M.Tech. in Materials Engineering

Program structure with courses

Cat.	*Course Number, Course Title*		*L-T-P*	*Credits*		*Cat.*	*Course Number, Course Title*		*L-T-P*	*Credits*
I Semester						**II Semester**				
C	MTL7XX0	*Thermodynamics of Materials*	2-0-2	3		C	MTL7XX0	*Advanced Phase Transformations*	3-0-0	3
C	MTL7XX0	*Characterization of Materials*	2-0-2	3		E	MTL7XX0	*Elective*	3-0-0	3
C	MTL7XX0	*Plastic Deformation and Microstructure evolution*	3-0-0	3		E	MTL7XX0	*Elective*	3-0-0	3
E	MTL7XX0	Elective	3-0-0	3		E	MTL7XX0	*Elective*	3-0-0	3
NG1	LAN7XX0	*Technical Communication*	1-0-0	S/U		NG2	OAL7XX0	*Innovation and IP Management*	1-0-0	S/U
			Total	**12**					*Total*	**12**
T	*MTS7XX0*	*Summer Thesis*								**8**
III Semester						**IV Semester**				
T	MTT7XX0	Thesis		16		T	MTT7XX0	Thesis		16
			Total	**16**					*Total*	**16**

S.No.	*Category*	*Course Category Title*	*Total Courses*	*Total Credits*
1	C	*COMPULSORY*	4	12
2	E	*ELECTIVES*	4	12
3	NG	*Non-Graded*	2	0
4	T	Thesis	**2 (16+16) +8**	32 + 8
		Total		**64**

*for Direct students and students with different background.

Program compulsory (C)	**Electives (E)**
Thermodynamics of Materials *Characterization of Materials* *Plastic Deformation and Microstructure evolution* *Advanced Phase Transformations*	Any from the Elective list

Department of Materials Engineering

Program Name M.Tech. Materials Engineering

1. The following four courses are compulsory for M.Tech. students of the department:

S.No.	Course Number	*Course Title*	L-T-P	Credits
1	MTL7XX0	*Thermodynamics of Materials* (existing course)	2-0-2	3
2	MTL7XX0	*Characterization of Materials* (existing course)	2-0-2	3
3	MTL7XX0	*Plastic Deformation and Microstructure evolution* (existing course)	3-0-0	3
4	MTL7XX0	*Advanced Phase Transformations* (existing course)	3-0-0	3

2. M.Tech. students shall have the option to choose four courses from the following list of courses:

Electives

S.No.	Course Number	*Course Title*	L-T-P	Credits
1	MTL7XX0	*Diffusion in Solids* (existing course)	3-0-0	3
2	MTL7XX0	*Thermo Mechanical Processing* (existing course)	3-0-0	3
3	MTL7XX0	*Light Metals and Alloys* (existing course)	3-0-0	3
4	MTL7XX0	*Solidification of Metals and Alloys* (existing course)	3-0-0	3
5	MTL7XX0	*High Temperature Materials* (existing course)	3-0-0	3
6	MTL7XX0	*Crystal Plasticity and its applications* (existing course)	3-0-0	3
7	MTL7XX0	*Non-ferrous metals extraction* (existing course)	3-0-0	3
8	MTL7XX0	*Advances in Iron and Steel Making* (existing course)	3-0-0	3
9	MTL7XX0	*Fracture and Fatigue* (existing course)	3-0-0	3
10	MTL7XX0	*Machine Learning for Materials Design* (existing course)	2-0-2	3
11	MTL7XX0	*Computational Modelling in Materials Engineering* (existing course)	2-0-2	3
12	MTL7XX0	Composite Materials (existing course)	3-0-0	3

DETAILED SYLLABUS FOR CORE COURSES

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

Objectives

1. To provide a basis for describing and understanding the stability of various forms of matter.
2. To provide a basis for predicting the properties of an equilibrated system as a function of its content and characteristics.
3. To understand fundamental principles of computational thermodynamics and CALculation of PHAse Diagrams methodology.

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.
3. Apply thermodynamic principles to real-world materials systems using computational tools.

Course Content

Laws of thermodynamics and Chemical reactions (13 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 (4 lectures).

Thermodynamics of solutions and phase diagrams (13 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 (4 lectures), phase equilibrium calculations. (4 lectures)

Laboratory Exercises:
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. Saunders, N., Miodownik, A. CALPHAD (Calculation of Phase Diagrams): A Comprehensive Guide. United Kingdom: Elsevier Science, 1998.

Self-Learning Material

1. Hillert, M., *Phase Equilibria, Phase Diagrams and Phase Transformations Their Thermodynamic Basis,* Second edition, Cambridge University Press 2008.

Title	**Characterization of Materials**	Number	MTL7XX0
Department	Metallurgical and Materials Engineering	L-T-P [C]	2–0–2 [3]
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.

Course Content

Structure of Materials (7 Lectures): Crystal structure, Symmetry elements, Miller indices, Stereographic projections, Reciprocal space, Structural characterization by X-ray diffraction, small angle scattering

Scanning electron microscopy (6 Lectures): Sample-electron interaction, Basis of image contrast and various operating modes, Low voltage SEM. Electron back scattered diffraction/OIM, micro-textural analysis.

Transmission electron microscope (6 Lectures): Lens defects, Mass-thickness contrast and diffraction contrast, Bright Field and Dark Field imaging, Electron Diffraction: SADP, Phase contrast and HRTEM.

Spectroscopic Characterization (7 Lectures): Optical emission spectroscopy, Energy dispersive spectroscopy, Electron Probe Microanalysis, Electron energy loss spectroscopy, X-ray fluorescence spectroscopy, X-ray photoelectron spectroscopy, FTIR, and Raman spectroscopy.

Lab Experiments

XRD Pattern Indexing;
XRD Profile fitting;
Lattice parameter and crystallite size calculation;
SEM/EDS analysis;
Orientation analysis using SEM-EBSD
Electron Diffraction Pattern Indexing;
Image Analysis;
UV-visible analysis and band gap calculation;
Functional group analysis using FTIR;
Calculation of thermodynamic parameters using DSC 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	**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. (5 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. (10 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	**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 (5 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 (9 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 (9 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/

DETAILED SYLLABUS FOR ELECTIVES

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 [6 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 *[7 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 [7 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

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. (12 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). (11 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	**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. (7 lectures)

Alloy designations and properties: specific alloy systems ((a) Al-alloys, (b) Mg-alloys, (c) Ti-alloys). (7 lectures)

Manufacturing and applications: aerospace, biomedical, automobile, domestic appliances. (7 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	**Solidification of 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. 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.

Solidification of metals and alloys [9 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.

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 [8 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	**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 (5 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 (8 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.
1. Hertzberg R. W., *Deformation and Fracture Mechanics of Engineering materials*, 4th Edition, John Wiley, USA, 1996.
2. 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	**Crystal Plasticity and its applications**	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. The objective of this course is to learn different aspects of plasticity in relation to the crystallographic orientation of metallic materials.

Learning Outcomes

1. Fundamental understanding of the correlation between microstructural aspects and deformation aspects.
2. Apply the fundamental concepts to use crystal plasticity modeling for a better understanding of different microstructural evolution phenomena during deformation.

Contents

Introduction: Metallurgical fundamentals of plastic deformation, Concepts of stress and strain, Introduction to continuum mechanics, Deformation gradient and deformation of line, Velocity gradient, Elastoplastic decomposition, Stress analysis and Yield surfaces (10 lectures)

Crystal orientation and its representation: Description of orientation and misorientation, Measurement techniques, Statistical representation of crystallographic texture (4 lectures)

Crystal plasticity modeling and numerical aspects:
Mean Field Models: Taylor Model, Grain Interaction Based Models, Viscoplastic Self consistent Models, Full Field Models : crystal plasticity finite element method, fast Fourier transformation method (9 lectures)

Work hardening models: Voce Model, extended Voce Model, Dislocation density based Kocks Mecking Model. Slip system interactions, latent hardening, Concepts of Taylor factor, Schmid factor and Single Crystal Yield Locus, Treatment of twinning in crystal plasticity. (9 lectures)

Examples of applications: Microscopic and Mesoscopic Examples: Plane strain deformation, Simple shear deformation, Single-and bicrystal deformation, Recrystallization, Multiphase steel (TRIP) deformation etc., Texture dependent properties and macroscopic examples such as deep drawing (7 lectures)

Books

1. Roters, F., Eisenlohr, P., Bieler, T., Raabe, D., Crystal Plasticity Finite Element Methods in Materials Science and Engineering, WILEY-VCH Verlag GmbH & Co. KGaA, 2010.
2. Hosford, W. F., The mechanics of crystals and textured polycrystals, Oxford University Press (USA), 1993

References:

1. R. J. Asaro and Vlado A. Lubarda, Mechanics of Solids and Materials, Cambridge University Press, 2006.
2. A. F. Bower, Applied Mechanics of Solids, CRC Press, 2009.
3. A. S. Argone, Strengthening Mechanisms in Crystal Plasticity, Oxford University Press, 2008.
4. Raabe, D., Roters, F., Barlat, F., and Chen, L. Q. (Eds.)., Continuum scale simulation of engineering materials: fundamentals-microstructures-process applications. John Wiley & Sons, 2004.

Online Course Material:

1. Biswas, S. and Toth, L. S., Crystallographic texture and crystal plasticity, GIAN-MHRD, IIT Kharagpur course.

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	Elective
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 *[6 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 equipment, 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 *[12 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	**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 *(13 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 *(13 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 *(6 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. Chatterjee 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 Chatterjee 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/

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 [7 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 [5 lectures]: K1c testing, J testing, CTOD testing, NDT evaluation of cracks

Fatigue [5 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	**Machine Learning for Materials Design**	Number	MTL7XX0
Department	Metallurgical and Materials Engineering	L–T–P: C	2–0–2: 3
Offered for	M.Tech.	Type	Elective
Pre-requisite			

Objectives

1. Introduce a selected set of Machine learning and Deep Learning techniques for Materials design.
2. Introduce hands-on experience with some practical methods and techniques in materials informatics for materials classification, regression, clustering, and adaptive design.
3. Introduce hands-on experience in analyzing data and applying ML approaches through a set of case studies pertaining to Materials Engineering.

Learning Outcomes

1. Aware of different data driven techniques for creating Materials Knowledge.
2. To use machine learning tools for solving problems in materials design

Course Content

Deep Learning Techniques:
Supervised Learning using deep networks: Convolutional Neural Networks (CNN), Recurrent Neural Networks (RNNs), Self-Supervised Learning, Few Shot Learning, adversarial Learning, and Transformers. (12 lectures)

Unsupervised Learning using deep networks: Auto encoders, Deep Belief Networks (5 lectures)

Ensemble Classifiers: Random Forests, Gradient Boosted Decision Trees (4 lectures)

Association Analysis: Mining association rules, Graph Neural Networks (5 lectures)

Laboratory exercises:
1. A deep-learning technique for phase identification using synthetic XRD powder patterns
2. Physics-driven ML for catalysts design
3. Data-Driven Prediction of Interatomic Potentials
4. Automated Micrograph Analysis: Optical, SEM, TEM and EBSD analysis.
5. Data-Driven Approach for design and rapid screening of High Entropy and Amorphous alloys
6. Materials Property Predictions Based on Data from Chemistry, Structure and Processing
7. Data Driven Modelling for Defect prediction during Additive Manufacturing Process
8. Fatigue life prediction using ML

Books

1. Pilania, G., Balachandran, P. V., Gubernatis, J. E., and Lookman, T., Data-Based Methods for Materials Design and Discovery: Basic Ideas and General Methods, Morgan & Claypool Publishers, 2020.
2. Machine Learning And Data Mining In Materials Science, Edited by Huber, N., Kalidindi, S. R., Klusemann, B. and Cyron, C. J., Frontiers in Materials, 2020.
3. Mueller, T., Kusne, A.G. and Ramprasad, R., Machine Learning in Materials Science. In Reviews in Computational Chemistry, Edited by Parrill, A.L., and Lipkowitz, K.B., John Wiley & Sons, 2016.

Reference Books:

1. *Materials Informatics: Methods, Tools, and Applications*, Edited by Olexandr Isayev, Alexander Tropsha, Stefano Curtarolo, John Wiley & Sons, 2019

2. *Informatics for Materials Science and Engineering-Data-driven Discovery for Accelerated Experimentation and Application*, Edited by: Krishna Rajan, Butterworth-Heinemann, 2013

Course Title	**Computational Modelling in Materials Engineering**	Number	MTL7XX0
Department	Metallurgical and Materials Engineering	L–T–P: C	2–0–2: 3
Offered for	M.Tech.	Type	Elective
Pre-requisite			

Objectives

1. Introduce first-principles calculations and molecular dynamics.
2. Introduce crystal plasticity and phase-field modelling techniques.
3. To provide hands-on experience in using computer simulation tools for studying materials.

Learning Outcomes

1. Able to use quantum and atomistic simulation tools
2. Awareness of modelling techniques at different length scales
3. Familiarity with the advantages and limitations of computational tools available for studying materials.

Course Content

First-principles calculations (7 lectures): Introduction, Periodic Structures, Supercells, Electronic kinetic energy cut-off, Total Energy, Geometry Optimization, Electronic Structure and Magnetic Properties, Calculations for Surfaces, Defects in solids.

Molecular dynamics simulations (7 lectures): Introduction, Application of various distribution functions in amorphous and crystalline materials, Study of Diffusion and activation energy barrier, Application of MD in studying the kinetics of battery electrodes and electrolytes, Steered molecular dynamics: Theory and application.

Phase-Field Modelling (6 lectures): Microstructure evolution, Continuum vs sharp interface description, The Ginzburg-Landau free energy functional, Equilibrium interfaces and surface tension, Conserved and non-conserved order parameters, Driving forces, fluxes, Spinodal decomposition in a binary alloy.

Introduction to Crystal Plasticity (6 lectures): Deformation gradient and finite strain, rotation and stretch, elastoplastic decomposition, Flow rules, hardening rules, slip systems and resolved shear stress, Pole figures and stereographic projection, Phenomenological models, dislocation-based constitutive laws.

Computer Simulations

1. Calculation of the electronic band structure and density of states in a semiconductor
2. Calculation of the electronic band structure and density of states in a metal
3. Calculate glass transition temp of polymer
4. Yield mechanism of an Au nanowire
5. Determination of the elastic stiffness tensor
6. Spinodal decomposition in a binary alloy
7. Modeling of grain growth:
8. Generation of synthetic 3D polycrystalline grain structure from Electron Backscatter Diffraction (EBSD) data
9. Simulation of uniaxial compressive stress-strain response of a polycrystalline FCC single-phase metal based on strain rate-independent and strain rate-dependent 3D Crystal Plasticity constitutive laws
10. Materials data visualization

Text Books

1. Lee, J., Computational Materials Science: An Introduction, 2nd Edition, CRC Press 2016.

2. Sholl, D. S., and Steckel, J. A., Density Functional Theory: A Practical Introduction, 1st Edition, Wiley, 2009.
3. Provatas, N., Elder, K., Phase-Field Methods in Materials Science and Engineering, John Wiley & Sons, 2011.
4. Roters, F., Eisenlohr,P., Bieler, T., Raabe, D., Crystal Plasticity Finite Element Methods in Materials Science and Engineering, WILEY-VCH Verlag GmbH & Co. KGaA, 2010.
5. LeSar, Richard, Introduction to Computational Materials Science: Fundamentals to Applications, Cambridge University Press, 2013.

References:

1. Raabe, D., Computational Materials Science: The Simulation of Materials, Microstructures and Properties, Wiley VCH, 1998.
2. Hull, D., and Bacon, D. J., Introduction to Dislocations, Butterworth-Heinemann (Elsevier), 5th Ed., 2011.

Online Course Materials:

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

2. Voorhees, P.W., Phase Field methods: From fundamentals to applications, Department of Material Science and Engineering, Northwestern University, https://www.youtube.com/watch?v=FTiBq1o-8e4

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: [7 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: [10 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/