Computational Thermodynamics and Kinetics of Materials**	**Number**	MTL7XX0
Department	Metallurgical and Materials Engineering	L-T-P [C]	3–0–2 [4]
Offered for	M.Tech.	Type	Compulsory
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

1. Understanding of the conditions for stability of a material and derive its properties.
2. Knowledge of parameters to control the evolution of microstructures.

Course Content

Laws of thermodynamics and Chemical reactions (14 lectures)
First, second and third laws (3 lectures), statistical interpretation of entropy (3 lectures) Free energy functions and criteria for equilibrium (3 lectures), reaction equilibrium, equilibrium constant; applications to materials and metallurgical systems (5 lectures).

Thermodynamics of solutions and phase diagrams (14 lectures)
Ideal and non-ideal solutions, partial and molar quantities, quasi-chemical model and regular solutions (3 lectures), Phase rule and binary phase diagrams (2 lectures), free energy composition diagrams (5 lectures), phase equilibrium calculations. (4 lectures)

Thermodynamics of interfaces and kinetics (14 lectures)
Interfaces, surface tension and surface energy (3 lectures), equilibrium at interfaces, nucleation (3 lectures), coherency (1 lecture), thermal activation, diffusion, concentration gradients, thermal gradients (3 lectures), Fick's laws, mechanisms of interface migration (3 lectures)

Computational Tutorials (Thermocalc and DICTRA):
1. Single-Point Equilibrium calculations
2. Calculation of thermodynamic properties of elements
3. Calculation Thermodynamic Properties of Compounds
4. Calculation Thermodynamic Properties of Solution Phases
5. Computation of Phase equilibria
6. Stepping in Temperature in the Fe-C System,
7. Fe-C Phase Diagrams calculations,
8. Fe-Cr-C Ternary Phase Diagram at 1000 K,
9. Stable and the Metastable Fe-C Phase Diagrams
10. Thermodynamics of reactions
11. Calculation of activation energy
12. Calculation of partition coefficient

Text Books

1. Gaskell, D.R., *Introduction to Metallurgical Thermodynamics*, McGraw-Hill 1995.
2. Swalin, R. A., *Thermodynamics of Solids*, reprint Edition, Wiley, 1962.
3. Balluffi, R. W., Samuel, M. A., Carter, W. C., *Kinetics of Materials*, Wiley, 2005.
4. Porter, D. A., Easterling, K. E., and Sherif, M. Y., *Phase Transformation in Metals and Alloys*, 3rd edition, CRC Press, 2009.

Self-Learning Material

1. Bird, R.B., Stewart, W.E. and Lightfoot, E.N., *Transport Phenomena*, Wiley, 1960.
2. Hillert, M., *Phase Equilibria, Phase Diagrams and Phase Transformations Their Thermodynamic Basis,* Second edition, Cambridge University Press 2008.

Title	**Structure and Characterization of Materials**	Number	MTL7XX0
Department	Metallurgical and Materials Engineering	L-T-P [C]	3–0–2 [4]
Offered for	M.Tech.	Type	Compulsory
Pre-requisite			

Objective

1. Understanding the principles of instruments and methods for characterising different materials and their properties.

Learning Outcomes

1. Basic working knowledge of various instruments.
2. Ability to identify and choose different characterization techniques for specific property analysis.

MTL7XX1 Introduction to Diffraction [1-0-0]

Structure of Materials (7 Lectures): Crystal structure, Symmetry elements and point group notations, Miller indices and Weiss zone law, Stereographic projections, Reciprocal space, Brillouin Zone

Diffraction based Characterization *(7 Lectures)*: Structure of crystalline and non-crystalline materials by X-ray diffraction, structure factor, indexing of lattice planes and lattice parameter determination, electron and neutron diffraction, small angle scattering

MTL7XX2 Characterization Using Electron Microscopy [1-0-0]

Scanning electron microscope (7 Lectures): Basis of image contrast and various operating modes, sample-electron interaction, cathodoluminescence, voltage contrast mode, Magnetic contrast mode, FEGSEM, Environmental SEM, Low voltage SEM. Electron back scattered diffraction/OIM, micro-textural analysis.

Transmission electron microscope (7 Lectures): Lens defects, aberration corrected TEM, Mass-thickness contrast, diffraction contrast and crystal defect, BF, DF, Weak beam DF images. Electron Diffraction: SADP. Phase contrast and HRTEM.

MTL7XX3 Spectroscopic Surface Analysis [1-0-0]

Chemical Analysis (5 Lectures): Optical emission spectroscopy, Energy dispersive spectroscopy, Wavelength dispersive spectroscopy, X-ray fluorescence spectroscopy, Electron Probe Microanalysis, Electron energy loss spectroscopy.

Surface analysis (5 Lectures): X-ray photoelectron spectroscopy, UPS, Dynamic SIMS and static SIMS.

Spectroscopic Characterization (4 Lectures): FTIR, and Raman spectroscopy, Mössbauer spectroscopy.

Lab Experiments

Calculation of thermodynamic parameters using DSC analysis;
Functional group analysis using FTIR;
XRD Pattern Indexing;
Lattice parameter and crystallite size calculation;
XRD Profile fitting;
SEM/EDS analysis;
UV-visible analysis and band gap calculation;
Electron Diffraction Pattern Indexing;
Image Analysis.

Text Books

1. Zhang, S., Li, L. and Kumar, A., *Materials Characterization Techniques*, CRC Press, 2008.
2. Brandon D., Kaplan W.D., Microstructural Characterization of Materials, 2nd Edition, Wiley, 2008
3. Barrett C. S., Massalski T. B., Structure of Metals. 3rd revised edition. Pergamon Press, 2006

Self-Learning Material

1. Evans, C., Brundle. R. and Wilson, *Encyclopaedia of Materials Characterization: Surfaces, Interfaces, Thin Films (Materials Characterization Series),* Butterworth-Heinemann, 1992.
2. Kaufmann, E.N., *Characterization of Materials, 3 Volume Set, 2nd Edition,* Wiley, 2012.

Online Course Material

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

Title	**Industry 4.0: Applications in Metallurgical and Materials Engineering**	Number	MTL7XX0
Department	Metallurgical and Materials Engineering	L-T-P [C]	2-0-0 [2]
Offered for	M.Tech. Materials Engineering	Type	Compulsory
Prerequisite	Nil		

Objectives

The Instructor will:

1. Introduce the importance of Industry 4.0 in context with Metallurgical and Materials Engineering
2. Provide a thought process to move from conventional to emerging technology in production and quality control

Learning Outcomes

The students are expected to gain:

1. Appreciation towards the evolutionary technology as a disruptive industrial growth
2. Knowledge to divide and integrate the production line steps and develop inclination to for optimising the production lines.

Contents

Introduction: Concept of Industry 4.0, Types of metallurgical and materials industries, Product range, Present production practice (4 Lectures)

Process and Product Line Analysis: Typical flow charts from raw materials to processing of intermediate and final products, Their quality control at different stages of production, Product qualification methods, Property and performance evaluation, Product life prediction, Recyclable and repair options, Methods for data collection and processing (6 Lectures)

Automation:
Introduction to IoT: Sensing, Actuation, Basics of IoT Networking, IoT Architecture, Integration of Sensors and Actuators for Implementation of IoT (6 Lectures);
Basics of Industrial IoT: Industrial Processes, Industrial Sensing & Actuation, Industrial Internet Systems, Basics of Predictive maintenance (6 Lectures)

Application of Industry 4.0 in Metallurgical & Materials Engineering:
Optimized energy costs, Adaptive manufacturing, Preventive maintenance,
Defect detection and minimisation, Yield optimisation (6 lectures)

Laboratory Experiments

NA

Textbook

1. Rana, R. and Singh, S.B., *Automotive Steels: Design, Metallurgy, Processing and Applications*, Woodhead Publishing, 2016.
2. Vignes, A., *Extractive Metallurgy 3: Processing, Operations and Routes*, John Wiley & Sons, 2013.
3. Kamal, R., Internet of Things - Architecture and Design Principles, 1st Edition, Mcgraw Hill, 2017.

Online Course Material

1. Misra, S., 2018, *Introduction to Industry 4.0 and Industrial Internet of Things*, IIT Kharagpur.
https://nptel.ac.in/courses/106/105/106105195/

DETAILED SYLLABUS FOR THE SPECIALISATION CORE COURSES

(a) Structural Materials

Title	**Advanced Phase Transformations**	Number	MTL7XX0
Department	Metallurgical and Materials Engineering	L-T-P [C]	3-0-0 [3]
Offered for	M.Tech. (MT) Program	Type	Compulsory
Prerequisite	None		

Objectives

The Instructor will:

1. Explain the fundamentals of phase transformations in metals, alloys, nanomaterials, polymers and ceramics

Learning Outcomes

The students are expected to have the ability to:

1. Understanding of microstructure evolution during the phase transformation
2. Understanding of different type of phase transformations (equilibrium and non-equilibrium) in metallic and non-metallic systems and their influence on phase evolution.

Contents

Thermodynamics of phase transformation (6 Lectures): Single component system - Thermodynamics of homogeneous and heterogeneous nucleation, Free energy, Activation Barrier, Driving force. Multi component system - Free energy composition diagram. Chemical Potential.
Diffusion (4 Lectures): interstitial and substitutional diffusion, the relationship between macroscopic diffusion and atomic mechanisms
Growth (8 Lectures): Theory of thermally activated growth, Interface controlled growth, Diffusion controlled growth, Interface instability. Isothermal and continuous cooling transformation diagrams. Ostwald ripening. Precipitation and particle coarsening, Kinetics of recrystallization, Theory of grain growth, Effect of second phase particles. Transformation Kinetics- Johnson-Mehl equation, Avrami model.
Phase transformation in metals and alloys (10 Lectures): Pearlite, Bainite and Martensitic Transformation. Ordered and disordered transformation, Athermal, isothermal and burst transformations, Thermoelastic transformations, Spinodal Decomposition- diffusion equation in spinodal region. Precipitation hardening.
Non-equilibrium phase transformation (4 Lectures): Nature and growth of solid-liquid interfaces, Rapid solidification, Glass transition, metallic glasses.
Phase Transformation in non-metallic system (10 Lectures): Phase transformation in ceramics. Phase transformation in Nanomaterials - role of surface energies in nanocrystals, entropy of nanomaterials. Phase transformation in polymers – supercooled liquids and crystallization, superheated crystals, liquid crystals, phase separation of polymer blends and co-polymers.

Textbooks

1. Raghavan, V., *Solid State Phase Transformations*, 1st edition, Prentice Hall India, 1987.
2. Porter, D. A., Easterling, K. E., and Sherif, M. Y., *Phase Transformation in Metals and Alloys*, 3rd edition, CRC Press, 2009
3. Abbaschian, R., Abbaschian, L., and Reed-Hill, R. E., *Physical Metallurgy Principles*, 4th edition, Cengate Learning, 2009

Reference Books

1. J. W. Christian, *The Theory of transformations in metals and alloys* , Pergamon press.
2. Khachaturyan, A. G., *Theory of Structural Transformations in Solids*, 1st edition, Dover publications, 2008.
3. 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	**Plastic Deformation and Microstructure Evolution**	Number	MTL7XX0
Department	Metallurgical and Materials Engineering	L-T-P [C]	3–0–0 [3]
Offered for	M.Tech.	Type	Compulsory
Prerequisite			

Objective

1. Provide background to assess the properties and mechanisms which help in optimizing the plastic deformation of metals over a wide range of service conditions.

Learning Outcomes

1. To provide basic understanding of the mechanisms that make the metal exhibit variation in deformation and strength for metal forming and applications.
2. Imparting knowledge in metals plastic deformation with respect to their microstructure evolution.

Course Content

1. Deformation behavior: single crystal vs polycrystalline material, stress-strain curves, geometrically necessary dislocations. (4 lectures)
2. Effect of microstructure on flow properties: Hall-Petch relationship, role of grain-boundaries. (6 lectures)
3. Strengthening mechanisms: solid solution strengthening, precipitation hardening, grain refinement. (10 lectures)
4. High Temperature deformation: creep, super-plasticity, dynamic recovery, recrystallization and grain growth. (12 lectures)
5. Deformation behavior of ceramics and polymeric materials: ductile ceramics, plasticity in specific ceramics, dislocation activity in ceramics, non-crystalline polymer, crystalline polymer, structure-property relationship in polymers. (10 lectures)

Text Books

1. Dieter, G. E., Mechanical Metallurgy, 3rd Edition, McGraw Hill Book Company, 1986.
2. Courtney, T. H., Mechanical Behavior of Materials, 2nd Edition, Waveland Pr. Inc., 2005.
3. Shetty, M.N., Dislocations and Mechanical Behavior of Materials, Prentice Hall India Learning Private Limited, 2013.

Suggested References

1. Honeycombe, R.W.K., The Plastic Deformation of Metals, 2nd Edition, ASM, 1984.
2. Meyers, M. A. and Chawla, K. K., Mechanical Metallurgy, Principles and Applications, Prentice-Hall, Inc 1984.

Online Course Material

1. Bauri, R., Introduction to Materials Science and Engineering, Department of Metallurgical & Materials Engineering, Indian Institute of Technology, Madras, NPTEL http://nptel.ac.in/courses/113106032/
2. Sundararaman, M., Defects in Materials, Department of Metallurgical and Materials Engineering, Indian Institute of Technology, Madras, NPTEL http://nptel.ac.in/courses/113106075/
3. Krystyn van Vliet. 3.22 Mechanical Behavior of Materials. Spring 2008. Massachusetts Institute of Technology: MIT OpenCourseWare, https://ocw.mit.edu. License: Creative Commons BY-NC-SA.

Title	**Structural Materials Laboratory**	Number	MTL7XX0
Departmen t	Metallurgical and Materials Engineering	L-T-P [C]	0-0-2 [1]
Offered for	M.Tech. (MT)	Type	Specialization Compulsory (SC) for Structural Materials
Prerequisite	NA		

Objectives

The Instructor will:

1. Provide background and hands on training on conducting experiments for processing of structural materials and measurement of structural properties of materials

Learning Outcomes

The students are expected to learn:

1. Basic materials processing and property measurement techniques
2. Role of processing parameters on material properties

Contents

NA

Laboratory Experiments

1. Metallography of steel, Copper, Aluminum, and Magnesium alloys
2. Solid-liquid transformation: Thermal analysis and DSC analysis
3. Heat treatment of Metals
4. Understanding the recovery of aluminium (high SFE) through changes in electrical conductivity
5. Hardenability measurement (end quench test)
6. Activation energy calculation
7. Ceramic powder preparation to Sintering of the samples.
8. Ceramic Casting and Forming Lab
9. Measurement of uniaxial stress-strain curve of metals, ceramics and polymers as a function of strain rate and determination of relevant mechanical properties
10. Slip-Line Observation
11. Measurement of fracture toughness
12. Rheology of polymers

Textbook

NA

Reference Books

NA

Online Course Material

NA

(b) Process Metallurgy

Title	**Non-Ferrous Metals Extraction**	Number	MTL7XX0
Department	Metallurgical and Materials Engineering	L-T-P [C]	3–0-0 [3]
Offered for	M.Tech.	Type	Compulsory
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

Course Content

Introduction *[7 Lectures]*: Non Ferrous Ores ore & mineral. Thermodynamics & kinetics of metal extraction from oxides, sulphides & other forms

Unit processes in Pyrometallurgy *[7 Lectures]*: Classification and design aspects of roasting process and equipments, calcinations, different types of smelting, refining

Unit processes in Hydrometallurgy *[7 Lectures]*: E-pH diagram, Leaching, Solvent extraction, Ion Exchange,
precipitation, cementation.

Unit processes in Electrometallurgy *[7 Lectures]*: Electrowinning, Electrorefining, Cell potential, polarization,
Electrolytic production of metals from aqueous & Fused salt electrolytes

Extraction of common metals *[14 Lectures]*: Cu, Ni, Zn, Pb, Al, Mg, Au & Ag, Cr, Ti, and rare earth metals.

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	**Ceramic Processing**	**Number**	MTL7XX0
Department	Metallurgical and Materials Engineering	L-T-P [C]	3–0-0 [3]
Offered for	M.Tech.	Type	Compulsory
Pre-requisite	Ceramic and Glass UG		

Objectives

1. Introduce principles and engineering practices of conventional as well as new, unconventional processing techniques for ceramics, especially advanced technical ceramics materials.

Learning Outcomes

1. students will be able to understand the state-of-the-art knowledge about processing of ceramic materials.
2. Students will how different processing variables impacts the microstructure and the resulting properties of ceramic materials.

Contents

1. Ceramic Raw Materials (2 Lectures)
2. Overview of Ceramic Powder Synthesis & their Characterization: i) Reactive powder preparation methods – Mechanical methods (Attrition Mill, Planetary Mill) ii) Chemical Methods: Precipitation, Sol-gel techniques, Spray pyrolysis, CVD, Combustion synthesis (SHS), Plasma synthesis etc. iii) Powder Characterization: chemical composition, Phase composition, Surface characterization, Different techniques of measurement of particle sizes, shape and size distribution, Powder agglomeration and granulation. (13 Lectures)
3. Colloidal Processing: DLVO theory, double-layer formation, Stern layer, zeta potential, zeta potential, electrophoresis, steric stabilization, rheology of colloidal suspension and ceramic slurry, sol-gel phenomena, shrinkage during dying of gel, role of plasticizers, binders, foaming and antifoaming agents (10 Lectures)
4. Forming Process: Particle packing, regular and random packing, i) Conventional Process – Dry and semi-dry pressing, Slip casting, Extrusion ii) Advanced Process – Cold Isostatic pressing & Hot Isostatic pressing, Tape casting, Injection molding, Hot-pressing. Drying behavior of ceramics: binder removal, drying defects, drying shrinkage, advanced drying technologies. (7 Lectures)
5. Sintering / Firing Process: i) Liquid Phase sintering, vitrification and Solid-state sintering, Driving force of sintering, sintering additives. A few case studies of sintering process. ii) Microwave Sintering – other recent trends in sintering. (6 Lectures)
6. Evolution of Ceramic Microstructures; Effect of green microstructure on sintered microstructures of the products. A few case studies. Mechanism of mass flow during sintering. Kinetic models for sintering. (4 Lectures)

Text Books

1. M. N. Rahaman, *Ceramic Processing and Sintering,*, CRC Press, 2003
2. J. S. Reed: - Introduction to the principles of ceramic processing
3. Singer and Singer: Industrial Ceramics

Self-Learning Materials

1. D. W. Richerson, *Modern Ceramic Engineering: Properties, Processing, and Use in Design, 3rd ed,*, CRC Press, 2006.
2. Ceramic Processing before Firing – Onada & Hench

Online Course Material

1. Principles of Ceramic Fabrication and processing. Prof. D. Bhattacharya, Materials Science Center IIT Kharagpur
https://www.youtube.com/watch?v=eB5ORUW_tUg&list=PLOZmn6GN1i-V7JCuDTRs-8QLr1RZtbq_o

Course Title	**Process Metallurgy Laboratory**	Number	MTL7XX0
Department	Metallurgical and Materials Engineering	L–T–P [C]	0–0–2 [1]
Offered for	M.Tech.	Type	Compulsory
Pre-requisite	-		

Objectives
To introduce various assessment methods of minerals

Learning Outcomes
The students will be able to characterize the mineral as per the size, metal content, etc.

Course Content

1. Determination of physical characteristics of sample like specific gravity, bulk density, angle of repose.
2. Size analysis, wet & dry sieve analysis, Sub-sieve analysis – Beaker decantation and Andreasen Pipette method, specific surface by permeability method,
3. Verification of basic energy laws, Denver grindability test. Determination of pulp density by actual, and specific gravity method [PD scale/tables].
4. Demonstration to different methods analytical techniques i.e. AAS, DTA/TGA, XRD, SEM, TEM etc. for qualitative and quantitative analysis
5. Chemical analysis of hematite/magnetite/chromite/goethite etc. for estimation of Fe, Mn, Al_2O_3, SiO_2, LOI and other elements.
6. Chemical analysis of limestone/magnesite/dolomite by volumetric/gravimetric methods Estimation of CaO, MgO, Fe, Al_2O_3, SiO_2, LOI in their respective minerals.
7. Chemical analysis of Copper, Lead, Zinc, Sulphide ore for estimation of Cu, Pb, Zn, Fe, Al_2O_3, SiO_2, LOI and other elements by volumetric /instruments methods.
8. Melting and casting of steel
9. Melting and casting of light alloys
10. Welding of metals and alloys

Text Books
1. Abouzeid, A. Z. M., *Mineral Processing Laboratory Manual*, Trans Tech Publications, 1990.
2. Venkatachalam. S., *Laboratory Experiments in Mineral Engineering*, Oxford & IBH Pub. Co (1982).

DETAILED SYLLABUS FOR THE SPECIALISATION ELECTIVE COURSES

(b) Structural Materials

Course Title	**Material Aspects in Additive Manufacturing**	Number	MTL7XX0
Department	Metallurgical and Materials Engineering	L-T-P [C]	3–0–0 [3]
Offered for	M.Tech.	Type	Elective
Prerequisite	None		

Objective:

1. Understanding the metallurgical and materials engineering aspects of additive manufacturing.

Learning Outcomes

1. Ability to learn the additive manufacturing process physics to design and fabricate the 3D parts with desired structure and property.
2. Ability to monitor and control the additive manufacturing (AM) process.

Course Content

1. AM Overview : Direct Digital Manufacturing and their importance. Different AM processes and relevant Process Physics. (5 Lectures)
2. AM Powder Production and Characterization: Different Mechanical and Chemical methods, Atomization of Powder, other emerging processes. Performance Evaluation of different processes. Chemical and Microstructural Characterization of powders. (6 Lectures)
3. Transport phenomena model for AM process: Temperature, Fluid Flow and Composition. (6 Lectures)
4. Metallurgical Aspects of AM process: Solidification. Texture. Non-equilibrium Microstructure. Residual stress. Process-Structure-Property relationship (8 Lectures)
5. Process monitoring and Control for AM: Defects, Geometry, Temperature, Composition and Phase Transformation (6 Lectures)
6. Post processing of AM parts: Support material removal. Machining. Heat Treatment. Hot Isostatic Processing. Hybrid manufacturing. (6 Lectures)
7. Applications of Additive Manufacturing: Additive Manufacturing in Aerospace, Automotive, Electronics industries and Biomedical applications. (5 Lectures)

Text Books

1. Gibson I., David W. R., Stucker B., Additive Manufacturing Technologies: 3D Printing, Rapid Prototyping, and Direct Digital Manufacturing, Springer, 2nd Ed. (2015).
2. Chua C.K., Leong K.F. and Lim C.S., Rapid prototyping: Principles and applications, 3rd Edition, World Scientific, 2010.

Self-learning Materials

1. Sands, R.L. and Shakespeare C.R., *Powder Metallurgy Practice and Applications*, Newness Publications, 1970.
2. Majumdar J.D. and Manna I., Laser-assisted fabrication of materials, Springer Series in Material Science, 2013.

Title	**Dislocations in Materials**	Number	MTL7XX0
Department	Metallurgical and Materials Engineering	L-T-P [C]	3–0–0 [3]
Offered for	M.Tech.	Type	Elective
Prerequisite			

Objective

1. Give a broad overview of dislocations and their interactions in crystals.

Learning Outcomes

1. The student would know the role of dislocations on properties of materials.

Course Content

1. *Defects in crystals:* types of defects, types of dislocations, perfect and partial dislocations, methods for observation of dislocations. (4 lectures)
2. *Movement of dislocations:* slip and slip plane, cross-slip and climb. (4 lectures)
3. *Elastic properties of dislocations:* forces on dislocations, stress field and strain energy of a dislocation. (8 lectures)
4. *Dislocations in different crystals:* dislocations in FCC, HCP and BCC metals, and other periodic systems. (8 lectures)
5. *Intersection of dislocations:* Jogs, movement of dislocations containing elementary jog, superjogs, intersection of extended dislocations and extended jogs. (4 lectures)
6. *Multiplication of dislocations:* nucleation, Frank-Reed sources, multiple cross-glide, climb & grain boundary. (5 lectures)
7. *Dislocation arrays and crystal boundaries:* dislocation boundaries, low-angle boundaries & steps in interfaces. (5 lectures)
8. *Dislocations in ordered structures and anti-phase boundaries* (4 lectures)

Text Books

1. Hull, D. and Bacon, D. J., *Introduction to Dislocations*, 4th edition, Butterworth-Heinemann, 2001.
2. Hirth, J. P., and Lothe, J. L., *Theory of Dislocations*, 2nd edition, Krieger, 1982.
3. Weertman J and Weertman J., *Elementary dislocation theory,* Oxford University Press, 1992.

Reference Books

1. *Dislocations in Solids*, Edited by Nabarro, F. R. N., North Holland.

Title	**Diffusion in Solids**	Number	MTL7XX0
Department	Metallurgical and Materials Engineering	L-T-P [C]	3–0–0 [3]
Offered for	M.Tech.	Type	Elective
Pre-requisite			

Objectives

The Instructor will:

1. Explain the mechanism of diffusion and their relevance to various metallurgical processes

Learning Outcomes

The students are expected to have the ability to:

1. Relate the role of diffusion in different metallurgical phenomena controlling the properties of materials

Course Content

Introduction [7 Lectures]: Thermodynamic parameters in a binary system. Chemical potential and Activity of elements. Equilibrium concentration of vacancy concentration in a pure element. Defects in the ordered phases.
Laws of diffusion [4 Lectures]: Fick's first law, Fick's second law, Kirkendall effect.
Atomic Mechanism of Diffusion *[8 Lectures]*: Interstitial diffusion, Concept of random walk Lecture, Substitutional diffusion, Activation energy for diffusion, Orientation dependence Diffusion in the ordered phases.
Phase diagram and diffusion in ternary and multicomponent systems [9 Lectures]: Ternary and multicomponent diffusion, Intrinsic, integrated and the average diffusion coefficients, Phase diagram determination by the diffusion couple technique.
Diffusion in semiconductors [6 Lectures]: self-diffusion, foreign atom diffusion, interstitial-substitutional diffusion.
Diffusion in other materials [8 Lectures]: ionic crystals, fast ion conductors, metallic glasses, oxide glasses, ceramics and polymers

Textbooks

1. Shewmon, P. G., Diffusion in Solids, 2nd Edition, Wiley-TMS, 1991
2. Helmut, M., Diffusion in Solids: Fundamentals, Methods, Materials, Diffusion-Controlled Processes, Springer, 2007
3. Philibert, J., *Atom Movements (Diffusion and Mass Transport in Solids),* Translated by S.J. Rothman, Editions de Physique, 1991

Online Course Materials

1. Paul, A., Diffusion in Solids, NPTEL Course Material, Indian Institute of Science Bangalore, http://nptel.ac.in/courses/113108052/
2. Allen, S., and Eagar, T., 3.205 Thermodynamics and Kinetics of Materials. Fall 2006. Massachusetts Institute of Technology: MIT OpenCourseWare, https://ocw.mit.edu. License: Creative Commons BY-NC-SA

Title	**Cellular Materials**	Number	MTL7XX0
Department	Metallurgical and Materials Engineering	L-T-P [C]	3-0-0 [3]
Offered for	M.Tech. (MT)	Type	Elective
Prerequisite	None		

Objective:

1. This course will essentially comprise of synthesis of metal foam, characterization, properties and application of metal foam.

Learning Outcomes

1. Build up knowledge on synthesis techniques of metallic foams and their design for a wide range of applications.

Course Content

Introduction: Definition and types of cellular materials, applications (2 lectures)

Processing techniques of metal foams: Liquid state processing, Solid state processing, Electro deposition technique, vapor deposition.(10 lectures)

Characterization methods: Structural characterization, mechanical properties testing, Quantitative 3D Characterization (Segmentation and Morphology), crashworthiness evolution.(10 lectures)

Design aspects: Analysis for materials selection, constitutive equations, Elastic deflection, and buckling, vibration and sound absorption capability, thermal management. (8 lectures)

Sandwich structures: Stiffness and strength, collapse mechanisms. (6 lectures)

Selection criteria for different applications: light weight structures, bio-medical implants, filters, electrodes, catalysts, heat exchangers. Packaging and blast protection.(6 lectures)

Text Books

1. Ashby, M. F., Evans, A.G., Fleck, N.A., Gibson, L.J., Hutchinson, J.W., Wadley, H.N.G., *Metal Foams: A Design Guide*, Butterworth-Heinemann, 2000.
2. Weaire, D. L., Hutzler, S., *The Physics of Foams*, Clarendon Press, 2001.
3. Clyne, T. W., Simancik, F., *Metal Matrix Composites and Metallic Foams,* Euromat 99, Volume 5, Wiley VCH, 2000.

Suggested References

1. Gibson, L. J., M.Ashby, M. F., *Cellular Solids: Structure and Properties*, 2nd edition, Cambridge University Press, 1999.
2. Banhart, J., Ashby, M.F., Fleck, N.A. (editors), *Cellular Metals and Metal Foaming Technology,* *Proceedings of the 2nd International Conference* (MetFoam2001), 18-20 June 2001, MIT-Verlag Bremen 2001.
3. Banhart, J., Ashby, M.F., Fleck, N.A.(editors),*Metal Foams and Porous Metal Structures,* *Proceedings of the International Conference* (MetFoam '99), 14-16 June 1999, MIT-Verlag Bremen 1999.

Title	**Fracture and Fatigue**	Number	MTL7XX0
Department	Metallurgical and Materials Engineering	L-T-P [C]	3-0-0 [3]
Offered for	M.Tech. (MT)	Type	Elective
Prerequisite	UG level Mechanical Behavior of Materials		

Objectives

The Instructor will:

1. Introduce the concept of fracture mechanics and explain the failures in the context of fracture mechnaics principles

Learning Outcomes

The students are expected to:

1. Understand the concepts of stress intensity factor and strain energy release rate
2. Apply fracture mechanics principles for failure prediction and analysis

Contents

Mathematical Foundation [4 lectures]: Introduction to elasticity, complex numbers, displacement formulation, and stress formulation, Airy's stress function

Linear Elastic Fracture Mechanics: [6 lectures]: Stress concentration around elliptical hole and, Modes of fracture, Crack tip stress fields for mode I, II, and III, Stress intensity factor, Griffith's theory of brittle fracture

Energy Method for fracture [6 lectures]: Elastic strain energy release rate, G, and its relationship with K, Displacement controlled and load controlled fracture, effect of machine compliance, Instability and R curve

Crack tip plasticity and Elastic-Plastic Fracture [8 lectures]: Plastic zone size, Dugdale and Irwin's approach, plastic zone shape, mixed mode crack, crack tip opening displacement, J-integral, crack growth resistance curves

Microstructural Aspects [6 lectures]: Ductile, brittle, and fatigue failure, fractography, fracture mechanics in metals, ceramics, and composites

Fracture Testing [6 lectures]: K1c testing, J testing, CTOD testing, NDT evaluation of cracks

Fatigue [6 lectures]: Stress-life and strain life approach, cyclic stress-strain curve, microstructural changes due to fatigue, fatigue crack propagation, creep-fatigue interaction

Laboratory Experiments

NA

Textbook

1. Anderson, T.L. (2017) *Fracture Mechanics: Fundamentals and Applications*, 4th Edition, CRC Press
2. Suresh, S., *Fatigue of Materials*; 2nd Edition, Cambridge University Press, 1998

Reference Books

1. Hertzberg, R. W., (2013) *Deformation and Fracture Mechanics of Engineering Materials*, 5th Edition, Wiley

Online Course Material

1. Ramesh, K., *Engineering Fracture Mechanics,*NPTEL Course Material, Department of Applied Mechanics, Indian Institute of Technology Madras, http://nptel.ac.in/courses/112106065/

Course Title	**Thermo Mechanical Processing**	Number	MTL7XX0
Department	Metallurgical and Materials Engineering	L-T-P [C]	3–0–0 [3]
Offered for	M.Tech.	Type	Elective
Prerequisite	None		

Objective

1. Methodology for developing varying microstructures to meet a range of properties for industrial applications.

Learning Outcomes

1. Development of methods using mechanical working and heat treatment effectively.

Course Content

1. *Introduction:* microstructure control, application of heat treatment. (4 lectures)
2. *Effect of mechanical working:* low temperature and dislocation structure, high temperature deformation and sub-structure evolution, concurrent relationship between flow properties and microstructure evolution. (12 lectures)
3. *Principles of thermo mechanical processing (TMP):* single phase versus multi-phase materials, sequencing of mechanical working and heat treatment, concurrent manipulation of microstructure. (14 lectures)
4. *Application of TMP:* deformation induced phase transformation, steel for car body, dual phase and TRIP steel, controlled rolling of HSLA steel, electrical steel, patented steel wire, aerospace applications (Aluminium, Special alloys). (12 lectures)

Text Books

1. Krauss G., *Steels: Processing, Structure and Performance*, ASM Int'l Materials Park, 2005.
2. Verlinden, B., Driver, J., Samajdar, I. and Doherty, R. D., *Thermo-Mechanical Processing of Metallic Materials*, Elsevier, 2007.
3. Krauss G., *Principles of Heat Treatment of Steel*, ASM Intl, 1989.

Suggested References

1. Sakaia, T., Belyakov, A., Kaibyshev, R., Miura, H. and Jonas, J.J., *Dynamic and Post-Dynamic Recrystallization Under Hot, Cold and Severe Plastic Deformation Conditions*, Progress in Materials Science 60, 130-207 (2014).
2. Sherby, O.D., Wadsworth, J., and Nieh, T. G., *Superplasticity in Metals and Ceramics*, Cambridge University Press, 2005.

Web Resources

1. Shekhar, S. and Gaur, A. Fundamentals of Materials Processing (Part- II) Department of Materials Science and Engineering Indian Institute of Technology, Kanpur, NPTEL http://nptel.ac.in/courses/113104075/
2. Gururajan, M.P. , Phase Transformations and Heat Treatment, Department of Metallurgical Engineering and Materials Science, Indian Institute of Technology, Bombay, NPTEL, http://nptel.ac.in/courses/113101003/
3. Schuh, C., 3.044 Materials Processing. Spring 2013. Massachusetts Institute of Technology: MIT Open Course Ware, https://ocw.mit.edu. License: Creative Commons BY-NC-SA.

Title	**Near Net Forming**	Number	MTL7XX0
Department	Metallurgical and Materials Engineering	L-T-P [C]	3–0–0 [3]
Offered for	M.Tech.	Type	Elective
Prerequisite	None		

Objective

1. Industrial processing technique of near net forming for their applications.

Learning Outcomes

1. Development of methods used by forging industry.

Course Content

1. *Introduction and Application of Near net forming.*(2 lectures)
2. *Manufacturing:*
    a. *Casting:* Robo-casting, additive manufacturing by 3D printing, investment casting, near net casting, direct coagulation casting, low pressure injection molding, state of the art casting & foam casting. (4 lectures)
    b. Pressure less spark plasma sintering, miniature components sintering near net rolling of soft parts, cross wedge rolling process. (3 lectures)
    c. *Spray forming:* electric arc spray forming, spraying-conform process & thermal spray forming. (3 lectures)
    d. Extrusion, infiltration, compound forming, precise shape forming, isothermal and near isothermal processing, friction stir forming & micro forming. (3 lectures)
    e. *Thixo Methods:* semi-solid processing, thixo-forming, thixo extrusion, shape forming from colloidal processing, polymer impregnation and pyrolysis. (4 lectures)
    f. *Powder methods:* Powder technology & die pressing powders. (3 Lectures)
    g. *Other methods:* Net shaped heaping, laser metal deposition, warm spinning of cast iron, diffusion bonding, explosive welding, micro-forming, micro deep drawing, thermo hydrogen processing, spinning, shear forming and flow forming & bulge forming. (8 lectures)
3. *Materials:* Bimetal, Ti and its composites, Al alloys (Al-Mg, Al-Ti, Al-Si), Ni super alloys, intermetallic porous materials, SiC, etc for different applications. (6 lectures)
4. *Biological applications:* Clinical Therapeutics and Health Monitoring. (3 lectures)
5. *Engineering applications:* Turbine Blade, Thermal coatings and Hollow turbine blades.(3 lectures)

Text Books

1. *Near Net Shape Manufacturing of Metal: A Review of Approaches and Their Evolutions*, Proceedings of the Institution of Mechanical Engineers Part B Journal of Engineering Manufacture, 2017.
2. Grant, P. S., *Spray forming*, Progress in Materials Science, 39, 497-545, 1995.
3. Waterman, N. A., *The Selection of Materials*, Engineering Design, 1982.

Further reading

1. G Giuliano, G., *Superplastic Forming of Advanced Metallic Materials*, Woodhead, 2011.

Title	**Light Metals and Alloys**	Number	MTL7XX0
Department	Metallurgical and Materials Engineering	L-T-P [C]	3–0–0 [3]
Offered for	M.Tech.	Type	Elective
Prerequisite			

Objective

1. Introduce the prospect of competitive structural materials with high specific strength.

Learning Outcomes

1. Appreciate the role of light metals for energy savings in different applications/sectors.

Course Content

Introduction: Importance of light metals, overview of light metals production. (4 lectures)

Techniques for melting and solidification: solidification, grain refinement, casting processes. (6 lectures)

Heat treatment: grain refinement, strengthening by solid solution, precipitation hardening, dispersion of second phase particles. (8 lectures)

Alloy designations and properties: specific alloy systems ((a) Al-alloys, (b) Mg-alloys, (c) Ti-alloys). (8 lectures)

Manufacturing and applications: aerospace, biomedical, automobile, domestic appliances. (8 lectures)

Novel processing methods: composites, metallic foams, rapid solidification, Quasi crystals, amorphous alloys, mechanical alloying, physical vapor deposition, additive manufacturing. (8 lectures)

Text Books

1. Polmear, I. J., St. John, D., Nie, J. F., Qian, M, *Light Alloys*, 5th edition, Elsevier 2016.
2. Brandes E. A. and Brook G. B., *Smithells Light Metals Handbook*, Elsevier, 1998.

Self-Learning materials

1. Totten G.E. and Mackenzie D.S., *Handbook of Aluminum Vol. 1: Physical Metallurgy and Processes*, CRC Press 2003.
2. Friedrich H.E., and Mordike B.L., *Magnesium Technology*, Springer, 2004.
3. Lütjering G., Williams J.C., *Titanium*, 2nd edition, Springer, 2007.

Title	**High Entropy Alloys**	Number	MTL7XX0
Departmen t	Metallurgical and Materials Engineering	L-T-P [C]	3–0–0 [3]
Offered for	M.Tech. (MT)	Type	Elective
Prerequisit e			

Objectives

The Instructor will:

1. introduce to the new class of materials in terms of their design strategy, thermodynamics and deformation behavior

Learning Outcomes

The students are expected to have the ability to:

1. Understand the fundamental difference in the design of conventional alloys and high entropy alloys.
2. Correlate the outstanding mechanical properties of these materials with the phase stability and microstructural evolution in them.

Contents

Basics of HEAs: Fundamental definitions of HEA, HEAs vs conventional materials, Classification of HEAs, Four core effects in HEAs *(4 lectures)*

Thermodynamics of HEAs: Role of maximization of entropy and enthalpy, Interrelationship of entropy Gibb's free energy and Stacking fault energy, formation of solid solutions in HEAs, intermetallic compounds/second phases in HEAs *(7 lectures)*

Fabrication and processing of HEAs: Casting and solidification in HEAs, Thermo-mechanical processing of HEAs, Severe plastic deformation in HEAs, Welding of HEAs *(8 lectures)*

Microstructural evolution and mechanical properties of HEAs: Single phase f.c.c. HEAs, f.c.c. and b.c.c. HEAs, f.c.c. and h.c.p. HEAs, b.c.c. and h.c.p. HEAs *(7 lectures)*

Deformation mechanisms in HEAs: Dislocation strengthening, solid solution strengthening, twinning induced plasticity, transformation induced plasticity, precipitation strengthening, dual phase strengthening *(8 lectures)*

Case Studies: FeMnCoCrNi HEA, AlCoCrFeNi HEA, FeMnCoCrSi HEAs, Refractory HEAs *(8 lectures)*

Textbook

1. Murty B.S., Yeh. J.W., Rangnathan S., Bhattacharjee P.P., (2019), *High Entropy Alloys*, 2rd Edition, Elsevier Publishing, Cambridge, MA United States
2. Srivatsan T.S., Gupta M., (2019) High Entropy Alloys: Innovations, Advances and Applications

Reference Articles

1. Miracle D.B., Senkov O.N., Critical review of high entropy alloys, Acta Materialia 122 (2017) 448-511.
2. George E.P., Raabe D., Ritchie R.O., High Entropy Alloys, Nature review Materials 4 (2019) 515-534.

Title	**Solidification of Metal and Alloys**	Number	MTL7XX0
Department	Metallurgical and Materials Engineering	L-T-P [C]	3–0–0 [3]
Offered for	M.Tech.	Type	Elective
Prerequisite			

Objective:

1. The fundamentals of liquid to solid transformation and practical implication to practice.
2. Processes such as crystal growth, interface stability, splat cooling, ingot casting shape casting will be dealt with paying particular emphasis to fundamentals of mass transport, heat flow and interface kinetics.

Learning Outcomes

1. Build up knowledge on fundamentals of solidification of metals and alloys and correlating with various casting processes and microstructure evolution.

Course Content

Fundamentals of solidification [8 Lectures]: Thermodynamics of nucleation and growth phenomena, crystal growth, homogenous and heterogeneous nucleation, role of contact angle grain refinement. (6 lectures)

*Solidification of metals and alloys [10 Lectures]:*Heat flow, plain front solidification, cellular solidification, constitutional undercooling, formation of dendrites, eutectic solidification, peritectic solidification, monotectic solidification.

Solidification processes *[8 Lectures]*: Solidification during welding, additive manufacturing, zone refining, directional solidification, single crystal fabrication, continuous casting. (10 lectures)

Rapid solidification processes (RSP) [6 Lectures]. Conventional and unconventional effects. Undercooling and recalescence. Amorphous state. Glass forming ability. Methods for preparing rapidly solidified material.

Recent developments [10 Lectures]: interface kinetics, interface dynamics, phase selection, microstructure selection. Effect of vibration. Theory convection effects. Solidification under external field, electromagnetic stirring, ultrasonic processing. Multicomponent alloys and numerical techniques.

Text Books

1. Flemings, M.C., *Solidification Processing*, Mcgraw-Hill Book Company, 1974.
2. Campbell, J., *Complete casting Handbook: Metal Casting Processes, Metallurgy, Techniques and Design*, Butterworth-Heinmann, 2015.

Reference Books

1. Minkoff, I., *Solidification and Cast Structure*, Wiley, 1986.

Title	**Composite Materials**	Number	MTL7XX0
Department	Metallurgical and Materials Engineering	L-T-P [C]	3-0-0 [3]
Offered for	M.Tech.	Type	Elective
Prerequisite	Structures of Materials, Physics of Materials		

Objectives

The course comprises

1. Classification and application of different composite materials
2. Structures and properties of different composite materials.
3. Design of composite materials, directional properties.

Learning Outcomes

Upon completion of this course, a student should be able to:

1. Acquire a deep knowledge and understanding about the structure property relationship of different types of composites
2. Conduct experiments and design composite materials in area of noise, vibration, and harshness (NVH).

Contents

Introduction: [8 lectures] Definition, application and Classifications, properties, advantages and limitations

Matrix and Fibres: [8 lectures] Glass, graphite, aramid, boron, ceramic fibres, polymer, ceramic, carbon matrix.

*Short fiber composites [6 lectures]*fabrication, hand lay-up, bag molding, resin transfer molding process.

*Orthotropic lamina: [12 lectures]*Unidirectional composites, density, longitudinal modulus, failure modes, minimum and critical volume fraction, transverse modulus, Helpin-Tsai relationship, Stress transformation, Hooks law for anisotropic materials, elastic constants, stiffness, Shear stress

Composite laminates: [8 lectures] Strain displacement relation, stress strain relation, resultant force and moments, curvature, physical significance of extensional stiffness matrix, coupling matrix and bending stiffness matrix.

Laboratory Experiments

NA

Textbook

1. Clyne, T. W. and Hull, D., *An Introduction to Composite Materials*, 3rd edition, Cambridge University Press, 2019.

Reference Book

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

Online Course Material

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

Title	**Continuum Plasticity**	Number	MTL7XX0
Department	Metallurgical and Materials Engineering	L-T-P [C]	3-0-0 [3]
Offered for	M.Tech. (MT)	Type	Elective
Prerequisite	UG level Mechanics of Solids, Mechanical Behavior of Materials		

Objectives

The Instructor will:

1. Provide background on fundamentals of the mechanics of continuous media.

Learning Outcomes

The students are expected to:

1. Understand basic concepts of plasticity and damage mechanics and understand the capabilities and limitations of the different constitutive models
2. Identify the material parameters associated with material models and prepare material input data for finite element modeling

Contents

Introduction and Background: [6 lectures] Index notation, Stress, deformation, and strain tensor, Generalized Hooke's Law, stress and strain deviators, crystal slip, critical resolved shear stress

Rate Independent Plasticity for Isotropic Solids: [8 lectures] Yield criteria, Physical interpretation, Yield surface in 3D-space and normality, plastic flow rule- general formulation, associated flow, effective plastic strain increment, proportional and non-proportional loading

Evolution of Yield Surface: [8 lectures] Correlation between plastic strain evolution and yield surface, Strain hardening, consistency condition, pressure-dependent plasticity, loading and unloading criteria, Drucker's stability postulate, Isotropic hardening, Kinematic hardening, combined hardening

Solutions to Elastic-Plastic Problems [8 lectures]: Examples of elastic-plastic problems such as, Plane strain bending and compression, cylindrical bars under tension and torsion, thin walled tubes under combined loading, thermal stress in thick walled tube, etc.

Implicit and Explicit Integration of von Mises Plasticity [6 lectures]: implicit and explicit integration of constitutive equations, implicit integration-radial return method, material jacobian, isotropic, kinematic and combined hardening

Ductile Damage [6 lectures]: Yield criteria for spherical voids geometry, Application of Gurson's model to the analysis of damage distribution in notched specimen, Applications

Laboratory Experiments

NA

Textbook

1. Dunne, F, Petrinic, N., (2006) *Introduction to Computational Plasticity*, 1st Edition, Oxford University Press
2. Malvern, L.E. (1969) *An Introduction to the Mechanics of Continuous Medium,* 1st Edition, Prentice Hall

Reference Books

1. Cazacu, O., Revil-Baudard, B., (2019) *Plasticity-Damage Couplings: From Single Crystal to Polycrystalline Materials*, Springer International Publishing

Online Course Material

1. Bag, S., Introduction to Crystal Elasticity and Crystal Plasticity, NPTEL Course Material, Department of Mechanical Engineering, Indian Institute of Technology Guwahati, https://nptel.ac.in/courses/113/103/113103072/

Title	**High Temperature Materials**	Number	MTL7XX0
Department	Metallurgical and Materials Engineering	L-T-P [C]	3-0-0 [3]
Offered for	M.Tech. (MT)	Type	Elective
Prerequisite			

Objectives

1. To understand the structure, properties and behavior of materials on elevated temperature.
2. To gain knowledge in the selection of suitable materials for various engineering applications at high temperature.

Learning Outcomes

1. Enrich knowledge of various behavior and property changes inside the material structure in raised temperature and methods to strengthening the material.

Contents

Creep (8 Lectures): Factors influencing functional life of components at elevated temperatures, definition of creep curve, various stages of creep, metallurgical factors influencing various stages, effect of stress, temperature and strain rate.

Design for creep resistance (8 lectures): Design of transient creep time, hardening, strain hardening, expressions of rupture life of creep, ductile and brittle materials, Monkman-Grant relationship.

Fatigue and fracture (7 lectures): S.N. curves - Endurance limits - Effect of mean stress, Goodman, Gerber and Soderberg relations and diagrams, Various types of fracture, brittle to ductile from low temperature to high temperature, cleavage fracture, and ductile fracture due to micro void coalescence-diffusion controlled void growth; fracture maps for different alloys and oxides.

Oxidation and hot corrosion (9 lectures): Oxidation, Pilling, Bedworth ratio, kinetic laws of oxidation- defect structure and control of oxidation by alloy additions, hot gas corrosion deposit, modified hot gas corrosion, fluxing mechanisms, effect of alloying elements on hot corrosion, interaction of hot corrosion and creep, methods of combat hot corrosion.

Super alloys and other materials (10 lectures): Iron base, Nickel base and Cobalt base super alloys, composition control, solid solution strengthening, precipitation hardening by gamma prime, grain boundary strengthening, TCP phase, embrittlement, solidification of single crystals, Intermetallics, High temperature ceramics-Smart materials

Textbook

1. Raj. R., *Flow and Fracture at Elevated Temperatures*, American Society for Metals, USA, 1985.
2. Hertzberg R. W., *Deformation and Fracture Mechanics of Engineering materials*, 4th Edition, John Wiley, USA, 1996.
3. Courtney T.H, *Mechanical Behavior of Materials*, McGraw-Hill, USA, 1990.

Reference Books

1. Boyle J.T, Spencer J, *Stress Analysis for Creep*, Butterworths, UK, 1983.
2. Bressers. J., *Creep and Fatigue in High Temperature Alloys*, Applied Science, 1981.
3. McLean D., *Directionally Solidified Materials for High Temperature Service*, the Metals Society, USA, 1985.

Title	**Processing of Polymer Matrix Composites**	Number	MTL7XX0
Department	Metallurgical and Materials Engineering	L-T-P [C]	2-0-0 [2]
Offered for	MTech	Type	Elective
Prerequisite	Polymer courses in UG level, Manufacturing processes		

Objectives

1. The main objective of the course is to impart an understanding of the processing of polymers and polymer composites such as Extrusion, Injection molding, Thermoforming, Compression molding and Transfer molding.

Learning Outcomes

1. Upon completion of this course, a student should be exposed to processing techniques of polymer and polymer composites.

Contents

Fractal 1

Introduction: [4 lectures] Engineering materials and processing techniques, Thermoplastics and thermosets, Processing of polymers, Composite materials: basic concepts, Classification of composite materials.

Processing of polymer composites: [10 lectures] Hand-layup, Spray-layup, Compression molding Injection molding. Reaction injection molding, Autoclaving, Resin transfer molding, Filament winding, Pultrusion. Sheet molding, Pre-pegging and challenges in primary processing of composites.

Fractal 2

*Detailed processing techniques: [7 lectures]*_Thermoforming process. Extrusion, Transfer molding, Rotational molding, Blow molding.

Secondary processing of polymer composites: [7 lectures] Joining of polymer composites, Adhesive joining. Mechanical joining, Microwave joining, Induction and resistance welding, Drilling of polymer composites.

Laboratory Experiments

NA

Textbook

1. Mallick, P. K., *Processing of Polymer Matrix Composites: Processing and Applications*, CRC Press, 2018
2. Debnath, K. and Singh, I., *Primary and Secondary Manufacturing of Polymer Matrix Composites*, CRC Press, 2018.

Reference Book

1. Osswald T. A., Ortiz J. P. H. (2006), Polymer Processing Modeling and Simulation, Hanser
2. Agassant J. F., Avenas P., Sergent J. P. and Carreau P. J. (1991), Polymer processing: Principles and modeling, Wiley

Online Course Material

1. Prof. Inderdeep Singh, Processing of Polymers abmnd Polymer Composites, NPTEL Course Material, Dept. of Mechanical & Industrial Engineering, IIT Roorkee, https://nptel.ac.in/courses/112/107/112107221/

Title	**Alloy Design: Computational Thermodynamic Approach**	Number	MTL7XX0
Department	Metallurgical and Materials Engineering	L-T-P [C]	3–0–2 [4]
Offered for	M.Tech	Type	Elective
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.
2. Ability to learn the assessment of binary phase diagram using PARROT module.

Contents

1. *Thermodynamics of Solution:* Ideal solution, configurational entropy, regular solution model, chemical potential, free energy composition diagram, evolution of phase diagrams quasichemical theory, Sub regular solution model. (8 Lectures)
2. *Alloy Design of multicomponent system:* 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. (14 Lectures)
3. CALPHAD modeling of non - metallic system. Cluster variance model. (6 Lectures)
4. *Calculation of thermodynamic parameters:* First principle calculation, Semi-empirical-Miedema approach. Calorimetric measurement, electrochemical measurement, Diffusion couple method. (8 Lectures)
5. *Assessment of thermodynamic system:* Optimization of binary isomorphous and eutectic phase diagram using PARROT module. (6 Lectures)

Lab Experiments

Construction of equilibrium and non-equilibrium phase diagram, Vertical section phase diagram and Property diagram for multi-component alloys, Scheil and equilibrium solidification simulation, Liquidus projections and monovariant reactions in ternary phase equilibria, Creation of user defined thermodynamic database for Solid solution, Stoichiometric compounds, non-stoichiometric compounds.

Textbooks

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

Self-Learning Material

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

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	**Principles of Continuum Mechanics**	Number	MTL7XX0
Department	Metallurgical and Materials Engineering	L-T-P [C]	3-0-0 [3]
Offered for	M.Tech. (MT)	Type	Elective
Prerequisite			

Objectives

The Instructor will:

1. Provide background on fundamentals of the mechanics of continuous media.

Learning Outcomes

The students are expected to understand:

1. Concepts and general principles of material mechanics
2. Mathematical formulations and tensor notations for understanding and developing constitutive equations

Contents

Mathematical Foundation: [6 lectures] Tensors and indicial notations, coordinate transformation, Transformation of cartesian tensors, Tensor multiplication, Vector and Tensor calculus

*Kinematics of Continuum: [8 lectures]*Lagrangian and Eulerian description of motion, Analysis of Deformation- Deformation gradient, stretch and rotation tensors, Deformation Tensors, Finite strain tensors, small deformation theory, Polar Decomposition, compatibility conditions

Analysis of Stress: [8 lectures] Body forces and surface forces, traction vector-stress tensor, stress equilibrium, stress transformation, principal axes, invariants, spherical and deviatoric stress tensors, maximum and minimum shear stress, other stress measures: 1^{st} and 2^{nd}Piola-Kirchhoff stress, Mohr's circle

Motion and Flow: [6 lectures] Material derivative, notations of velocity, acceleration and instantaneous velocity field, Rate of deformation and Spin, material derivative of volume, area and line elements

Fundamental Laws of Continuum Mechanics: [8 lectures] Tensor notation of conservation of mass, linear momentum and angular momentum principle, Equations of motion, Conservation of energy, First Law and Second Law of Thermodynamics, Clausius-Duhem inequality and Dissipation function

Constitutive Relation: [6 lectures] Generalized Hooke's law, Stiffness and compliance tensor, crystal symmetry and its effect on stiffness tensor, Frame indifference, Jaumann stress-rate

Laboratory Experiments

NA

Textbook

1. Reddy, J.N, (2013) *An Introduction to Continuum Mechanics*, 2^{nd} Edition, Cambridge University Press
2. Malvern, L.E. (1969) *An Introduction to the Mechanics of Continuous Medium,* 1^{st} Edition, Prentice Hall

Reference Books

1. Fung, Y.C., (1994) *A First Course in Continuum Mechanics: For Physical and Biological Engineers and Scientists*, Prentice Hall

Online Course Material

1. Reddy, A.N., Continuum Mechanics, NPTEL Course Material, Department of Mechanical Engineering, Indian Institute of Technology Guwahati, https://nptel.ac.in/courses/112/103/112103167/

Title	**Symmetry, Structure and Tensor Properties**	**Number**	MTL7XX0
Department	Metallurgical and Materials Engineering	L-T-P [C]	3–0–0 [3]
Offered for	M.Tech.	Type	Compulsory
Pre-requisite	Linear Algebra and Matrix Mathematics, MATLAB/Mathematica		

Objectives

1. Introduce the concept of symmetry in crystal lattices; point groups, space groups, and use of symmetry in tensor representation of crystal properties, including anisotropy and representation surfaces; and applications to piezoelectricity and elasticity.

Learning Outcomes

1. Students would learn how to calculate different thermodynamic properties of different materials.
2. The student would understand how crystalline anisotropy affects/governs the property anisotropy.

Contents

Introduction: Spherical trigonometry and Applications in Crystallography: (5 lectures)

Crystal lattices: Direct lattice, Crystal systems, Bravais Lattice (2 lectures)

Point Groups: Stereographic projection, Proper Cubic point groups, Improper point groups (Dihedral angle, inversion symmetry), Types of point groups: 2D and 3D lattices (7 lectures)

Space Groups: Enumeration of the operations, Different space groups with specific materials examples (7 lectures)

Group Theory: Basic Concepts, Character Tables, Examples (5 lectures)

Symmetry and Lattice Vibrations: Symmetry and Local Mode Vibrations, Jahn-Teller Effect, IR and Raman Effect (6 lectures)

Tensor Properties of Materials: Basic Tensorial Operations: Transformation of Axis, Eulerian Angles, Orthogonality Neumann Principle, Pseudo Tensors, Symmetry and Mathematical Properties of Tensors, Different ordered tensors: 2nd order(Stress-Strain, Permittivity, Permeability, Thermal Expansion), 3rd order(Piezoelectricity), 4th order (Elasticity Tensor) (10 lectures)

Text Books

1.Newnham, R. E., *Structure-property relations* (Vol. 2). Springer Science & Business Media, 2012.

2. Nye, J. F., *Physical properties of crystals: their representation by tensors and matrices*. Oxford university press, 1985.

Reference Books

1. International Tables for Crystallography Volume A: Space-group symmetry

2. Buerger, M. J., *Elementary crystallography*, John Wiley & Sons, 1956.

Online Course Material

1. Prof. Bernhardt Wuensch, Symmetry, Structure, and Tensor Properties of Materials, DMSE MIT, MIT OCW, https://ocw.mit.edu/courses/materials-science-and-engineering/3-60-symmetry-structure-and-tensor-properties-of-materials-fall-2005/syllabus/

(b) Process Metallurgy

Title	**Advances in Iron and Steel Making**	Number	MTL7XX0
Department	Metallurgical and Materials Engineering	L-T-P [C]	3–0–0 [3]
Offered for	M.Tech.	Type	Elective
Pre-requisite			

Objectives

The Instructor will:

1. Explain principles of thermodynamics and process metallurgy involved in traditional and advanced iron and steel making processes
2. Expose students to advanced methods of making super clean steel

Learning Outcomes

The students are expected to have the ability to:

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

Course Content

Advanced Concepts in Iron Making *(14 Lectures)*: Thermodynamics of C-O, Fe-O, C-O-Fe and C-O-Fe-H2 systems. Models for gas-solid reaction kinetics. Blast furnace reactions and process dynamics; models for the blast furnace; agglomeration: sintering and pelletization mechanisms; blast furnace aerodynamics; irregularities. Direct reduction: gas-based and coal based; reactions in Midrex/Hyl processes, rotary kiln, rotar hearth processes and operational difficulties. Smelting reduction-COREX, Romelt, HiSmelt, Finex process.

Primary steel making *(14 Lectures)*: Review of thermodynamics of steel making. Reactor models: CSTR and plug flow reactors, residence time distributions; Structure and thermodynamics of slags.C-O, Si-O, Mn-O reactions, reactions of S and P, sulphide and phosphate capacities. Oxygen steelmaking : design parameters for vessel and lance, material and heat balances. Process dynamics, static dynamic and process models, process control. Electric arc furnace : reaction mechanisms, material and heat balances, equipment design principles., inclusion shape control.

Secondary and alloy steel making *(7 Lectures)*: Thermodynamics and kinetic analysis, model building. Ladle metallurgy; Deoxidation: thermodynamic and kinetic analysis. Continuous casting: solidification mechanisms and structure, fluid flow and heat transfer in tundish and strand, physical and mathematical models, understanding defects.

Recent trends in steel making *(7 Lectures)* : CONARC process, EOF process, recent trends in stainless steel making, manufacture of ultra - low carbon steel, alloy steel making, different slag practices in EAF steel making, direct steel making.

Textbooks

1. Chatterjje A., *Beyond the Blast Furnace*, CRC Press, 1994.Making, Shaping and Treating of Steel, Vol.1: Ironmaking, 11th Edition, AISE Steel Foundation, 1999.
2. Ghosh A. and Chatterji A., *Ironmaking and Steelmaking : Theory and Practice*, Prentice- Hall (India), 2008.
3. A First Course in Iron and Steel Making, Dipak Mazumdar, Universities Press(India) Pvt. Ltd. (2015), ISBN 10: 817371939X

Online Course Materials

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/

Course Title	**Mineral Processing Technology**	Number	MTL7XX0
Department	Metallurgical and Materials Engineering	L–T–P [C]	3–0–0 [3]
Offered for	M.Tech.	Type	Elective
Pre-requisite	-		

Objectives
1. To learn beneficiation and processing of coal and minerals.
2. To get fundamental understanding of operation of industrial coal preparation plants and mineral beneficiation plants.

Learning Outcomes
The students will be able to
1. Understand the construction and operation of crushers and screens used for coal preparation
2. Understand the operation of beneficiation units for coal and mineral.

Course Content
Introduction: Scope and importance; Basic unit operations, relative merits and demerits of processing of ores. Definitions: ore, mineral, gangue, concentrate, tailing, yield, recovery and ratio of concentration etc. Properties of different minerals relevant to their processing. (6 lectures)

Comminution: Fundamentals of size reduction, purpose, liberation of minerals, degree of liberation, comminution laws, different types of crushers (reciprocating, impact, roll, etc.) and grinding mills, their features and application. Grindability indices. (4 lectures)

Screening: Measurement of particle size. Introduction to various size separation processes and their importance, types of screens – static and dynamic, screening surfaces and screen efficiency, factors influencing screening, screening surfaces and Screen efficiency. (6 lectures)

Classification: Movements of solids in fluid. Free settling, hindered settling, equal settling particles. Reynolds number and its importance. Types of classifiers, their principles and operations. (6 lectures)

Gravity Separation: Washability testing and applications. Principles, construction, operation, merits and demerits of industrial gravity separators: pneumatic jigs, dense medium baths, dense medium cyclones, spirals, tables, water only cyclones etc. Medium recovery circuits for dense medium separation. Enhanced gravity separation. Comparison between the gravity separators. (6 lectures)

Performance evaluation: partition curve, misplacement, probable error in separation, imperfection, yield reduction factor, organic efficiency. (4 lectures)

Magnetic and electro-static separation: Principles, different types of magnetic and electrical separators, their features and applications. (4 lectures)

Flotation: Fundamentals and practice of flotation, types of reagents and their importance. Critical pH curves. Flotation circuits. Factors affecting flotation performance of coal and minerals. (6 lectures)

Text Books
1. Wills, B. A., and Finch, J., *Wills' Mineral Processing Technology: An Introduction to the Practical Aspects of Ore Treatment and Mineral Recovery,* 8th Edition, Butterworth-Heinemann, 2015.
2. Kelly, E. G., and Spottiswood, D. J., *Introduction to Mineral Processing*, Wiley, 1982.
3. Gaudin, A. M., *Principles of Mineral Dressing*, Tata McGraw-Hill, 1975.

References
1. The Coal Handbook: Towards Cleaner Production (*Volume 1: Coal Production*), Edited by Osborne, D., Elsevier, 2013.

2. King, R. P., *Modeling and Simulation of Mineral Processing Systems*, Elsevier, 2012

Online Course Materials

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

Title	**Mass and Energy Balance in Metallurgical Processes**	Number	MTL7XX0
Department	Metallurgical and Materials Engineering	L-T-P [C]	3-0-0 [3]
Offered for	M.Tech. (MT) Program	Type	Elective
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

1. *Metal-slag interactions: (6 Lectures)* Thermo-physical properties of metals and slags, slag-metal equilibrium calculations, application of slag capacity during metal refining
2. *Mass and Energy balance in Iron and Steel Making: (12 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.
3. *Mass and energy balance in calcination and roasting: (12 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.
4. *Mass and energy balance in non-ferrous smelting: (12 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., *Advanced Physical Chemistry for Process Metallurgy*, Academic Press, 1997
2. Shamsuddin M., *Physical Chemistry of Metallurgical Processes*, John Wiley & Sons, 2016
3. Alan Fine H, Gordon H. Geiger, "Handbook on Material and Energy Balance Calculations in Metallurgical Processes", 2nd Revised Edition, Wiley, 1998.

Self-Learning Materials

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

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	**Refractory Materials and Applications**	**Number**	MTL7XX0
Department	Metallurgical and Materials Engineering	L-T-P [C]	3–0–0 [3]
Offered for	M.Tech.	Type	Elective
Pre-requisite			

Objectives

1. Introduce advance principles and engineering practices of refractory materials.

Learning Outcomes

1. students will gain knowledge about the state-of-the-refractory materials and their applications in various industries.
2. Students will be able to understand the choice of different refractory materials their properties and their concomitant usage.

Contents

Raw materials, preparation, properties, special additives and bonding systems, advantages (also disadvantages), importance and applications of some special refractories like mullite (with phase diagram), spinel (with phase diagram), carbon, zircon, zirconia, fused cast, insulating, ceramic fiber, silicon carbide. (14 Lectures)

Ceramic cup in blast furnace – role and function, advantages, compositions. Tap hole clay – function, raw materials & their function, composition, mushroom formation, properties, details of application. Trough castable – raw materials & their functions, properties, development of trough refractory. (14 Lectures)

Slag arrestor dart cone – role & function, composition, working procedure, advantages. Tap hole sleeve – role, composition, advantages. Slide gate refractory - raw materials, composition, function & requirements, working environment, properties, working mechanism, wear out, ZrO_2 inserts, etc. Porous plug – types, raw materials, functions, advantages, top and bottom purging, details of different porous plugs. (6 Lectures)

Continuous casting refractories – properties and functions. Monoblock stopper (MBS) – function, different parts, compositions and role of different portion, failure. Ladle shroud – role, different portions, their functions and composition, failure. Sub entry nozzle (SEN) – advantages & role, different zones and their function, compositions, failure. (8 Lectures)

Text Books

1. R Sarkar,, *Refractory Technology: Fundamentals and Application,*, CRC Press, 2016.
2. J. H. Chesters,, *Refractories- Production and Properties,*, The Iron and Steel Institute, London, 1973.

Self-Learning Materials

1. P. P. Budnikov,, *The Technology of Ceramics and Refractories,*, Translated by Scripta Technica, Edward Arnold, The MIT Press, 4th Ed, 2003.
2. C. A. Schacht,, *Refractory Linings: Thermo-mechanical Design and Applications,*, CRC Press, 1995.
3. R. Amavis (ed.),, *Refractories for the Steel Industry,*, Elsevier Applied Science, 1990.

Online Course Material

1. Fuels Refractory and Furnaces. Prof. Satish Ch. Koria, Metallurgy and Material Science, IIT Kanpur https://nptel.ac.in/courses/113/104/113104008/s

Course Title	**Clean Coal Technology**	Number	MTL7XX0
Department	Metallurgical and Materials Engineering	L–T–P [C]	3–0–0 [3]
Offered for	M.Tech.	Type	Elective
Pre-requisite	-		

Objectives

1. To provide fundamentals concept of efficient way of utilizing coal in different applications with minimum environmental impact.

Learning Outcomes

The students will be able to

1. identify various techniques of utilizing coal for cleaner environment.

Course Content

Introduction to clean coal technology: Coal quality parameters for utilization in thermal power plant, cement, steel and DRI plant. Pre-combustion cleaning, during combustion cleaning, post-combustion cleaning, burning time, unburned carbon estimation and control. Biological and chemical cleaning methods. (10 lectures)

Emission control: Fly ash, SOx and NOx control strategies during combustion and after combustion. Use of ESP, Cyclones, Filters and settling chambers. (4 lectures)

Coal gasification: Gasifying agents: oxygen, air, steam, reactions involved in gasification. Effect of fuel properties on product, blending of fuels. Syn gas, Fuel gas. (14 lectures)

Types of gasifiers: Fixed bed, moving bed, fluidized bed, entrained bed etc. Product gas cleaning and energy utilization, removal of H2S, NH3, tar, suspended particulate matter. (6 lectures)

Other technologies: Underground coal gasification (UCG), Coal bed methane, recovery methane from CBM (Coal Bed Methane), CMM (Coal Mine Methane), AMM (Abandoned Mine Methane), combined cycle power generation (IGCC), oxy-fuel combustion. (8 lectures)

Text Books

1. Miller, B. G., *Clean Coal Engineering Technology*, 2nd Edition, Butterworth-Heinemann, 2016.
2. Sarkar, S., *Fuels and Combustion*, 3rd Edition, Universities Press, 1974.

References

1. Speight, J. G., The Chemistry and Technology of Coal, Second Edition, CRC Press, 1994.

Title	**Glass Science and Technology**	**Number**	MTL7XX0
Department	Metallurgical and Materials Engineering	L-T-P [C]	3–0–0 [3]
Offered for	M.Tech.	Type	Elective
Pre-requisite			

Objectives

1. Introduce the basic scientific principles of glass science
2. Engineering practices of glass manufacturing including raw materials and applications.

Learning Outcomes

1. Students will be able to understand the underlying basic science of glass as well as the unique properties of glasses.
2. Get introduced to industrial glass manufacturing starting from raw materials and be able to correlate glass processing to final desirable properties.

Contents

1. The non-crystalline solids & the glasses. Formation from liquid phase. Formation from a gaseous phase. Formation from a solid phase. Definition of glass. (2 Lectures)
2. Rheological properties of glasses, Viscosity, Elastic & Visco-elastic properties of glasses. (2 Lectures)
3. Vitreous transition. Phenomenological study. Thermodynamic study. Theory of vitreous transition. Relaxation behavior of glass in the transition interval. Determination of transition temperature. (5 Lectures)
4. Conditions of vitrification. Structural theory (Zachariasen model etc.). Kinetic theory of glass (Nucleation & Growth). (4 Lectures)
5. Structural models of glass. Reaction mechanisms. Ion exchange & network breakdown processes. Glass durability controlling factors. Improvement of durability. (3 Lectures)
6. Thermodynamic basis of phase separation in glasses. Immiscibility in glasses. Spinodal decomposition. (5 Lectures)
7. Density & Thermal expansion measurements & their implications and their dependence on compositions. Thermal history effects. Effect of crystallization. Additive rule. (4 Lectures)
8. Diffusion in Glasses. Electrical conductivity of glasses. Dielectric properties;
9. Thermal Properties of glasses, Specific heat, Thermal conductivity, Thermal expansion. (4 Lectures)
10. Glass production, Basic processes of glass making, Batch process, Continuous process, Raw materials selection, Batch house & mixing, Batch transportation, Tank furnace, Batch feeding, Melting & refining, Bottle glass, Sheet glass, Other glasses, Annealing, Thermal treatment, Chemical treatment, Production control & planning, Optical fibre glass production & processes. (11 Lectures)
11. Batch calculation of the glass and determination of the oxide composition of the glass (2 Lectures)

Text Book

1. Tooley, F.V., Handbook of Glass Manufacture, 3rd Edition, Ashlee Publishing Company, 1985.
2. Shand, E. B., and W. H. Armistead, *Glass Engineering Handbook*, Literary Licensing, LLC, 2012.

Reference books

1. Doremus, R. H., *Glass Science*, Wiley, 1994.
2. Varshneya, A. K., and Mauro, J. C., *Fundamentals of Inorganic Glasses*, 3rd Edition, Elsevier, 2019.

Online Course Material

1. Glass Processing Technology, Prof. K.N. Satyanarayana, Civil Engineering, IIT Madras https://nptel.ac.in/courses/105/106/105106178/

Title	**Metallurgical Industrial Waste Management**	Number	MT7LXX0
Department	Metallurgical and Materials Engineering	L-T-P [C]	2–0–0 [2]
Offered for	M.Tech.	Type	Elective
Prerequisite			

Objective:

1. Classification of metallurgical waste products and technological management for their environmental sustainability

Learning Outcomes

1. Differentiate among the different kinds of metallurgical waste.
2. Find optimum method for metallurgical waste management.

Course Content

1. *Types of waste:* Solid, Liquid and gaseous (4 lectures)
2. *Sources of waste:* Metallurgical waste (4 lectures)
3. *Treatment, Storage and Disposal of waste:* Long term storage Land filling, incineration; Short term storage and container materials (5 lectures)
4. *Recycling of waste:* Metal Scrap remelting, Extraction of precious and harmful metals from electronic waste (6 lectures)
5. *Waste to wealth:* Waste for energy, Production of commercial nano particles from waste (5 lectures)
6. *Case Studies:* Steel industry, other metallurgical industries (4 lectures)

Text Book

1. Ramachandra Rao, S. R., *Resource Recovery and Recycling from Metallurgical Wastes*, Elsevier, 2011.

Reference book

1. Gupta, R. C., *Energy And Environmental Management In Metallurgical Industries*, PHI Learning Pvt. Ltd., 2012.

Title	**Modelling of Metallurgical Processes**	Number	MTL7XX0
Department	Metallurgical and Materials Engineering	L-T-P [C]	3-1-0 [4]
Offered for	M.Tech. (MT)	Type	Elective
Prerequisite	None		

Objectives

The Instructor will:

1. Introduce methods for developing simple models of metallurgical processes considering important process variables
2. The models will be evaluated for their industrial adoptability

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 modelling

Contents

Thermodynamic aspects: laws of thermochemistry, Ellingham diagram, solution thermochemistry (6 lectures)

Process metallurgy: transport phenomena, reaction kinetics, rate phenomena, chemical reaction kinetics, fluid flow, heat and mass transfer (12 lectures)

Metal-slag interactions: Thermo-physical properties of metals and slags, slag-metal equilibrium calculations, application of slag capacity during metal refining (12 lectures)

Process phenomena: bubble formation, foaming, gas-liquid reactions, reactions between liquid phases (10 lectures)

Process control in metallurgical processes: iron making, converter steel making, electric arc furnace, secondary steel making (12 lectures)

Textbooks

1. Sano N., Lu W., Riboud P., *Advanced Physical Chemistry for Process Metallurgy*, Academic Press, 1997
2. Shamsuddin M., *Physical Chemistry of Metallurgical Processes*, John Wiley & Sons, 2016.

Reference books

1. Seetharaman S.S., *Treatise on Process Metallurgy*, Volume 1: Process Fundamentals, Elsevier Ltd., 2014
2. Seetharaman S.S., *Treatise on Process Metallurgy*, Volume 2: Process Phenomena, Elsevier Ltd., 2014
3. Seetharaman S.S., *Treatise on Process Metallurgy*, Volume 3: Industrial Processes, Elsevier Ltd., 2014

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/