NATIONAL INSTITUTE OF TECHNOLOGY DURGAPUR

CURRICULUM

OF

MASTER OF TECHNOLOGY IN SUSTAINABLE MATERIALS AND TECHNOLOGY

OFFERED BY

THE DEPARTMENT OF METALLURGICAL AND MATERIALS ENGINEERING

2025 ONWARD ADMISSION BATCH

V0:

Curriculum and Syllabus Recommended by members of DAC	23.06.2025
Curriculum and Syllabus Recommended by PGAC	29.07.2025
Curriculum and Syllabus Approved by the 74th Senate (Item No. 74.3 (v))	03.08.2025

M.Tech in Sustainable Materials and Technology

Course Curriculum

First Semester

Sl. No.	Sub. Code	Subject	L-T-P	Credits	Hours
1	MM1001	Materials Thermodynamics	3-0-0	3	3
2	MM1002	Introduction to Sustainable Materials	3-1-0	4	4
3	MM1003	Sustainable Metal Production Technology	3-1-0	4	4
4	MM90XX	Elective - I	3-0-0	3	3
5	MM90XX	Elective - II	3-0-0	3	3
6	MM1051	Engineering Materials Laboratory	0-0-4	2	4
7	MM1052	Advanced Manufacturing Laboratory	0-0-4	2	4
TOTAL				**21**	**25**

Second Semester

Sl. No.	Sub. Code	Subject	L-T-P	Credits	Hours
1	MM2001	Principles & Techniques of Materials Characterization	3-1-0	4	4
2	MM90XX	Elective - III	3-0-0	3	3
3	MM90XX	Elective - IV	3-0-0	3	3
4	MM90XX	Elective - V	3-0-0	3	3
5	MM90XX	Elective - VI	3-0-0	3	3
6	MM2051	Testing and Characterization of Materials Laboratory	0-0-6	2	4
7	MM2052	Mini Project with Seminar	0-0-6	3	6
TOTAL				**21**	**26**

Third Semester

Sl. No.	Sub. Code	Subject	L-T-P	Credits	Hours
1	XX9030	Audit Lectures/ Workshops	0-0-0	0	2
2	MM3051	Dissertation – I	0-0-24	12	24
3	MM3052	Seminar – Non-Project/Evaluation of Summer Training	0-0-4	2	4
TOTAL				**14**	**30**

Fourth Semester

Sl. No.	Sub. Code	Subject	L-T-P	Credits	Hours
1	MM4051	Dissertation – II/Industrial Project	0-0-24	12	24
2	MM4052	Project Seminar	0-0-4	2	4
TOTAL				**14**	**28**
Total Program Credit				**70**	**109**

LIST OF ELECTIVE SUBJECTS

Sub. Code	Subject	L-T-P	Credits
MM9030	Life Cycle Assessment	3-0-0	3
MM9031	Properties and Selection of Engineering Materials	3-0-0	3
MM9032	Mechanical Properties of Sustainable Materials	3-0-0	3
MM9033	Electronic and Magnetic Materials	3-0-0	3
MM9034	Energy Materials	3-0-0	3
MM9035	Biomaterials	3-0-0	3
MM9036	Phase Equilibria and Phase Transformation in Materials	3-0-0	3
MM9037	Additive Manufacturing	3-0-0	3
MM9038	Non Destructive Evaluation	3-0-0	3
MM9039	Nanomaterials for Sustainability	3-0-0	3
MM9040	Solidification Processing	3-0-0	3
MM9041	Fracture and Fatigue of Materials	3-0-0	3
MM9042	Advanced Powder Technology	3-0-0	3
MM9043	Metallurgy of Advanced Joining	3-0-0	3
MM9044	High Temperature Sustainable Materials	3-0-0	3
MM9045	Corrosion Engineering of Advanced Materials	3-0-0	3
MM9046	Advanced Electroplating and Pulse Plating	3-0-0	3
MM9047	Advanced Ceramic Materials	3-0-0	3
MM9048	Plasma Technology for Metallurgical Applications	3-0-0	3
MM9049	Sustainable Composites	3-0-0	3
MM9050	Environmental Degradation of Materials	3-0-0	3
MM9051	Strengthening Mechanisms of Materials	3-0-0	3
MM9052	Surface Engineering	3-0-0	3
MM9053	Electron Microscopy	3-0-0	3
MM9054	Advanced Metal Forming Processes	3-0-0	3
MM9055	Severe Plastic Deformation	3-0-0	3
MM9056	Raw Materials Characterization	3-0-0	3
MM9057	Production of Critical Minerals	3-0-0	3
MM9058	Secondary Refining of Steel	3-0-0	3
MM9059	Agglomeration Techniques	3-0-0	3
MM9060	Kinetics of Metallurgical Processes	3-0-0	3
MM9061	Computational Materials Science	3-0-0	3
MM9062	AI and ML in Materials Science and Engineering	3-0-0	3
MM9063	Numerical Methods	3-0-0	3
MM9064	Advanced Materials Science	3-0-0	3
MM9065	Fluid Flow Phenomena in Metallurgical Processes	3-0-0	3
MM9066	Environmental Management in Metallurgical Industries	3-0-0	3
MM9067	Human Resource Management	3-0-0	3
MM9068	Hydrogen and Fuel Cells	3-0-0	3
MM9069	Waste Management	3-0-0	3

Syllabus

Department of Metallurgical & Materials Engineering								
Course Code	Title of the course	Program Core (PCR) / Electives (PEL)	Total Number of contact hours				Credit
			Lecture (L)	Tutorial (T)	Practical (P)	Total Hours	
MM1001	Materials Thermodynamics	PCR	3	0	0	3	3

Pre-requisites	Course Assessment methods (Continuous (CT) and end assessment (EA))
NIL	CT + EA
Developer	M. K. Mondal
Course Outcomes	CO1: Apply laws of thermodynamics to processes and reactions. CO2: Calculate thermodynamic properties and predict the feasibility of reactions. CO3: Formulate the thermodynamic system for the development of materials.
Topics Covered	Introduction and definition of terms - Thermodynamics systems, variables and processes, heterogeneous and homogeneous systems, extensive and intensive properties, simple equilibrium. [2 hours] The First law of thermodynamics - Conservation of Energy, Heat Capacity and definition of enthalpy, Reference and standard states, Enthalpy of physical transformations and chemical reactions. [4 hours] The second and third laws of thermodynamics - the second law and the definition of entropy, reversible and irreversible processes, conditions for equilibrium and the definition of Helmholtz and Gibbs energies, Maximum work and maximum non-expansion work, the variation of entropy with temperature, the statistical interpretation of entropy, the most probable microstate, configurational entropy and thermal entropy, the third law of entropy, Maxwell relations. [8 hours] Single component systems - One component systems, Clapeyron and Clausius-Clapeyron equations. [1 hours] Solution thermodynamics - Ideal and regular solutions, Raoult's law, activity, Gibbs-Duhem equation, partial molar properties, partial excess properties. [8 hours] Phase diagrams - Free energy-composition and phase diagrams of binary systems, phase diagrams with non-ideal behaviour in the solid, freezing point depression, congruent and incongruent melting points. [3 hours] Multi component systems - Equilibrium in multi-component, multiphase systems, reactions involving gases, equilibrium constant, extent of reaction and molar balance techniques Reactions involving gases and solids - Ellingham diagrams, Effect of temperature on oxidation reactions, effect of phase transformations on oxidation reactions, stability of oxides, relative stability of oxides, oxygen potential and CO/CO_2 ratios, H_2/H_2O ratios and equilibrium constants in oxide, chloride, nitrate and sulphide system. [6 hours] Systems containing components in condensed solution - Change of standard states, phase rule, common tangent construction, solubility of gases in metals. [2 hours] Electrochemistry - Introduction to electrochemistry, the relationship of electromotive force to reversible work and free energy, the Nernst equation, half cell reactions, activities in aqueous solutions, standard states in aqueous cells, measurements of activities using cells and heat effects. [4 hours] Thermodynamics of surfaces and interfaces - Surface tension, mechanical analogy of surface energy, approximate calculation of solid surface energy, effects of surface curvature, effect of surface curvature on vapour pressure and melting temperature, thermodynamics of point defects. [4 hours]

Text Books, and/or reference material	Text Books and Reference Books: 1. Introduction to the Thermodynamics of Materials by David R. Gaskell and David E. Laughlin, CRC Press. 2. Thermodynamics of Solids by R. A. Swalin, John Wiley and Sons. 3. Chemical Thermodynamics of Materials by C. H. P. Lupis, Elsevier Science Publishing Co., New York. 4. Stoichiometry and Thermodynamics Computations in Metallurgical Processes by Y. K. Rao, Cambridge University Press.

Mapping of COs with POs and PSOs

POs / COs	PO1	PO2	PO3	PSO 1	PSO 2
CO1	3	1	2	3	3
CO2	2	1	2	2	2
CO3	2	1	2	2	3

Correlation levels 1, 2 or 3 as defined below:
1: Slight (Low) 2: Moderate (Medium) 3: Substantial (High)

Department of Metallurgical & Materials Engineering							
Course Code	Title of the course	Program Core (PCR) / Electives (PEL)	Total Number of contact hours				Credit
			Lecture (L)	Tutorial (T)	Practical (P)	Total Hours	
MM1002	**Introduction to Sustainable Materials**	PEL	3	1	0	4	4

Pre-requisites	Course Assessment methods (Continuous (CT), mid-term (MT) and end assessment (EA))
NIL	CT+MT+EA

Course Outcomes	CO1: To understand the fundamental aspects of sustainable materials. CO2: To analyze the principles, theory and mechanisms of different kind of advanced manufacturing processes with reduced energy, water, and materials footprint. CO3: To correlate the science and technological aspects of material recycling and materials recovery
Topics Covered	**Introduction:** Importance of Sustainable materials; Sustainable Material: Challenges and Prospect; The Vision: A Circular Materials Economy; Challenges, Future Outlook, and Opportunities [4 hours] **Structure Properties, production, and environmental implications of materials** [6 hours] **Sustainable ceramics:** Durable ceramics Produced by Clay Brick Residue; Nanoclay-Based Sustainable Materials [6 hours] **Advanced manufacturing processes** [6 hours] **Sustainable Materials for Various Green Technology Applications** Energy Applications; Building and Infrastructure Applications; Environmental Applications; Sustainable Materials in Civil Infrastructure [6 hours] **Advances in Sustainable Materials** [6 hours]

	Sustainable Materials Management Understanding the Flow of Materials; Trends in Global Material Consumption and Environmental Impact; How Does Materials Management Differ from Current Approaches? Workgroup Recommendations for Achieving Sustainable Materials Management [4 hours] **Materials Recycling** [6 hours] **Life Cycle Analysis.** [6 hours]
Text Books, and/or reference material	**Text Books:** (1) Materials Science and Engineering- An Introduction W. D. Callister, John Wiley & Sons Inc 1985 New York. (2) Renewable and Sustainable Materials in Green Technology, Springer, 2017 (3) New Environmentally-Friendly and Sustainable Materials, MDPI, Switzerland, 2022 **Reference books:** (1) Lecture Notes and Published Papers (2) Nanoclay Based Sustainable Materials, Elsevier, 2024

Mapping of COs with POs and PSOs

POs / COs	PO1	PO2	PO3	PSO1	PSO2
CO1	2	1	2	2	2
CO2	2	2	2	2	2
CO3	2	1	2	2	2

Correlation levels 1, 2 or 3 as defined below:

1: Slight (Low) 2: Moderate (Medium) 3: Substantial (High)

Department of Metallurgical and Materials Engineering							
Course Code	Title of the course	Program Core (PCR) / Electives (PEL)	Total Number of contact hours				Credit
			Lecture (L)	Tutorial (T)	Practical (P)	Total Hours	
MM1003	Sustainable Metal Production Technology	PCR	3	1	0	38	4
Pre-requisites		Course Assessment methods (Continuous (CT) and end assessment (EA))					
		CT+EA					

Course Outcomes	CO1: Ability to understand the environmental impacts of traditional and emerging metal production techniques CO2: Ability to learn waste management strategies for metal production CO3: Ability to develop practices to develop sustainable, energy-efficient, and cost-effective metal production methods.
Topics Covered	Introduction to Sustainable Metal Production (8 Hours): Fundamentals of metal production and processing, A brief process overview of process metallurgy including physicochemical principle including pyro, hydro, electrometallurgy and associated impact on costs, pollution, energy, cycle time, simplification. Environmental impacts of conventional metal production, Principles of sustainability in metallurgy, Regulatory frameworks and international standards Kinetics of Metallurgical Processes: Ellingham Diagram, Rate Laws, Order of Reaction Raw Material Preparation and Sustainability (8 Hours): Sustainable mining practices, Life

	cycle assessment of raw materials, Alternative and recycled raw materials, Case studies of sustainable mining operations Iron and Steel Making Processes (5 Hours): Basics of iron ore beneficiation, Primary steelmaking processes and secondary Steel making Environmentally sustainable steelmaking practices, Innovations in reducing emissions in steel production, Energy-efficient technologies in steelmaking Non-Ferrous Metal Production Techniques (5 Hours): Production processes for copper, aluminum, zinc, lead, etc., Sustainable refining and smelting methods, Use of recycled non-ferrous metals, Innovations in non-ferrous metallurgy for sustainability Energy-efficient Technologies in Metal Production (4Hours): Energy consumption in smelting and refining, Innovative energy-saving technologies, Use of renewable energy sources in metal manufacturing, Waste heat recovery systems Waste Management & Environmental Impact (4 Hours): Waste minimization and management strategies, Environmental impact assessment methods, Monitoring pollutants and land reclamation, Case studies of reclamation projects Future Trends & Innovations in Sustainable Metallurgy (4 Hours): Digitalization, automation, and Industry 4.0 , Policy, global initiatives, and sustainable development goals
Text Books, and/or reference material	Text Books: 1. B.F. Iron making principles – Biswas (1985) 2. Physical chemistry of iron & steel manufacture – C. Bodsworth (1980) 3. Iron and steel making, theory and practice – Ghosh and Chatterjee (2012) 4. Fuels, Furnaces And Refractories,- R. C. Gupta (2016) 5. Extraction of Nonferrous Metals-H.S. Ray, R. Sridhar, K.P. Abraham Reference books: 1. Proceedings of international seminar on innovative technologies for clean, green & automated steel plants- A better tomorrow – Steel tech/ NIT Durgapur , sept. 2015 2. The Production of aluminium and alumina, Vol. 20-Alfred Richard Burkin 3. Extractive Metallurgy of Copper-A. K. Biswas & W. G. Davenport 4. BLAST FURNACE IRONMAKING: Analysis, Control, and Optimization- Ian Cameron, Mitren Sukhram , Kyle Lefebvre & William Davenport (Published by Elsevier, 2020) 5. "Environmental Aspects of Iron and Steelmaking" by A. R. B. Smith and R. W. H. Grant 6. "Sustainable Metals Production" by K. N. Kessler (Editor) 7. "Principles of Extractive Metallurgy" by S. K. Haldar 8. "Green Metallurgy: Principles and Practices" by K. K. Prasad and J. D. H. Bell 9. "Environmental Impact and Sustainability in the Metal Industry" by S. K. Sharma (Editor)

Mapping of COs with POs and PSOs

COs \ POs	PO1	PO2	PO3	PSO1	PSO 2
CO1	2	1	3	3	2
CO2	1	1	2	2	1
CO3	3	1	3	1	3

Correlation levels 1, 2 or 3 as defined below:

1: Slight (Low) 2: Moderate (Medium) 3: Substantial (High)

Department of Metallurgical & Materials Engineering							
Course Code	Title of the course	Program Core (PCR) / Electives (PEL)	Total Number of contact hours				Credit
			Lecture (L)	Tutorial (T)	Practical (P)	Total Hours	
MM1051	Engineering Materials Laboratory	PEL	0	0	4	4	2

Pre-requisites	Course Assessment methods (Continuous (CT) and end assessment (EA))
MM1002	CT+EA

Course Outcomes	CO1: Learn metallography sample preparation and observe microstructure under a microscope. CO2: Evaluation of mechanical properties of different materials. CO3: To assess and understand the structure-property correlation
Topics Covered	Overview of metallography [3 hours] To study the microstructure of Stainless steels [3 hours] To study the microstructure of titanium alloys [3 hours] To study the microstructure of ceramics [3 hours] Hardness measurement of the concrete [3 hours] Indentation fracture toughness measurement of ceramics [3 hours] Tensile testing of polymers [6 hours] Sustainable carburization of low carbon steel [6 hours]
Text Books, and/or reference material	Reference books: (1) W. D. Callister, Materials Science and Engineering an Introduction, Wiley, New York (2003). (2) V. Raghavan, Materials Science and Engineering, Prentice Hall India, New Delhi, (1998).

Mapping of COs with POs and PSOs

POs / COs	PO1	PO2	PO3	PSO1	PSO2
CO1	2	1	2	2	2
CO2	2	2	2	1	1
CO3	2	1	2	2	2

Correlation levels 1, 2 or 3 as defined below:

1: Slight (Low)   2: Moderate (Medium)   3: Substantial (High)

Department of Metallurgical & Materials Engineering							
Course Code	Title of the course	Program Core (PCR) / Electives (PEL)	Total Number of contact hours				Credit
			Lecture (L)	Tutorial (T)	Practical (P)	Total Hours	
MM1052	Advanced Manufacturing Laboratory	PEL	0	0	4	4	2

Pre-requisites	Course Assessment methods (Continuous (CT) and end assessment (EA))
MM1002	CT+EA

Course Outcomes	CO1: To learn the science and technological aspects of the synthesis/ production of sustainable metals and materials. CO2: To understand the fundamental principles, and techniques, of sustainable metal production, additive manufacturing and advanced machining processes CO3: To explore the eco-friendly metal production routes and processing-structure-property relationship through laboratory assignment.
Topics Covered	Exp 1: Sustainable synthesis of nano powders [3 hours] Exp 2: Preparation of agglomerates for metal production [3 hours] Exp 4: DRI production from agglomerates [3hours] Exp 4: Synthesis and characterization of Al-Fly ash composites [6 hours] Exp 5: 3D printing of polymeric samples and assessment of mechanical properties [3 hours] Exp 6: Microstructural and mechanical property evaluation of 3D printed Al alloy component (3 hours) Exp 7: 3D printing of ceramic prototypes [3 hours] Exp 8: Microstructural characterization and assessment of mechanical properties of 3D printed components [3 hours] Exp 9: Nonferrous metal extraction by leaching experiment [6 hours] Exp 10: Learn EDM machine and machining a job using EDM. [3 hours]
Text Books, and/or reference material	TEXTBOOK BOOKS: 1.Gupta R.C. Theory and Laboratory Experiments in Ferrous Metallurgy, PHI Learning Pvt. Ltd, New Delhi, India 2. Powder Metallurgy – A Upadhyaya and G S Upadhyaya. 3. W. D. Callister, Materials Science and Engineering an Introduction, Wiley, New York (2003). 4. V. Raghavan, Materials Science and Engineering, Prentice Hall India, New Delhi, (1998). 5. Kalpakjian, Schmid, Manufacturing Processes for Engineering Materials, 6th edition, Pearson Education

Mapping of COs with POs and PSOs

POs / COs	PO1	PO2	PO3	PSO1	PSO2
CO1	2	1	2	2	2
CO2	2	2	2	2	2
CO3	2	1	2	2	2

Correlation levels 1, 2 or 3 as defined below:

1: Slight (Low) 2: Moderate (Medium) 3: Substantial (High)

Department of Metallurgical & Materials Engineering								
Course Code	Title of the course	Program Core (PCR) / Electives (PEL)	Total Number of contact hours				Credit
			Lecture (L)	Tutorial (T)	Practical (P)	Total Hours	
MM2001	Principles and Techniques of Materials Characterization	PCR	3	1	0	4	4
Pre-requisites		Course Assessment methods (Continuous (CT) and end assessment (EA))					
Knowledge on physics, chemistry, mathematics and basic physical metallurgy.		CT + EA (Mid semester examination and End semester examination)					
Developer		Dr. B.K.Show and Dr. S. Bera					

Course Outcomes	I. Learn fundamentals of X-ray diffraction, electron microscopy and other characterization techniques. II. Understand X-ray diffraction, electron microscopy and other characterization techniques in detail. III. Identify the crystal structure and index the diffraction patterns of different phases to meet contemporary needs (including tutorials) and learn different applications in characterization techniques.
Topics Covered	**X-ray diffraction Techniques:** The continuous and characteristic spectrum; Absorption; Filters; Real and reciprocal lattice ; Bragg's Law; Ewald sphere construction; Diffraction methods–Laue method, rotating crystal methods, powder methods; Diffractometers; Diffraction under non- ideal condition. Intensity of diffracted beams: scattering by an electron- Coherent scattering, Incoherent scattering; scattering by an atom-atomic scattering factor, Scattering by a unit cell: Structure factor, Structure factor calculations; Extinction rules, indexing. (16 hours) **Application of X-ray diffraction:** Crystal structure determination; determination of precise lattice parameter; Phase diagram determination, Chemical analysis by diffraction, residual stress determination, particle size determination. (10 hours) **Electron Microscopy:** Specimen beam interaction; Interaction volume; Construction, modes of operation and application of Scanning electron microscope; Different contrast formation; Effect of different operational variables on the resolution and depth of field of a SEM; Specimen preparation; EDS and WDS. Transmission electron microscopy (TEM): basic principles of electron diffraction in transmission electron microscope in view of Ewald sphere construction, Selected area diffraction: generation of spot pattern, spotted ring pattern and continuous ring pattern; basic relationship of electron diffraction in transmission electron microscope ($Rd = L\lambda$); Interpretation of SAD pattern for fine grained polycrystalline material: Indexing ring pattern, determination of camera constant; Interpretation of SAD patterns of single crystal (single grain): Indexing spot pattern; interpretation of the standard patterns from different crystals,viz. simple cubic, BCC, FCC etc. (14 hours) **Current advancement in electron microscope:** Different types of advanced and state ofthe art electron microscopes. (02 hours) **Thermal Analysis:** Differential thermal analysis, Differential scanning calorimetry and Thermogravimetric analysis (04 hours) Atomic force microscopy, Advanced technique for particle size analysis (04 hours)
Text Books, and/or	1. "Elements of X-Ray Diffraction", by B.D. Cullity, Addision Wesley Publishing Co., Massachusetts, 1968.

reference material	2. "X-ray diffraction-a practical approach", by C. Suryanarayana and M. Grant Norton, Springer, 1998. 3. "X-ray Diffraction: Its Theory and Applications", by S. K. Chatterjee, Prentice-Hall of India Pvt. Limited, 2004. **4. "Electron Microscopy in the Study of Materials"**, by **P.J. Grundy and G.A. Jones**, Arnold, London, 1976. 5. "Transmission Electron Microscopy: A Textbook for Materials Science (4 Vol set)", by David B. **Williams** and C. Barry **Carter**, 2nd ed., Springer, 2009. 6. "Electron Microscopy and Analysis", by Peter J. Goodhew, John Humphreys and Richard Beanland, Third Edition, CRC Press, 2000. 7. Principles of Metallographic laboratory Practice – G. L. Kehl, London: McGraw-Hill Publishing Co., Ltd., 1939. 8. **Metallography**, Principles and Practice-George F. **Vander Voort**, ASM International, 1984.

Mapping of COs with POs and PSOs

POs / COs	PO1	PO2	PO3	PSO1	PSO2
CO1	2	1	2	2	2
CO2	2	2	2	1	2
CO3	2	1	2	2	2

Correlation levels 1, 2 or 3 as defined below:
1: Slight (Low) 2: Moderate (Medium) 3: Substantial (High)

Department of Metallurgical & Materials Engineering							
Course Code	Title of the course	Program Core (PCR) / Electives (PEL)	Total Number of contact hours				Credit
			Lecture (L)	Tutorial (T)	Practical (P)	Total Hours	
MM2051	Testing and Characterization of Materials Laboratory	PCR-Practical	0	0	4	4	2
Pre-requisites		Course Assessment methods (Continuous (CT) and end assessment (EA))					
Knowledge on physics, chemistry, mathematics and basic physical metallurgy.		Laboratory report and viva voce examination					
Developer		Dr. B.K.Show and Dr. S. Bera					

Course Outcomes	I. Learn fundamentals of different testing and characterization techniques. II. Learn to perform different testing and characterization techniques. III. Ability to analyze test results of different samples to meet contemporary need and write necessary report..
Topics Covered	Experiment 1: Charaterization.by optical Metallography and Hardness measurement. [4 hours] Experiment 2: Determination of yield strength, ultimate tensile strength and ductility using an Universal testing machine [4 hours] Experiment 3: Study of non-destructive testing techniques for material characterisation. [4 hours]

	Experiment 4: Determination of electrical conductivity of different materials using 4-probe technique. [4 hours] Experiment 5: Indexing the X-ray diffraction (XRD) pattern of different phases. Part (I): Indexing the XRD pattern of BCC structure. [2 hours] Part(II): Indexing the XRD pattern of FCC structure. [2 hours] Part(III): Indexing the XRD pattern of HCP structure. [2 hours] Part(IV): Indexing the XRD pattern containing a mixture of BCC and FCC phases.[2 hours] Experiment 6: X-ray diffraction of powders exhibiting the effect of powder size on peak broadening. [4 hours] Experiment 7: Interpretation of microstructures obtained through scanning electron microscopy. [4 hours] Experiment 8: Indexing selected area diffraction patterns (SADP) obtained through transmission electron microscopy. [4 hours] Experiment 9: Wear testing of materials [4 hours]
Text Books, and/or reference material	1. "Elements of X-Ray Diffraction", by B.D. Cullity, Addision Wesley Publishing Co., Massachusetts, 1968. **2. "Electron Microscopy in the Study of Materials"**, by **P.J. Grundy and G.A. Jones**, Arnold, London, 1976. 3. "Transmission Electron Microscopy: A Textbook for Materials Science (4 Vol set)", by David B. **Williams** and C. Barry **Carter**, 2nd ed., Springer, 2009. 4. Principles of Metallographic laboratory Practice – G. L. Kehl, London: McGraw-Hill Publishing Co., Ltd., 1939. 5. **Metallography**, Principles and Practice-George F. **Vander Voort**, ASM International, 1984. 6. Mechanical Metallurgy, George E. Dieter, International Student Edition, Mc. Graw-Hill Kogakusha Ltd. /Fourth (S. I. Metric) Edition, 1988.

Mapping of COs with POs and PSOs

COs \ POs	PO1	PO2	PO3	PSO1	PSO2
CO1	2	1	2	2	1
CO2	3	2	2	2	2
CO3	2	3	2	2	2

Correlation levels 1, 2 or 3 as defined below:
1: Slight (Low) 2: Moderate (Medium) 3: Substantial (High)

Department of Metallurgical & Materials Engineering							
Course Code	Title of the course	Program Core (PCR) /	Total Number of contact hours				Credit
			Lecture	Tutorial	Practical	Total	

		Electives (PEL)	(L)	(T)	(P)	Hours	
MM9030	Life Cycle Assessment	PEL	3	0	0	3	3

Pre-requisites	Course Assessment methods (Continuous (CT), and end assessment (EA))
NIL	CT+EA
Developer	M. K. Mondal
Course Outcomes	CO1: Understand the basic concept of life cycle assessment CO2: Apply LCA to process selection, design and optimization CO3: Develop methodological framework for life cycle process design
Topics Covered	Introduction to Life Cycle Assessment (LCA) (4 hours) Methodological framework for LCA (5 hours) Stages in the life cycle of a product; Interactions between LCA stages (5 hours) Environmental system analysis (4 hours) Applications of LCA; Uses of LCA by the industry (4 hours) LCA for process selection, design and optimization (6 hours) Examples and case studies; LCA flow diagrams (8 hours) General methodological framework for Life Cycle Process Design (6 hours)
Text Books, and/or reference material	Text Books and Reference Books: 1. Life Cycle Sustainability Assessment for Decision-Making Methodologies and Case Studies, Edited by: Jingzheng Ren and Sara Toniolo, Elsevier 2. Life Cycle Assessment Theory and Practice, by Michael Z. Hauschild, Ralph K. Rosenbaum, Stig Irving Olsen, Springer. 3. Background and Future Prospects in Life Cycle Assessment, Edited by: Walter Klöpffer, Springer. 4. Life Cycle Assessment Principles, Practice and Prospects, By Ralph Horne, Tim Grant and Karli Verghese, CSIRO Publishing. 5. Life Cycle Assessment Handbook A Guide for Environmentally Sustainable Products, Edited by Mary Ann Curran, Wiley.

Mapping of COs with POs and PSOs

POs / COs	PO1	PO2	PO3	PSO 1	PSO 2
CO1	2	1	2	2	3
CO2	3	1	2	2	3
CO3	3	1	3	3	3

Correlation levels 1, 2 or 3 as defined below:
1: Slight (Low) 2: Moderate (Medium) 3: Substantial (High)

Department of Metallurgical & Materials Engineering							
Course Code	Title of the course	Program Core (PCR) / Electives (PEL)	Total Number of contact hours				Credit
			Lecture (L)	Tutorial (T)	Practical (P)	Total Hours	
MM9031	Properties and Selection of	PEL	3	0	0	3	3

	Engineering Materials						
Pre-requisites		Course Assessment methods (Continuous (CT) and end assessment (EA))					
NIL		CT+EA					
Developer		D. Mandal and M. Mallik					
Course Outcomes	CO1: To understand the Fundamentals of internal structure and properties of materials CO2: To understand the principles and processing techniques of engineering materials CO3: To design sustainable materials depends on their working environment						
Topics Covered	**Introduction:** Introduction to Materials Selection, Factor affecting the selection of materials, Procedure for materials selection. Material Properties, Processing, Materials Cost and Availability and Environment [5 hours] **Engineering Materials, Ferrous Metals:** Classification of Engineering Materials: Ferrous Metals. Advanced High Strength Steels (AHSS), Types of AHSS, Strengthening mechanism of AHSS steels, Processing, structure and properties of Dual phase (DP), High strength low alloy (HSLA), Complex phase (CP), Transformation Induced Plasticity (TRIP) and Twin Induced plasticity (TWIP) and quenched and tempered (Q&P) steels. General Properties and applications, [15 hours] **Non-ferrous metals,** Non-ferrous metals, Aluminium alloys, Al-Li alloy, Rapid solidification processing of Al alloys, Classification of making metal foams, Characterisation of cellular Metals, Materials Properties and application, Nickel-based super alloy, Ti-based super alloys, Processing, Properties and Applications of super alloys, [6 hours] **Bio-Materials** Requirements for biomaterials, Classification of biomaterials, Dental Materials, Materials for replacement of joints and surgical, Bioceramics and their properties and applications [4 hours] **Bulk Metallic Glass, Nano Materials and Smart Materials**: Criteria for glass formation, Examples and mechanical behaviour, Nano-materials: Classification, Processing and properties of nanocrystalline materials, Nanofluids. Introduction to smart structure, Classification of smart materials, Introduction to sensors and actuators, Piezo-electrics, shape memory alloys [6 hours] **Ceramics Materials**: Material Selection, Structure of ceramics, Properties and Applications, Classification, ZrB_2 and HfB_2 based Ultra High Temperature Ceramic Composites, Processing, mechanical behaviour and oxidation resistance [8 hours]						
Text Books, and/or reference material	Text Books: (1) Materials Science and Engineering- An Introduction W. D. Callister, John Wiley & Sons Inc 1985 New York. (2) W. O. Soboyejo and T. S. Srivastan (ed.), Advanced Structural Materials: Properties, Design, Optimization and Applications, CRC Press, New York (2007). (3) G.W. Meetham and M.H. Van de Voorde, Materials for High Temperature Engineering Applications, Springer, Berlin (2000). Reference books: (1) D. Vollath, Nanomaterials: Synthesis, Properties and Application, WILEY_VCH, Germany (2008). (2) Lecture Notes and Published Papers (3) Introduction to Ceramics - Kingery, Bowen and Uhlmann 2. ASM Handbook Volume 21: Composites						

Mapping of COs with POs and PSOs

POs / COs	PO1	PO2	PO3	PSO 1	PSO 2
CO1	3	2	2	3	2
CO2	3	2	2	3	2
CO3	3	2	2	3	2

Correlation levels 1, 2 or 3 as defined below:
1: Slight (Low) 2: Moderate (Medium) 3: Substantial (High)

Department of Metallurgical & Materials Engineering							
Course Code	Title of the course	Program Core (PCR) / Electives (PEL)	Total Number of contact hours				Credit
			Lecture (L)	Tutorial (T)	Practical (P)	Total Hours	
MM9032	**Mechanical Properties of Sustainable Materials**	PEL	3	0	0	3	3
Pre-requisites		Course Assessment methods (Continuous (CT), mid-term (MT) and end assessment (EA))					
MM1002		CT+MT+EA					
Course Outcomes	CO1: Learn fundamental aspects of mechanical behaviour of materials. CO2: Understand different mechanical behaviour processes in detail with mechanisms. CO3. Solve problems on mechanical behaviour of materials to meet contemporary needs.						
Topics Covered	Introduction to Statics [2 hours] Concepts of stress and strain [2 hours] Elasticity and Viscoelasticity [2 hours] Basic theory of dislocation [2 hours] Mechanism of plastic deformation [4 hours] Strengthening mechanism of materials [4 hours] Mechanical properties of sustainable materials [4 hours] Fracture: General aspects of fracture; Linear elastic plastic fracture mechanics (LEFM); Elastic plastic fracture mechanics; Fracture toughness testing of metals: K1C, CTOD and J1C. [10 hours] Deformation under cyclic load: High and low cycle fatigue, application of fracture mechanics for fatigue cracking, effect of different factors on fatigue; cumulative fatigue damage rule; corrosion fatigue; fretting; high temperature fatigue. [6 hours] Deformation at High temperature: Creep and stress rupture, creep mechanisms and creep mechanism maps, Superplasticity; design of creep resistant alloys, Prediction of long time properties. [4 hours]						

Text Books, and/or reference material	**Text books:** 1. Mechanical Metallurgy, George E. Dieter, International Student Edition, Mc. Graw-Hill Kogakusha Ltd. /Fourth (S. I. Metric) Edition, 1988. 2. Mechanical Behavior of Materials, Marc André Meyers and Krishan Kumar Chawla, Cambridge University Press, 2008. 3. Anderson, T. L. Fracture Mechanics. 2nd ed. CRC Press, 1995 **Reference books:** 1. Introduction to dislocations, D. Hull and D.J. Bacon, Fifth Edition, ButterworthHeinemann, 2011. 2. Plastic Deformation of Metals, R. W. K. Honeycombe, Edward Arnold, 1984. 3. Lecture notes

Mapping of COs with POs and PSOs

POs / COs	PO1	PO2	PO3	PSO1	PSO2
CO1	2	1	2	2	1
CO2	2	2	2	1	2
CO3	2	1	2	2	2

Correlation levels 1, 2 or 3 as defined below:

1: Slight (Low) 2: Moderate (Medium) 3: Substantial (High)

Department of Metallurgical and Materials Engineering								
Course Code	Title of the course	Program Core (PCR) / Electives (PEL)	Total Number of contact hours				Credit
			Lecture (L)	Tutorial (T)	Practical (P)	Total Hours	
MM9033	Electronic and Magnetic Materials	Width elective	3	0	0	3	3
Pre-requisites		Course Assessment methods (Continuous (CT) and end assessment (EA))					
Introduction to Metallurgy and Materials Engineering Physics, Engineering Chemistry		CT+MT+EA					
Developer		Dr. B. Roy					
Course Outcomes	CO1: To get an overview of electronic materials as well as to understand the synthesis, properties, and characterization of electronic materials. CO2: To understand the types and Properties of magnetic materials. CO3: Sustainability of electronic and magnetic materials and their applications.						

Topics Covered	Introduction of Electronic Materials, Semiconductors- Intrinsic and Extrinsic. Junctions- Metal-Semiconductors, pp junctions, junction breakdown, and heterojunctions. [6 hours] Transistors- Overview and work assignment. [2 hours] Optoelectronics properties and optoelectronics devices- LEDs, Solid state Semiconductors, laser, Photodetectors, Solar cell. [6 hours] Characterization and applications of electronic materials. [2 hours] Introduction of Magnetic Materials. Type of magnetism- Diamagnetism, Paramagnetism, Ferromagnetism, Ferrimagnetism, Antiferromagnetism, Superparamagnetic. [6 hours] Magnetic properties- Hysteresis, Magnetization, Susceptibility, Permeability, Saturation, Coercivity, Giant Magnetoresistance. [6 hours] Magnetic materials- Soft and hard magnetic materials: Design and Processing. Magnetic losses and frequency dependence. [4 hours] Application of magnetic materials. [2 hours]
Text Books, and/or reference material	Text Books: 1. Materials Science and Engineering: An Introduction – William D. Callister, Jr., John Wiley & Sons, Inc., 2007 2. Materials: Engineering, Science, Processing, and Design – Michael Ashby, Hugh Shercliff and David Cebon 3. Introduction to Magnetic Materials – B. D. Cullity and C. D. Graham 4. Electronic Materials – L.A.A. Warnes

Mapping of COs with POs and PSOs

POs / COs	PO1	PO2	PO3	PSO 1	PSO 2
CO1	3	2	3	2	2
CO2	3	2	3	2	2
CO3	1	1	2	3	3

Correlation levels 1, 2, or 3 as defined below:

1: Slight (Low) 2: Moderate (Medium) 3: Substantial (High)

Department of Metallurgical and Materials Engineering							
Course Code	Title of the course	Program Core (PCR) / Electives (PEL)	Total Number of contact hours				Credit
			Lecture (L)	Tutorial (T)	Practical (P)	Total Hours	
MM9034	Energy Materials	PEL	3	0	0	3	3
Pre-requisites		Course Assessment methods (Continuous (CT), mid-term (MT) and end assessment (EA))					
NIL		CT+MT+EA					
Course Outcomes	• CO1: Alternative and sustainable energy sources and technologies. • CO2: Advanced materials for sustainable energy technologies. • CO3: To train the students to select and design specific materials for specific energy technology.						

Topics Covered	**Introduction:** Requirement for alternative and sustainable energy sources. [2h] **Thermoelectric materials:** Sustainable materials for Thermoelectric devices. [4h] **Photovoltaic materials:** Sustainable materials for Inorganic and organic photovoltaic Cell. [8h] **Advancement in new materials for hydrogen energy:** Hydrogen production, transportation, storage, and use; hydrogen storage – compressed storage, liquid state storage, solid state storage, metal hydrides, complex and chemical hydrides. [10h] **Advanced materials for electrochemical energy storage:** Electrochemical Reactions; Electrochemical Energy Storage Systems, Batteries and Supercapacitors. [6h] **Fuel cells:** Introduction, different types, SOFC, Bio fuel cells. [5h] **Other energy technologies and materials:** Nuclear, geothermal, hydro and wind. [5h]
Text Books, and/or reference material	**Text Books:** 1. Materials for Sustainable Energy Applications: Conversion, Storage, Transmission, and Consumption, David Munoz-Rojas and Xavier Moya (Editors), CRC Press, 2016. **Reference Books:** 1. Fundamental studies connected with electrochemical energy storage; by E.Buck; Washington, DC: NASA (1975) 2. Electrochemical Supercapacitors; by B. E. Conway; Kluwer Academic/Plenum; New York (1999) 3. Handbook of Hydrogen Storage - New Materials for Future Energy Storage - by M Hirscher, 2010, Wiley-VCH 4. Fuel cells: from fundamentals to applications; by Supramaniam Srinivasan; Springer Science + Business Media; New York (2006)

Mapping of CO (Course Outcome) and PO (Programme Outcome)

POs / COs	PO1	PO2	PO3	PSO1	PSO2
CO1	1	2	3	2	2
CO2	1	1	3	2	2
CO3	3	2	3	3	2

Correlation levels 1, 2 or 3 as defined below:

1: Slight (Low)   2: Moderate (Medium)   3: Substantial (High)

Department of Metallurgical and Materials Engineering							
Course Code	Title of the course	Program Core (PCR) / Electives (PEL)	Total Number of contact hours				Credit
			Lecture (L)	Tutorial (T)	Practical (P)	Total Hours	

<table>
<tr><td>MM9035</td><td>Biomaterails</td><td>PEL</td><td>3</td><td>0</td><td>0</td><td>3</td><td>3</td></tr>
<tr><td colspan="2">Pre-requisites</td><td colspan="6">Course Assessment methods (Continuous (CT), mid-term (MT) and end assessment (EA))</td></tr>
<tr><td colspan="2">NIL</td><td colspan="6">CT+MT+EA</td></tr>
<tr><td>Course Outcomes</td><td colspan="7">• CO1: To develop the knowledge based for biomaterials science and technology, different types and properties of biomaterials.
• CO2: To understand the interactions of biological molecules and cells with biomaterials.
• CO3: To learn the applications in different field, designing and sustainability.</td></tr>
<tr><td>Topics Covered</td><td colspan="7">Introduction to Biomaterials: Introduction to biomaterials and its history, Properties of Biomaterials. [4h]

Different types of Biomaterials: Polymeric materials and blends, Metal based biomaterials, Ceramics and bioglasses [6h]

Biological responses: Host reactions to biomaterials, Protein-Surface Interactions, Cell-Surface Interactions, biocompatibility, implant associated infection. [5h]

Testing of biomaterials: in vitro assessment, in vivo assessment, cytotoxicity test, cell adhesion test; Antibacterial assessment, blood materials interactions [5h]

Degradation of Materials in Biological Environment: Degradation of Polymers, Metals and Ceramics. [2h]

Applications: Dentistry and orthopaedics; Implantation techniques for soft tissue and hard tissue replacements, biomedical and biosensors; Other miscellaneous applications, Design of materials. [15h]

Biomaterial device development and Regulation, Commercialization, Ethical issues, Clinical trials, sustainability. [3h]</td></tr>
<tr><td>Text Books, and/or reference material</td><td colspan="7">Text Books:
2. Biomaterials Science (Third Edition), An Introduction to Materials in Medicine, ISBN 9780-12-374626-9, Academic Press, Edited by: Buddy D. Ratner et al.

Reference Books:
5. J.B. Park and J.D. Bronzino. Biomaterials: Principles and Applications. CRC Press. 2002. ISBN: 0849314917
6. Bikramjit Basu; Biomaterials Science and Tissue Engineering: Principles and Methods; Cambridge University Press; [ISBN: 9781108415156]; 2017</td></tr>
</table>

Mapping of CO (Course Outcome) and PO (Programme Outcome)

POs / COs	PO1	PO2	PO3	PSO1	PSO2
CO1	2	1	2	2	2
CO2	2	1	2	2	2
CO3	2	2	3	3	2

Correlation levels 1, 2 or 3 as defined below:

1: Slight (Low) 2: Moderate (Medium) 3: Substantial (High)

Department of Metallurgical and Materials Engineering							
Course Code	Title of the course	Program Core(PCR) / Electives(PEL)	Total number of contact hours				Credit
			Lecture (L)	Tutorial (T)	Practical (P)	Total Hours	
MM9036	Phase equilibria and phase transformation in materials	PEL	3	0	MM9036	Phase equilibria and phase transformation in materials	PEL
Pre-requisites		Course assessment methods (Continuous(CT) and end assessment (EA))					
Basic UG level knowledge on thermodynamics and materials		CT+EA					
Course outcomes	• To understand and interpret phase equilibria prevailing in material systems • To understand phase transformation in view of diffusion phenomena and other modes prevailing in material systems. • To understand and interpret phase transformation in analytical terms in correlation to phase equilibria for necessary application of fundamental aspects.						
Syllabus (Topics covered)	Introduction to the degrees of freedom, component, phase and external variables of a system: Gibbs Phase Rule; Concept of equilibrium and phase equilibria; Invariant, univariant/monovariant, bivariant and trivariant phase equilibria. (6 h) Binary phase equilibria: Tie line principle, Lever rule, binary isomorphous, eutectic, eutectoid, peritectic, monotectic and syntectic systems; Unary system: G-T diagram; Mixing of two components and associated enthalpy change, entropy change and Gibbs free energy change; Free energy (G)-composition (X) diagram; G-X diagram for ideal and non-ideal solutions; G-X diagram in correlation to binary phase diagrams. (8 h) Ternary phase equilibria: Gibbs triangle; Ternary isomorphous system: Isotherms, Isopleths, ternary single phase and two-phase equilibria; Ternary three phase equilibria: Tie-triangle principle, Three phase equilibria in space model (isomorphous coupled with eutectic systems); Ternary four phase equilibria: Ternary eutectic system. (8 h) Introduction and classification of phase transformation; conventional classification: homogeneous and heterogeneous phase transformations; Solidification: thermodynamic aspects, thermal supercooling, constitutional supercooling, morphology of solidified structure with respect to solidification parameter; solid state phase transformations: thermally activated transformation, athermal transformation; Buerger's classification: reconstructive transformation and displacive transformation; paraequilibrium state, concept of invariant plane strain. (8 h) Diffusion: Phenomenological equation of diffusion, Chemical potential gradient as the driving force, Fick's first law of diffusion, Representation of diffusion flux in terms of chemical potential gradient; Diffusion in ideal and non-ideal solutions; Uphill diffusion, dependency of diffusion coefficient on jump frequency and jump distance, atomic mechanism of diffusion; Expression of diffusion coefficient for vacancy mechanism and interstitial mechanism; Steady state diffusion and transient diffusion; Fick's second law of diffusion; determination of self diffusion coefficient by radioactive method; Solutions of Fick's second law: Thin film solution and Grube solution, Variable diffusivity: Boltzmann-Matano analysis, Matano interface, determination of diffusivity as a function of concentration; Diffusion in substitutional solid solution: Kirkendall effect, Darken's analysis. (8 h) Analytical treatment to phase transformation: stable and metastable matrix, concept of fluctuation,						

	embryo, volume free energy change, surface energy, strain energy, free energy change for formation of an embryo, critical embryo, activation energy for critical embryo formation; homogeneous nucleation, heterogeneous nucleation, expressions of homogeneous nucleation rate and heterogeneous nucleation rate; effect of strain energy on shape of embryo, temperature dependence of nucleation rate, time dependence of heterogeneous nucleation rate; effect of prior cold working on nucleation rate, expression of growth rate; Johnson-Mehl equation-overall transformation rate, origin of time temperature-transformation (TTT) diagram; (10 h)
Text Books, and/or reference material	Text Books: **1.** Phase Equilibria, Phase Diagrams and Phase Transformations: Their Thermodynamic Basis-Mats Hillert, Cambridge University Press, 2007. 2. Phasetransformations in metals and alloys-D.A. Potter and, K.E. Easterling, CRC Press, 1992. 3. Transformationsin Metals, P.G. Shewmon, Mc-Graw Hill, 1969. 4. Introduction to Physical Metallurgy– S. N. Avner, Tata McGrawHill, 1997. 5. Physical Metallurgy–Peter Haasen, Cambridge University Press, 1996. 6. PhysicalMetallurgyPrinciples,R.E.Reed-HillandR.Abbaschian,3rded,PWS-Kent 7. Publishing,1992. 8. Physical Metallurgy for Engineers–A. G.Guy,Addison-WesleyPub.Co.,1962. 9. Modern Physical Metallurgy, R.E. Smallman, Butterworths,1963.

Mapping of Cos with Pos and PSOs:-

POs / COs	PO1	PO2	PO3	PSO 1	PSO 2
CO1	2	3	3	3	3
CO2	3	2	3	3	2
CO3	3	3	3	3	3

Correlation levels 1, 2 or 3 as defined below:

1: Slight (Low) 2: Moderate (Medium) 3: Substantial (High)

Department of Metallurgical & Materials Engineering							
Course Code	Title of the course	Program Core (PCR) / Electives (PEL)	Total Number of contact hours				Credit
			Lecture (L)	Tutorial (T)	Practical (P)	Total Hours	
MM9037	Additive Manufacturing	PEL	3	0	0	3	3
Pre-requisites		Course Assessment methods (Continuous (CT), and end assessment (EA))					
NIL		CT+EA					
Developer		M. K. Mondal and Krishna Priya Yagati					
Course Outcomes	CO1: Understand the fundamentals of Additive Manufacturing Technologies for engineering applications. CO2: Apply the knowledge of additive manufacturing for various real-life applications. CO3: Suggest mitigation techniques for additive manufacturing defects.						

Topics Covered	Introduction: Overview, Basic principle needed and advantages of additive manufacturing, Procedure of product development in additive manufacturing, Classification of additive manufacturing processes, Materials used in additive manufacturing, Challenges in Additive Manufacturing. [5 hours] Generic additive manufacturing processes: Computer-Aided Design (CAD), Conversion of StereoLithography (STL), Transfer to AM machine and STL file manipulation, machine setup, Build, Removal, Distinction between AM and CNC machining, Reverse engineering. [6 hours] Additive Manufacturing Processes: Z-Corporation 3D-printing, Stereolithography apparatus (SLA), Fused deposition modeling (FDM), Laminated Object Manufacturing (LOM), Selective deposition lamination (SDL), Ultrasonic consolidation, Material Jetting, Binder jetting. [7 hours] Powder bed Fusion processes: Selective laser sintering (SLS), Laser engineered net shaping (LENS), Selective laser melting (SLM), Electron beam melting (EBM), Materials, Powder fusion mechanisms (Solid-state sintering, chemically induced sintering, liquid phase sintering, Full melting), powder handling challenges, powder recycling, defects. [5 hours] Direct energy deposition processes: DED process description, powder feeding, wire feeding, laser and electron based deposition processes. [4 hours] Post-Processing in Additive Manufacturing: Support material removal, surface texture improvement, accuracy improvement, aesthetic improvement, preparation for use as a pattern, property enhancements using non-thermal and thermal techniques, Brief information on characterization techniques used in additive manufacturing, Applications of additive manufacturing in rapid prototyping, rapid manufacturing, rapid tooling, repairing and coating. [10 hours]. Future scope in Additive Manufacturing: Evaluation of additive manufactured structures/ components, scope of AM in various fields. Its importance and applications. [5 hours]
Text Books, and/or reference material	Text Books and Reference Books: 1. C.K. Chua, K.F. Leong, C.S. Lim: Rapid prototyping- Principles and applications, 3rd Ed., World Scientific Publishers, 2010. 2. Gibson, I, Rosen D W., and Stucker B., Additive Manufacturing Methodologies: Rapid Prototyping to Direct Digital Manufacturing, Springer, 2010. 3. Chee Kai Chua, Kah Fai Leong, 3D Printing and Additive Manufacturing: Principles and Applications: Fourth Edition of Rapid Prototyping, World Scientific Publishers, 2014. 4. A. Gebhardt: Rapid prototyping, Hanser Gardener Publications, 2003. 5. L.W. Liou, F.W. Liou: Rapid Prototyping and Engineering applications: A tool box for prototype development, CRC Press, 2007. 6. A.K. Kamrani, E.A. Nasr: Rapid Prototyping- Theory and Practice, Springer, 2006. 7. P.D. Hilton, P.F. Jacobs: Rapid Tooling- Technologies and Industrial Applications, CRC Press, 2000. 8. D.T. Pham, S.S. Dimov: Rapid Manufacturing- The Technologies and Applications of Rapid Prototyping and Rapid Tooling, Springer, 2001. Applied Numerical Analysis by C. F. Gerald and P. O. Wheatley, Addison Wesley, Massachusetts

Mapping of COs with POs and PSOs

POs / COs	PO1	PO2	PO3	PSO 1	PSO 2
CO1	2	1	3	2	2
CO2	2	1	2	3	2
CO3	2	1	2	3	2

Correlation levels 1, 2 or 3 as defined below:

1: Slight (Low) 2: Moderate (Medium) 3: Substantial (High)

Department of Metallurgical and Materials Engineering								
Course Code	Title of the course	Program Core (PCR) / Electives (PEL)	Total Number of contact hours				Credit
			Lecture (L)	Tutorial (T)	Practical (P)	Total Hours	
MM9038	Non-Destructive Evaluation	PER	3	0	0	3	3

Pre-requisites	Course Assessment methods (Continuous (CT), mid-term (MT) and end assessment (EA))
Manufacturing Processes	CT+MT+EA

Course Outcomes	• CO1:to classify various non destructive testing methods and their application • CO2: to understand defect indentification and quantification • CO3:to attain instrument knowledge and interpretation
Topics Covered	**Visual Testing (VT):** Fundamentals of visual inspection, including lighting, magnification, and interpretation of indications.Application in various materials and welds. (3hrs) **Liquid Penetrant Testing (PT):** Principles, types of penetrants and developers, preparation of test materials, application, interpretation of results, and relevant codes and standards. (5hrs) **Magnetic Particle Testing (MT):** Theory of magnetism, application to ferromagnetic materials, magnetic field characteristics, and interpretation of indications. (5hrs) **Ultrasonic Testing (UT):** Principles of ultrasonic waves, types of transducers, techniques (pulse-echo, through-transmission), data presentation (A, B, C scans), and applications. (5hrs) **Radiographic Testing (RT):** X-ray and gamma-ray principles, radiation safety, image interpretation, and applications. **Advanced NDT Techniques: (6hrs)** Thermography, computed tomography (CT), acoustic emission, and other emerging techniques. (6hhrs)
Text Books, and/or reference material	Suggested Text Books: 1. Introduction to non destructive testing of welded joint R Halmshaw 2. Electrical and magnetic methods of non destructive testing Jack Blitz

Mapping of CO WITH PO AND PSO

PO / CO	PO1	PO2	PO3	PSO 1	PSO 2
CO1	3	3	3	2	1
CO2	3	2	2	3	1
CO3	2	3	3	3	2

Correlation levels 1, 2 or 3 as defined below:

1: Slight (Low) 2: Moderate (Medium) 3: Substantial (High)

Department of Metallurgical and Materials Engineering							
Course Code	Title of the course	Program Core (PCR) / Electives (PEL)	Total Number of contact hours				Credit
			Lecture (L)	Tutorial (T)	Practical (P)	Total	
MM9039	Nanomaterials for sustainability	Width Elective	3	0	0	3	3

Pre-requisites	Course Assessment methods (Continuous (CT) and end assessment (EA))
Engineering Physics, Engineering Chemistry	CT+EA
Developer	Dr Barna Roy

Course Outcome	CO1: Introduction to the basic concept of nanomaterials and nanotechnology CO2: To get an overview of the processing and characterization of nanomaterials. To understand the structure-property correlation of nanomaterials. CO3: To understand the sustainability of nanomaterials and their applications.
Topics Covered	1. Introduction: Definition of nanomaterials, Types of nanomaterials, uses of nanomaterials. Processing of nanomaterials: Different methods and approaches. Characterization of nano-materials and nano-structured materials by different techniques. Properties of nanomaterials. Comparative studies between the properties of nanomaterials and conventional materials. Structure-property correlation of nanomaterials. [16 hours] 2. Nanomaterials in Sustainable energy- Energy storage and efficiency, Renewable energy. [4 hours] 3. Nanomaterials for Environment- Environment protection and remediation, Bioremediation, Nanotechnology in agriculture. [4 hours] 4. Nanomaterials in Biomedical applications- Drug delivery, Biomedical imaging, Antimicrobial and Antibacterial applications. [4 hours] 5. Sustainability and Nanomaterials- Life cycle assessment, Toxicity and Risk assessment, Sustainable design and fabrication. [6 hours]
Text Books, and/or reference material	Text Books: 1. Materials Science and Engineering: An Introduction - William D. Callister, Jr., John Wiley & Sons, Inc., 2007 2. Nanomaterials Nanotechnologies and Design – D.L. Schodek, P. Ferreira, M.F. Ashby, Butterworth-Heinemann, 2009 3. Introduction to Nanotechnology – C.P. Poole, F.J. Owens, Wiley Interscience, 2003

Mapping of COs with POs and PSOs

POs COs	PO1	PO2	PO3	PSO 1	PSO 2
CO1	1	1	3	1	1
CO2	1	3	3	2	2
CO3	1	2	2	3	3

Correlation levels 1, 2 or 3 as defined below:
1: Slight (Low) 2: Moderate (Medium) 3: Substantial (High)

Department of Metallurgical and Materials Engineering							
Course Code	Title of the course	Program Core (PCR) / Electives (PEL)	Total Number of contact hours				Credit
			Lecture (L)	Tutorial (T)	Practical (P)	Total Hours	
MM9040	Solidification Processing	PER	3	0	0	3	3
Pre-requisites		Course Assessment methods (Continuous (CT), mid-term (MT) and end assessment (EA))					
Manufacturing Processes		CT+MT+EA					
Course Outcomes	• CO1: Understand solidification theories to industrial processes • CO2: Predict microstructures as a function of process parameters. • CO3: Understand solidification of alloys in different industrial conditions						
Topics Covered	Properties of metals and alloys before and during solidification. Surface phenomena. (2) Basic terms: surface energy, surface tension, Wetting angle. Wetting speed. Classification and influence of wetting. (4) Rapid solidification processes (RSP). Classification of high cooling rates. Conventional and unconventional effects. (2) Under cooling and recalescence. Amorphous state. Glaze-ability. (1) Processing of alloys in the semi-solid state. Rheology. Newton's law of viscosity. Newtonian and non-Newtonian materials. (3) Distribution of non-Newtonian materials, physical models of materials and their rheograms. The apparent viscosity. Thixotropy.. Submersible rotational viscometry. (3) High-speed mixing. The intensity of the flow and its significance for the primary crystallization. The materials in the semi-solid state - SSM (Semi-Solid Metals). (2) Theories of solid solution morphology spheroidization. Types of alloys suitable for SSM. Case studies of selected castings. (4) Pressure solidification processes (PSP). Effect of pressure on the primary crystallization, change the thermo-physical properties, cooling rate and the force induced solidification flow. Alloys used in PSP. (3) Practical use of the rheological behavior of the alloys in the solidification processes and its importance. Case studies of selected castings. (4)						
Text Books, and/or reference material	Suggested Text Books: 1. Principles of Solidification by Laurens Kagerman 2. Modelling the Flow and Solidification of Metals by T. A Smith 3. Physical Metallurgy- Principles and Practise by A Raghavan Suggested Reference Books: Kirkwood, D.H. – Suéry, M. – Kapranos, P. – Atkinson, H.V. – Young,K.P. Semi-solid processing of Alloys. Springer.						

Mapping of CO WITH PO AND PSO

PO / CO	PO1	PO2	PO3	PSO 1	PSO 2
CO1	3	3	3	3	1
CO2	3	3	3	3	1
CO3	3	3	3	3	2

Correlation levels 1, 2 or 3 as defined below:
1: Slight (Low) 2: Moderate (Medium) 3: Substantial (High)

Department of Metallurgical and Materials Engineering							
Course Code	Title of the course	Program Core (PCR) / Electives (PEL)	Total Number of contact hours				Credit
			Lecture (L)	Tutorial (T)	Practical (P)	Total Hours	
MM9041	Fracture and Fatigue of Materials	PEL	3	0	0	3	3
Pre-requisites		Course Assessment methods (Continuous (CT), mid-term (MT) and end assessment (EA))					
Basic UG level knowledge on Mechanical Behaviour of Materials		CT+MT+EA					
Course Outcomes	I. Learn fundamentals of fatigue and fracture (including fracture mechanics). II. Understand fatigue and fracture in details including mechanisms and methods of testing. III. Solve problems on fatigue and fracture and different design problems to meet contemporary needs (including tutorials).						
Topics Covered	**Fracture:** Modes of fracture, Theoretical strengths and defects, Stress concentration, Griffith criterion, Energy release rate, R-Curve, Plane stress and Plane strain, stress analysis of cracks, stress intensity factor, Plastic zone size-Irwin and Dugdale, Concept of Crack tip opening displacement (CTOD), J-integral and J_{IC}, HRR singularity, Experimental determination of K_{IC}, J_{IC} and CTOD. Different types of fracture: Ductile, Cleavage, Intergranular fracture, DBTT, Microstructural aspect of fracture, Different toughening mechanisms. 22h **Fatigue:** Introduction to fatigue, Different stress cycles, Stress controlled fatigue, S-N diagram and endurance limit, Various failure relations, viz., Goodman, Soderberg, Gerber parabola; Fatigue crack nucleation and propagation; application of fracture mechanics for fatigue cracking cyclic stress strain curve; low cycle fatigue; effect of stress concentration on fatigue; size effect; surface effects; effect of metallurgical variables on fatigue; Fatigue life improvement due to surface protection, cumulative fatigue damage rule; concept reverse plastic zone; corrosion fatigue; fretting; high temperature fatigue. 18 h						
Text Books, and/or reference material	Text Books: 1. Anderson, T. L. Fracture Mechanics. 2nd ed. CRC Press, 1995. 2. Mechanical Metallurgy by George Dieter 3. Suresh, S. Fatigue of Materials. 2nd ed. Cambridge University Press, 1998. 4. Elementary engineering fracture mechanics by David Broek, 1982, Martinus Nijhoff						

	Publishers 5. Fracture Mechanics by M. Janssen, J. Zuidema and R. J. H. Wanhill, 2nd edition, Spon Press, Taylor and Francis group.

Mapping of COs with POs and PSOs

POs / COs	PO1	PO2	PO3	PSO1	PSO2
CO1	2	1	2	2	2
CO2	2	1	2	1	2
CO3	2	2	2	2	2

Correlation levels 1, 2 or 3 as defined below:
1: Slight (Low) 2: Moderate (Medium) 3: Substantial (High)

Department of Metallurgical and Materials Engineering							
Course Code	Title of the course	Program Core (PCR) / Electives (PEL)	Total Number of contact hours				Credit
			Lecture (L)	Tutorial (T)	Practical (P)	Total Hours	
MM9042	**Advanced Powder Technology**	PEL	3	0	0	3	3
Pre-requisites		Course Assessment methods (Continuous (CT) and end assessment (EA))					
NIL		CT+EA					

Course Outcomes	• CO1: Learn science and technological aspects of the Advanced Powder Metallurgy Techniques. • CO2: Emphasis is put on methods for those types of powders that are important for production of engineering components. • CO3: Solve problems of near net shape fabrication of powder metallurgy parts through tutorials/ assignment/ group task.
Topics Covered	**Topic 1:** **Introduction:** Basic powder production and characterization; Powder Treatment and Sintering **[12]** **Topic 2:** **Advanced Powder Synthesis:** Sustainable synthesis of powders; Sustainable production of powder feedstock from machining waste; Advances in atomisation techniques; Powders by electrolysis; Mechanochemical synthesis of nanocrystalline powders; Plasma synthesis of metal nanopowders; Powder metallurgy for steel; Powder metallurgy of titanium alloys **[10]** **Topic 3:** **Advanced Densification Processes**: Sustainable Powder-Based Additive Manufacturing; Microwave sintering; Spark Plasma Sintering; Hot Pressing **[10]** **Topic 4:** **Applications:** Powder metallurgy in automotive applications; Applications of powder metallurgy in biomaterials; Applications of powder metallurgy to cutting tools **[10]**
Text Books, and/or reference material	**Text Books:** 1. Powder Metallurgy – A Upadhyaya and G S Upadhyaya. 2. Powder Metallurgy Science – R. M. German, 2nd Edition, MPIF, 1994 3. Advances in powder metallurgy- Edited by Isaac Chang and Yuyuan Zhao, Woodhead Publishing Limited, 2013 **Reference Books:** 1. Powder metallurgy: principles and applications, Fritz V. Lenel, Metal Powder Industries Federation, 1980

Mapping of COs with POs and PSOs

POs / COs	PO1	PO2	PO3	PSO 1	PSO 2
CO1	2	2	2	3	3
CO2	2	2	2	3	3
CO3	3	3	2	3	3

Correlation levels 1, 2 or 3 as defined below:
1: Slight (Low) 2: Moderate (Medium) 3: Substantial (High)

Department of Metallurgical & Materials Engineering							
Course Code	Title of the course	Specialisation Elective - III	Total Number of contact hours				Credit
			Lecture (L)	Tutorial (T)	Practical (P)	Total hours	
MM9043	Metallurgy of Advanced Joining	SE	**3**	**0**	**0**	**3**	**3**

Pre-requisites	Course Assessment methods: [Continuous Assessment (CA) and end semester examination (ES))
Introductiion to Metallurgy and Materials	CA + ES
Developer	K S GHOSH

Course Outcomes	To acquiant with the various joining/welding processes, advantages, limitatiions, applications To know the heat flow in welding, and welding metallurgy of plain carbon steel, ferrous and non-ferrous alloys To understand the defects, problems and their remedies in joining, and actual testing of joints
Topics to be Covered	**Introduction**: Historical of joining, classification; abbreviation for welding processes; welding procedure; welding terms and characteristics; welding joits; welding positions, welding vs. other joining processes. (05) **Gas Welding**: Oxy-acetylene welding, flame characteristics, advantages and drawbacks of gas welding, oxy-acetylene cutting, other gas-oxy welding processes. (01) **Arc Welding:** Arc welding power sources, power source characteristics (PSC); Manual Metal Arc Welding/Shielded Metal Arc Welding (MMAW/SMAW); welding electrodes; AWS and BIS electrodes specifications; arc blow; weaving; Metal Inert Welding (MIG), shielding gases, modes of metal transfer; Tungsten Inert Welding (TIG); Submarged arc welding (SAW); Plasma Arc Welding (PAW); Electroslag welding (ESW), Thermit welding etc., advantages, limitations, applications of these processes. (06) **Resistance Welding**: Priciple of heat generation; process description; welding sequence; resistance spot welding; resistance seam welding; flash butt welding etc.; limitations and application; energy requirements; types of welding electrodes; heat balance of welding varying thickness and materials. (02) **Radiant Welding**: Electron beam welding (EBW), process description, power density, weld characteristics; Laser beam welding (LBW), principles of LASER generation; advantages, limitations and applications of the processes. (02) **Solid State Welding processes**: Friction welding; diffusion bonding; explosive welding; ultrasonic welding; atomic hydrogen welding; etc. (02) **Frction Stir Welding (FSW):** Welding process; welding forces; generation and heat flow;

	FSW process parameters; heat input; advantages, limitations and applications. (01) **Heat Flow in Welding:** Temperature distribution – in linear butt welding; thermal diffusivity; heat conduction equation in welding; Temperature distribution in semi-infinite (3-D case) and with large (infinite) plate with finite thickness; Adam's solution and Well's modification in finding peak temperarture; Temperarture-Time curve (*T-t,* Thermal curve), plate thichness and preheating; Calculation of cooling rate etc. (10) **Welding Metallurgy**: Introduction; weld metal composition – dilution, pick up; weld metal structure – epitaxial solidifivatiion; heat affected zone (HAZ); HAZ in multipass welding; weldability; structure of HAZ in hardenable steel; weldability vs. hardenability; carbon equivalent; actual weldability tests; gas-metal reactions etc. (10) **Welding of Specific Alloys**: Welding of stainless steels; susceptibility microfissuring or hot cracking; influence of d-ferrite in welding austentic statinles steel; Schaeffler and Delong diagrams; weld decay and knife-line attack (KLA); welding of cast irons, Al base alloy, Cu base, Ti-base, Mg-base alloys; welding of dissimilar metals and alloys. (06) **Weld Defects and Cracking:** Various weld defects - hot cracking, cold cracking, Lamellar tearing, fish-eye defects etc.; thermal, and residual, stresses, effect of thermal cycle; mitigation of residual stresses; distortion in welds etc. (02) **Testing and Inspection**: All weld tests – tension, bend, tensile-shear, hardness, impact etc. Non destructive testing – dye penetran (Zyglo), magnetic particle, radiographic, eddy current etc., reliability of welded joints. (02) **Brazing and soldering:** Metallurgy of brazing and soldering; different brazing processes – furnace, induction, dip, resistance, vacuum etc., brazing filler metals; soldering, soldering processes; soldering filler materials; fluxes, applications. (01)
Text Books and Reference Books	**Text Books:** 1. Foundation of Welding Technology, K S Ghosh, PHI Learning Publication, 2022. 2. Welding Process and Technology, R S Parmar, Khanna publishers. 3. Metallurgy of Welding, J F Lanchster, Abington publication, 6th Ed., 1999, UK. 4. Welding Technology – H Cary, Prentice Hall, 1988. 4. Welding Metallurgy, Sindo Kou, A John Wiley and Sons Inc. Publication. **Reference Books**: 1. Metal Handbook – Welding, Brazing and Soldering, Vol 6, American Society for Metals, 1993, 10th Editiion, USA. 2. AWS Handbook – Residual Stress and Distortion, 9th Editiion, Vol 1, 2001, USA.

Mapping of COs with POs and PSOs

POs / COs	PO1	PO2	PO3	PSO 1	PSO 2
CO1	2	3	3	3	3
CO2	3	2	3	3	3
CO3	2	3	3	2	3

Correlation levels 1, 2 or 3 as defined below:
1: Slight (Low) 2: Moderate (Medium) 3: Substantial (High)

Department of Metallurgical and Materials Engineering							
Course Code	Title of the course	Program Core (PCR) / Electives (PEL)	Total Number of contact hours				Credit
			Lecture (L)	Tutorial (T)	Practical (P)	Total Hours	

MM9044	**High temperature sustainable materials**	PEL	3	0	0	3	3

Pre-requisites	Course Assessment methods (Continuous (CT) and end assessment (EA))
NIL	CT+EA

Course Outcomes	CO1: Understand fundamental aspects of a selection of high-temperature materials. CO2: Illustrate environmentally friendly engineering materials that are capable of withstanding extreme heat. CO3: Correlate structure-property relationships of high-temperature structural application.
Topics Covered	**Introduction:** Overview of the high temperature sustainable materials [2] **High temperature resistant metal and alloys:** Processing, characterization and applications of Titanium, Tungsten, Refractory metals, stainless steel etc. [10] **Heat resistant ceramics:** Structure property correlation of Alumina, Magnesia, ZrO_2, Silicon carbide etc. [8] **Heat resistant plastics:** Study on high temperature plastics such as **Polybenzimidazole (PBI), Polyimide, Polyether Ether Ketone (PEEK), Teflon etc.** [8] **Consideration of sustainability: Recyclability, Renewable Resources and Reduced Environmental Impact for high temperature materials.** [8] **Applications: Aerospace; Industrial Processes; Electronics; Construction etc.** [6]
Text Books, and/or reference material	**Text Books:** 1. Engineering Materials: M. F. Ashby and D. R. N. jones, Pergamon press Oxford (1980). 2. G.W. Meetham and M.H. Van de Voorde, Materials for High Temperature Engineering Applications, Springer, Berlin (2000). Suggested Reference Books: 1. W. O. Soboyejo and T. S. Srivastan (ed.), Advanced Structural Materials: Properties, Design, Optimization and Applications, CRC Press, New York (2007). 2. The Super alloys by C. T. Sims and W. C. Hegel –Wily-Interscience. 3. Lecture Notes and Published Papers

Mapping of COs with POs and PSOs

POs / COs	PO1	PO2	PO3	PSO 1	PSO 2
CO1	2	2	3	3	2
CO2	3	3	3	3	2
CO3	2	2	3	3	2

Correlation levels 1, 2 or 3 as defined below:

1: Slight (Low) 2: Moderate (Medium) 3: Substantial (High)

Department of Metallurgical and Materials Engineering							
Course Code	Title of the course	Specialisation Elective - I	Total Number of contact hours				Credit
			Lecture (L)	Tutorial (T)	Practical (P)#	Total Hours	

MM 9045	Corrosion Engineering of Advanced Materials	SE - I	3	0	0	3	3

Pre-requisites	Course Assessment methods [Continuous assesment (CA) and end semester examnation (ES)]
Engineering Chemistry & Corrosion Engineering	CA + ES
Course Outcomes	CO1: To learn the corrosion science, themodymanic and kinetics, and various forms of corrosion and mechanisms including high temperature corrosion CO2: To know the different corrosion preventive techniques including nano-materials corrosion and prevention CO3: To understand the detailed corrosion testings including eletrochemical impedance spectroscopy (EIS)
Topics Covered	**Introduction**: Cost of corrosion, definition of corrosion, Environments. [02] **Corrosion principles:** Introduction, electrochemical reactions, thermodynamics, free energy, electrode potential, cell potential, EMF series, galvanic series, IUPAC convention of cell reaction, electrode kinetics, exchange current density, polarisation, passivity, Poubaix diagram (E – pH diagram). [10] **Forms of corrosion:** Uniform attack. Galvanic or two-metal corrosion, EMF series and galvanic series, metallurgical effects, beneficial effects and prevention. Intergranular corrosion. Crevice corrosion. Pitting corrosion. Selective leaching. Environment Assisted /Induced Cracking (EAC/ EIC) - Stress corrosion cracking (SCC), Corrosion fatigue, and Hydrogen damage (HE). [10] **Corrosion prevention:** Materials selection, alteration environments, inhibitors – inorganic, organic, green etc, cathodic and anodic protection, coating. [05] **Corrosion testing:** Corrosion rate expression, potentiodynamic and cyclic polarisation techniques, Scanning Vibrating Electrode Technique (SVET), Corrosion rate determination - Tafel extrapolation, linear polarisation, stress corrosion cracking test, SSRT, valuation of hydrogen rmbrittlement (HE) [05] **Electrochemical Impedance Spectroscopy (EIS):** Introduction, AC circuit theory and complex impedance, circuit description code, representation of Nyquist Plot and Bode Plot of Electrical Components, Nyquist and Bode Plots of *RC*, *R*(*RC*) and *R-L-C* circuits. experimental set-up of electrochemical measurement, analysis and interpretation of EIS, constant phase element (CPE), Electrode coated by a porous, two porous layers and equivalent circuit (EC), Kramers−Kronig Relationship, EIS study of alloys, micro-alloyed steel and dental amalgam. [08] **Nano-material and Corrosion – prevention:** Introduction, characteristics of nanomaterials, surface characteristics, dimensions of nanosized particles, corrosion of nanostructured alloys, electrochemical behaviour of nanocrystalline (NC) alloys, corrosion protection by nano-crystalline (NC) materials and nanocoating. [05] **High temperature corrosion:** Introduction, Pilling–Bedworth ratio, electrochemical and morphological aspects, and hot corrosion. [05]
Text books/ Reference books	**Text Books**: 1. K S Ghosh, Foundations of Corrosion Science and Engineering, PH Learning, New Delhi, 2024. 2. Mars G Fontana, Materials Science and Engineering, McGraw Hill Internatinal Editions, Materials Science and Metalurgy Series, 3rd Editions. 3. Kennth R Trethewey and John Chamberlin, Materials for Science and Engineering, Adition Wesley Longman Ltd. 4. Denny A Jones, Principles and Prevention of Corrosion**,** Macmilliaan Maxwell Publication.

	5. L.L. Shreir, Corrosion & Corrosion Control, Vol. 1 and vol 2, John Wiley, New York, 1985. 6. N. Birks, G.H. Meier. Introduction to High Temperature Oxidation of Metals. London, U.K.: Edward Arnold, 1983. **References:** 1. ASM Handbook, Vols. 13, 13A, 13B, 13C, "Corrosion", ASM International, 1987, 2005.

Mapping of COs with POs and PSOs

POs / COs	PO1	PO2	PO3	PSO 1	PSO 2
CO1	2	3	3	3	3
CO2	2	3	3	3	3
CO3	3	2	3	2	3

Correlation levels 1, 2 or 3 as defined below:

1: Slight (Low) 2: Moderate (Medium) 3: Substantial (High)

Department of Metallurgical and Materials Engineering							
Course Code	Title of the course	Specialisation Elective - V	Total Number of contact hours				Credit
			Lecture (L)	Tutorial (T)	Practical (P)	Total hours	
MM9046	Advanced Electroplating and Pulse Plating	SE	**3**	**0**	**0**	**3**	**3**
Pre-requisites		Course Assessment methods [Continuous assesment (CA) and end semester examnation (ES)]					
Engineering Chemistry & Introductiion to Metallurgy and Materials		CA + ES					
Developer		K S GHOSH					
Course Outcomes	CO1: To acquiant with the electroplating of different metals and processes, advantages, limitatiions, applications CO2: To know the pulse plating of metals and alloys, advantages, limitatiions, applications CO3: To understand the defects, problems in electrodeposition, and their remedies, and actual testing of electroplated metals and alloys						
Topics Covered	**Ch 1:** Introduction, Brief History of Electroplating, Electroplating Process, Electrochemical Reactions and Electrode Potential, Kinetics and Mechanism of Electroplating, Current - Potential Relationship, Effects of Mass Transport, Diffusion, Faraday's Law of Electrolysis, Cathode Current Efficiency (CCE), Throwing Power, Deposit Thickness, Methods of Electroplated Thickness Measurement, Electrodeposition – Initiation and Growth Mechanisms (Atomistic Aspects), Roles of Additives, Impurities, Applications of Electrodeposition. [10] **Ch 2:** Electrodeposition of common metals: Inroduction, Copper Electroplating, Different Copper Plating Baths – compositions of Copper Sulphate, Cyanide and Pyro-phosphate, fluoborite, Reactions in Copper Sulphate Plating, Operating Conditions or Variables - Current Density, Agitation, Temperature, Anode Materials, Cathodic Current Efficiency (CCE) of Cu, Ni, Cr, Rate of Deposition, Electroplating of Nickel, Bath Compositions and Operating Factors, Role of Additive Agents, Deposit Thickness Distribution, Theory of Chromium Electroplating, Bright Plating, Preparation of the Chromic Acid Bath, Solution composition, Current Density,						

	Anode Materials, Hard Chromium Plating, Advantages and Limitations, Applications of Cu, Ni, Cr Plating. [12] **Ch 3:** Electrodeposition of Others Metals: Zn, Sn, Cd, Pd, Steps in Zinc Plating, different bath compositon, agitation, Soluble and Insoluble Anodes, Advantages, Limitations applications of these metals. [05] **Ch 4:** Electrodeposition of Precious Metals: Silver, Gold, Platinum, different bath compositon, Advantages, Limitations applications of these Metals. [03] **Ch 5:** Electroless (EN) Plating: Nickel, bath composition and reactions, Advantages, Limitations and Applications. [03] **Ch 6**: Pulse Electroplating: Introduction, Process characteristics, Nano-crystalline (NC) Ni Coating, Bath and variables, Electrochemical Impedance Spectra (EIS) of Nano-crystalline (NC) Ni Coating, Nano-crystalline Ni-Mo Coating Various Unipolar Pulsation Processes, Different Bipolar Pulsation Processes, Advantages, Limitations and Applications. [08] **Ch 7:** Alloy plating: Principles of alloy plating, Determination of partial current densities, Electroplating of brass - bath composition, Electroplating of bronze, Advantages, Limitations and Applications. [04]
Text Books, and/or reference material	**Text Books:** 1. Electroplating – Basic Principles, Processes and Practice, Nasser Kanani, Elsevier, 2006. 2. Modern Electroplating, Edited by Mordechay Schlesinger, Milan Paunovic, A John Wiley & Sons, Inc, Publicatuion, 2010. 3. Electroplating - Fundamentals of Surface Finishing: by Frederick Adolph Lowenheim, American Electroplaters Society, 2000. 4. An Introductiion to . Electrometallurgy, Satys Narain and Rajendra Sharan, Standard Publishers Distributions, 2011. **Reference Book**: 1. Electroplating Engineering Handbook, Lawrence J. Durney, Van Nostrand Reinhold Co., 1984.

Mapping of COs with POs and PSOs

POs / COs	PO1	PO2	PO3	PSO 1	PSO 2
CO1	3	2	3	3	3
CO2	3	2	3	3	3
CO3	3	2	3	2	3

Correlation levels 1, 2 or 3 as defined below:

1: Slight (Low) 2: Moderate (Medium) 3: Substantial (High)

Department of Metallurgical and Materials Engineering								
Course Code	Title of the course	Program Core (PCR) / Electives (PEL)	Total Number of contact hours				Credit
			Lecture (L)	Tutorial (T)	Practical (P)	Total Hours	

MM9047	**Advanced Ceramic Materials**	PEL	3	0	0	3	3
Pre-requisites		Course Assessment methods (Continuous (CT) and end assessment (EA))					
NIL		CT+EA					
Course Outcomes	• CO1: Describe generic classification of ceramics and their specific engineering applications. • CO2: Solve problems of fabrication of high performance ceramic parts • CO3: Correlate structure-property relationships of ceramics						
Topics Covered	**Topic 1: Introduction:** Processing, characterization and applications of Advanced Ceramics [12] **Topic 2: Ceramic Structures:** Microstructural Design of Ceramics, Mesoscopic Ceramic Structures in One, Two, and Three Dimensions; Bulk Ceramic Nanostructures [10] **Topic 3: Classification and properties:** Oxides; Nitrides; Carbides; Mechanical Properties; Thermal, Electrical, and Magnetic Properties [10] **Topic 4: Applications:** Structural Applications; Nanosized and Nanostructured Hard and Superhard Materials and Coatings; High-Temperature Engineering Ceramics; Advanced Ceramic Glow Plugs; Thermal Barrier Coatings [10]						
Text Books, and/or reference material	**Text Books:** 1. Ceramics Science and Technology, Edited byRalf Riedel and I-Wei Chen, 2008 WILEY-VCH 2. Advanced Ceramic Materials, Ashutosh Tiwari, Rosario A. Gerhardt, Magdalena Szutkowska, Wiley, 2016 **Reference Books:** 1. Advances in Ceramics - Characterization, Raw Materials, Processing, Properties, Degradation and Healing Edited by Costas Sikalidis, InTech 2011						

Mapping of COs with POs and PSOs

POs / COs	PO1	PO2	PO3	PSO 1	PSO 2
CO1	2	2	3	3	2
CO2	3	3	3	3	2
CO3	2	2	3	3	2

Correlation levels 1, 2 or 3 as defined below:

1: Slight (Low) 2: Moderate (Medium) 3: Substantial (High)

Department of Metallurgical & Materials Engineering							
Course Code	Title of the course	Program Core (PCR) / Electives (PEL)	Total Number of contact hours				Credit
			Lecture (L)	Tutorial (T)	Practical (P)	Total Hours	
MM9048	Plasma technology for metallurgical applications	PCR	3	0	0	3	3
Pre-requisites		Course Assessment methods (Continuous (CT), mid-term (MT) and end assessment (EA))					

Sustainable Metal Production Technology	CT+EA
Course Outcomes	CO1: To understand the core principles of plasma physics and generate plasma for metallurgical applications. CO2: To learn plasma technologies and processes for smelting, refining, and surface coating of metals. CO3: To apply emerging plasma-based techniques for sustainable and innovative metallurgical processes, including waste treatment and nanomaterials synthesis
Topics Covered	**Introduction to Plasma Technology (4 Hours):** Fundamentals of plasma physics and chemistry, Types of plasma: thermal, non-thermal, arc, dielectric barrier, Generation and properties of plasma, Overview of applications in industry and metallurgy **Principles of Plasma Arc and Non-Transfer Plasmas (6 Hours):** Arc plasma torch operation and design, Non-transfer plasma torches and their characteristics, Material interactions with plasma, Advantages of plasma over conventional thermal methods **Applications of Plasma in Metallurgy (10 Hours):** Plasma smelting and refining, Directly reducing metals from ores and concentrates, Producing high-purity metals and alloys, Waste treatment and recycling processes using plasma **Plasma Methods for Surface Modification and Coatings (6 Hours):** Plasma spray coating techniques, Surface alloying and functionalization, Benefits for corrosion resistance and wear properties, Case studies of plasma surface treatments **Plasma Reactors and Equipment Design (2 Hours):** Design considerations for plasma reactors and torches, Energy efficiency and operational stability, Control systems and instrumentation, Safety considerations and environmental impact **Emerging Plasma Technologies in Metallurgy (4 Hours):** Plasma-based advanced materials processing, Nanomaterials synthesis using plasma, Plasma for additive manufacturing and 3D printing, Innovations and future trends **Environmental and Economic Aspects (4 Hours):** Plasma technology for waste minimization and pollution control, Cost analysis and energy consumption, Sustainability aspects and environmental benefits
Text Books, and/or reference material	Suggested Text Books: 1. Jerome Feiman: Plasma technology in Metallurgical Processing; Iron & Steel Society, USA 2. V Dembovsky: Plasma Metallurgy -The Principle (Elsevier) 3. "Introduction to Plasma Technology" by P. K. Singh and D. R. K. Rai 4. "Plasma Chemistry and Plasma Processing" edited by M. S. Mittal 5. "Thermal Plasma Technology" by S. R. A. P. S. L. R. Kumar 6. "Plasma Surface Engineering" by K. S. Kim 7. "Plasma Processing of Materials" by M. A. Lieberman, A. J. Lichtenberg, and R. H. Stark

Mapping of CO (Course Outcome) and PO (Programme Outcome)

POs / COs	PO1	PO2	PO3	PSO1	PSO 2
CO1	2	1	3	3	2
CO2	1	1	2	2	1
CO3	3	1	3	1	3

Correlation levels 1, 2 or 3 as defined below:

1: Slight (Low) 2: Moderate (Medium) 3: Substantial (High)

Department of Metallurgical & Materials Engineering							
Course Code	Title of the course	Program Core (PCR) / Electives (PEL)	Total Number of contact hours				Credit
			Lecture (L)	Tutorial (T)	Practical (P)	Total Hours	
MM9049	Sustainable composites	PEL	3	0	0	3	3
Pre-requisites		Course Assessment methods (Continuous (CT) and end assessment (EA))					
NIL		CT+EA					
Developer		D. Mandal					

Course Outcomes	CO1: To understand the fundamentals of developing composite materials CO2: To describe the different processing methods of composite Materials CO3: To explain the structure, Properties, correlations, and Sustainability of composites
Topics Covered	**Introduction:** Definitions and Classification of Composites, Reinforcements and matrices, Types of reinforcements, Types of matrices, Types of composites, continuous and discontinuous fibre reinforced composites MMC, PMC, CMC., Applications of metal, ceramic and polymer matrix composites, [4 hrs] **Metal Matrix Composites Processing**: Liquid state processes, Infiltration process, Stir melting process, Rheocasting process, solid state processes and in situ processes. Different reinforcement and different matrix [10 hrs] **Polymer Matrix Composites Processing**: Introduction of polymers, Moulding: Resin transfer moulding, bag and injection moulding, sheet moulding compound. Matrix: Polymer, Resins, thermoplastics and thermosetting matrix. Reinforcing fibres- Natural fibres (cellulose, jute, coir, etc), carbon fibre, glass fibre, etc. Particulate fillers-importance of particle shape and size. Coupling agents- surface treatment of fillers and fibres, significance of interface in composites. short and continuous fibre reinforced composites, critical fibre length, and anisotropic behaviour. Processing, Properties and Applications. [10 hrs] **Ceramic Matrix Composites Processing**: Cold pressing & sintering, hot pressing, reaction bonding processes, infiltration, in-situ chemical reaction, Sol-Gel and polymer pyrolysis, self-propagating high temperature synthesis. Carbon-carbon composites, Interfaces. [4 hrs] **Other Composites**: Sustainable Natural composite, Green composites, Sustainability of composites, Recycling of composites [6 hrs] **Mechanical Properties** –Estimating Stiffness and Strength: Geometrical aspects – volume and weight fraction. Unidirectional continuous fibre, discontinuous fibres, Short fibre systems, woven reinforcements –Mechanical Testing: Determination of stiffness and strengths of unidirectional composites; tension, compression, flexure and shear, Rule of mixtures. Stress, strain transformations. [10 hrs]
Text Books, and/or reference material	Text Books: 1. K. K Chawla, Composite Materials Science and Engineering, Springer, 2012 2. D. Hull, An introduction to composite materials, Cambridge University Press, New York, 1996, 2nd Edition 3. Steven L. Donaldson, ASM Handbook Composites Volume 21, 2001. 4. F. L Mathews and R.D Rawlings, Composite Materials: Engineering and Science, CRC Press, 1999 5. Suresh G. Advani, E. Murat Sozer, Process Modelling in Composites Manufacturing, 2nd Ed. CRC Press.

Mapping of COs with POs and PSOs

POs / COs	PO1	PO2	PO3	PSO 1	PSO 2
CO1	3	2	1	2	2
CO2	3	2	1	2	2
CO3	3	2	1	2	2

Correlation levels 1, 2 or 3 as defined below:
1: Slight (Low) 2: Moderate (Medium) 3: Substantial (High)

Department of Metallurgical and Materials Engineering							
Course Code	Title of the course	Program Core (PCR) / Electives (PEL)	Total Number of contact hours				Credit
			Lecture (L)	Tutorial (T)	Practical (P)	Total Hours	
MM9050	Environmental Degradation of Materials	PEL	3	0	0	3	3
Pre-requisites NIL		Course Assessment methods (Continuous (CT) and end assessment (EA))					
		CT+EA					
Course Outcomes	CO1: Ability to understand the impact of different factors for Environmental Degradation CO2: Ability to learn mitigation of environmental degradation CO3: Ability to develop practices for industrial failure of materials						
Topics Covered	Defining environmental degradation, its impact on materials, and the importance of understanding and mitigating it. (2 hrs) Types of Degradation : Broad overview of different types of Degradation of Materials. (5 Hrs) Factors affecting degradation of Materials (3 Hrs) Importance of materials usage and impact on the environment (4 Hrs) Corroson in Marine , industrial and atmospheric system (4 hrs) Wear and Failure analysis (4 hrs) Surface treatment Techniques (2 hours) Life cycle Assessment (2 Hours) Degradation of Specific Material such as Composites and Polymers (3 Hours) Environmental impacts of material degradation (3 hours) Case Studies on failure analysis (8 Hours)						
Text Books, and/or reference material	Text Books: Corrosion Engineering (classification of Corrosion), By: M.G. Fontana, M.C. Graw Hill, N. York, 1987 **"Environmental Degradation of Advanced and Traditional Engineering Materials" by Lloyd H. Hihara, Ralph P.I. Adler, and Ronald M. Latanision** **Handbook of Environmental Degradation of Materials" by Myer Kutz** Environmental Impact and Sustainability in the Metal Industry by S. K. Sharma (Editor)						

Mapping of COs with POs and PSOs

POs / COs	PO1	PO2	PO3	PSO1	PSO 2
CO1	2	3	3	3	2
CO2	2	1	2	2	1
CO3	3	1	3	2	3

Correlation levels 1, 2 or 3 as defined below:
1: Slight (Low) 2: Moderate (Medium) 3: Substantial (High)

<table>
<tr><td colspan="9">Department of Metallurgical & Materials Engineering</td></tr>
<tr><td rowspan="2">Course Code</td><td rowspan="2">Title of the course</td><td rowspan="2">Program Core (PCR) / Electives (PEL)</td><td colspan="4">Total Number of contact hours</td><td rowspan="2">Credit</td></tr>
<tr><td>Lecture (L)</td><td>Tutorial (T)</td><td>Practical (P)</td><td>Total Hours</td></tr>
<tr><td>MM9051</td><td>Strengthening Mechanism of Materials</td><td>PEL</td><td>3</td><td>0</td><td>0</td><td>3</td><td>3</td></tr>
<tr><td colspan="2">Pre-requisites</td><td colspan="6">Course Assessment methods (Continuous (CT) and end assessment (EA))</td></tr>
<tr><td colspan="2">NIL</td><td colspan="6">CT+EA</td></tr>
<tr><td colspan="2">Developer</td><td colspan="6">D. Mandal</td></tr>
<tr><td>Course Outcomes</td><td colspan="7">CO1: To understand the basic strengthening mechanism of materials
CO2: To explain the mechanism of strengthening of high-strength steel and alloys
CO3: To learn the science and technological aspects of designing materials based on strengthening mechanisms</td></tr>
<tr><td>Topics Covered</td><td colspan="7">Introduction:
Basic structure of alloys, ceramics, polymers and composites. Relation between the structure of materials and their mechanical, thermal, chemical and electrical magnetic properties.
[5 hours]
Elemental Plasticity and Dislocation Theory:
Mechanism and micromechanism of strengthening in engineering materials. Plastic flow in metals and alloys, Strengthening and dislocation structure and solid solution strengthening, Resistance to dislocation induced flow, Strengthening due to sub- and grain boundaries, precipitation strengthening, dispersion strengthening, martensitic strengthening, grain size strengthening, order hardening, dual phase. Physical phenomena that contribute towards high mechanical strength in engineering materials. Principles for designing high-strength materials will be addressed, including high-temperature materials. Two-phase hardening, Solution hardening, Order strengthening. Strengthening mechanism of amorphous materials, Polymer, ceramic, glass and composite materials, fibre reinforcement, four stages of deformation, tensile strength, Anisotropy. Strengths at High Temperature, Strengthening against diffusion flow, Strengthening against dislocation creep, Strengthening against high rate of deformation.
[20 hours]

Strengthening of Ceramic Materials:
Advanced Ceramic Materials - Crystal Structures - Silicate Ceramics - Glasses – Glass Ceramics – Strengthening of ceramics, properties and applications of ceramic materials – Classification of composites - Fibre reinforced materials – Law of mixtures – Continuous fibres – discontinuous fibres – Particle-reinforced materials – Cermets. Strengthening</td></tr>
</table>

	mechanism of composites, Dispersion strengthened – Laminates - Application of composites in electrical and mechanical components – nuclear industry. [10 hours] **Strengthening of Polymer Materials:** Classification of polymer – Mechanisms of polymerisation - Some commercially important individual polymer – Thermoplastics - Elastomers – Thermosets – Engineering plastics - Liquid crystal polymers - Conductive polymers – adding fibres, particles for strengthening of polymer materials - Biomedical applications – Photonic polymers. [10 hours]
Text Books, and/or reference material	Text Books: 1. William D. Callister, Jr., Materials Science and Engineering an Introduction, 6th Edition , John Wiley & Sons, Inc., 2004. 2. Structure of Metals, 3rd revised edition, C. S. Barrett, T. B. Massalski, Pergamon press Oxford, 1981. 3. George Dieter, Mechanical Metallurgy, McGraw-Hill, 3rd Edition Reference Books: 1. William F.Smith, Structural Properties of Engineering Alloys, Tata Mc-Graw-Hill, Inc., 1993. 2. Kingery. W.D., Bowen H.K. and Uhlmann D.R., Introduction to Ceramics, 2nd Edition, John Wiley & Sons, New York, 1976.

Mapping of COs with POs and PSOs

POs / COs	PO1	PO2	PO3	PSO 1	PSO 2
CO1	2	1	2	3	1
CO2	2	1	2	3	1
CO3	2	1	2	3	1

Correlation levels 1, 2 or 3 as defined below:
1: Slight (Low) 2: Moderate (Medium) 3: Substantial (High)

Department of Metallurgical & Materials Engineering							
Course Code	Title of the course	Program Core (PCR) / Electives (PEL)	Total Number of contact hours				Credit
			Lecture (L)	Tutorial (T)	Practical (P)	Total Hours	
MM9052	Surface Engineering	PEL	3	0	0	3	3
Pre-requisites		Course Assessment methods (Continuous (CT) and end assessment (EA))					
NIL		CT+EA					
Developer		D. Mandal					
Course Outcomes	CO1: To understand the basic principle for the surface degradation of materials CO2: To learn surface morphology of different kinds of materials and their response in working conditions CO3: To understand principles, theory, mechanisms and key variables of different advanced surface modification techniques.						

Topics Covered	**Introduction of conventional casting:** Introduction of surface engineering, Philosophy of surface, general applications and requirements. Engineering components, surface-dependent properties and failures, importance and scope of surface engineering. [4 hours] **Surface Degradation**: Basic principles of electrochemistry and aqueous corrosion processes; Oxidation and related concept; Mechanical Friction and Wear like abrasive, erosive and sliding wear etc.; Interaction between wear and corrosion. Surface engineering processes and their types (only basic idea, Conventional surface heat treatment processes. Surface engineering by material removal: Cleaning, pickling, etching, grinding, polishing, buffing / puffing (techniques employed, its principle). Role and estimate of surface roughness, material addition: From liquid bath - hot dipping (principle and its application with examples). [15 hours] **Surface Engineering Process:** General classification, scope and principles, types and intensity/energy deposition profile; Laser assisted microstructural modification – surface melting, hardening, shocking and similar processes; Laser assisted compositional modification – surface alloying of steel and non-ferrous metals and alloys; surface cladding, composite surfacing and similar techniques; Electron beam assisted modification and joining; Ion beam assisted microstructure and compositional modification. [12 hours] **Advanced Process:** Physical vapour deposition, PEPVD, Chemical vapour deposition, Electrodeposition, Anodising, Galvanising, Thermal Spraying (all types), Plasma-based techniques like plasma nitriding, plasma carburising, PSII, LSH, LSA, LSM, etc. Weld surfacing, friction surfacing, explosive cladding [10 hours] **Characterization of engineered surface:** XRD, XPS, surface-mechanical characterization, corrosion study etc. (Apart from common techniques) [4 hours]
Text Books, and/or reference material	Text Books: 1. T Burakowski and T. Wierzchon, Surface engineering of metals, CRC Press 2. A. W. Batchelor, L. N. Lam and M. Chandrasekaran, Materials degradation and its control by surface engineering, Imperial college press 3. S Grainger and J. Blunt, Engineering coatings, William Andrew Publishing **Reference Books:** 1. K.G. Budinski, Surface Engineering for Wear Resistances, Prentice Hall, Englewood Cliffs, 1988. **2. Laser Surface Engineering Processes and Applications, J. R. Lawrence, C. Dowding, D. Waugh and J. B. Griffiths, A volume in Woodhead Publishing, 2015**

Mapping of COs with POs and PSOs

POs / COs	PO1	PO2	PO3	PSO 1	PSO 2
CO1	3	2	2	3	1
CO2	3	2	2	3	1
CO3	3	2	2	3	1

Correlation levels 1, 2 or 3 as defined below:
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<tr><td>Lecture (L)</td><td>Tutorial (T)</td><td>Practical (P)</td><td>Total Hours</td></tr>
<tr><td>MM9053</td><td>Electron Microscopy</td><td>PEL</td><td>3</td><td>0</td><td>0</td><td>3</td><td>3</td></tr>
<tr><td colspan="3">Pre-requisites</td><td colspan="5">Course Assessment methods (Continuous (CT), mid-term (MT) and end assessment (EA))</td></tr>
<tr><td colspan="3">NIL</td><td colspan="5">CT+MT+EA</td></tr>
<tr><td>Course Outcomes</td><td colspan="7">• CO1: To learn the fundamentals of light and electron optics, and electron microscopes.
• CO2: Concept of image formation, microstructural, crystallographic and compositional analysis.
• CO3: Current advancement in electron microscopes and utilize the tool for different requirements in materials science.</td></tr>
<tr><td>Topics Covered</td><td colspan="7">Basics on light and electron microscopes: Basic optics; Image formation; Magnification, resolution, depth of field; Abberations; Comparison between elctron and light. [3h]

Electron-specimen interaction: Electrons; Scattering of electrons by an atom; Generation of different signals and their utilization. [3h]

Components of electron microscope: Electron Gun; Magnetics lenses. [4h]

Electron diffraction: Geometry of electron diffraction; Use of reciprocal lattice; Diffraction patterns and analysis; Other types of diffraction patterns. [8h]

Scanning electron microscope: Mechanism of image formation; Different types of images/information; Crystallographic information; Operating parameters. [8h]

Transmission electron microscope: Basic mechanism; Contrast mechanism. [6h]

Chemical analysis: Generation of X-rays; Quantitative analysis. [4h]

Sample preparation technique: Powder sample preparation; Solid sample preparation. [2h]

Current advancement in electron microscope: Different types of advanced and state of the art electron microscopes. [2]</td></tr>
<tr><td>Text Books, and/or reference material</td><td colspan="7">Text Books:

3. Electron Microscopy and Analysis, 3rd Edition: Peter J. Goodhew, John Humphreys, Richard Beanland.

Reference Books:

7. Transmission Electron Microscopy: David B. Williams, C. Barry Carter</td></tr>
</table>

Mapping of CO (Course Outcome) and PO (Programme Outcome)

POs / COs	PO1	PO2	PO3	PSO1	PSO2

CO1	1	2	3	2	2
CO2	2	2	3	2	2
CO3	3	2	3	3	3

Correlation levels 1, 2 or 3 as defined below:

1: Slight (Low) 2: Moderate (Medium) 3: Substantial (High)

Department of Metallurgical and Materials Engineering							
Course code	Title of the course	Program Core (PCR) / Electives (PEL)	Total Number of contact hours				Credit
			Lecture (L)	Tutorial (T)	Practical (P)	Total Hours	
MM9054	**Advanced Metal Forming Processes**	PEL	3	0	0	3	3
Pre-requisites		Course assessment methods (continuous (CT) and end assessment (EA))					
Nil		CT+EA					
Developer		Dr. Madan Mohan Ghosh					
Course outcomes	CO1: To be familiar with different HERF and SPD processes with their important process parameters and applications CO2: To know the technology of different advanced forming and processing of materials CO3: To build up a knowledge base to the future professionals for producing products with enhanced quality and/or productivity for advanced applications						
Topics covered	**1.** Overview of conventional metal forming processes; Introduction to High Energy Rate Forming (HERF) or High Velocity Forming (HVF) processes; Classification of HERF processes; Important parameters of HERF processes in comparison with the conventional metal forming processes; Merits and demerits of HERF processes; Quality and productivity of HERF processes. [10 h] **2.** Principle, technique and important process parameters of: (a) Explosive forming – noncontact type and contact type, (b) Magnetic forming, (c) Electro-hydraulic forming, and (d) Other HERF processes; Advantages and limitations of different HERF processes; Applications of different HERF processes. [18 h] **3.** Severe plastic deformation (SPD) for manufacturing materials for advanced applications: Principle and techniques; Equal channel angular pressing (ECAP), High pressure torsion (HPT), etc.; Important process parameters, product characteristics and applications. [8 h]						
Text books and/or reference materials	• "Non-traditional Manufacturing Processes" by Gary F. Benedict, Marcel Dekker, Inc. New York, 2017 • "Modern Manufacturing Processes" by M. Koc and T. Ozel, Wiley, 2019 • "Severe Plastic Deformation: Methods, Processing and Properties" by G. Faraji, H.S. Kim and H.T. Kashi, Elsevier, 2018						

Mapping of COs with POs and PSOs

POs / COs	PO1	PO2	PO3	PSO 1	PSO 2
CO1	2	2	2	3	2
CO2	3	2	2	2	2
CO3	3	2	2	3	2

Correlation levels 1, 2 or 3 as defined below:
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Department of Metallurgical & Materials Engineering								
Course Code	Title of the course	Program Core (PCR) / Electives (PEL)	Total Number of contact hours				Credit
			Lecture (L)	Tutorial (T)	Practical (P)	Total Hours	
MM9055	Severe Plastic Deformation	PEL	3	0	0	3	3
Pre-requisites		Course Assessment methods (Continuous (CT) and end assessment (EA))					
NIL		CT+EA					
Developer		M. K. Mondal + D. Mandal					
Course Outcomes	CO1: To understand the Fundamentals of Severe Plastic Deformation. CO2: To understand the principles of ultrafine grained (UFG) and nanostructured bulk metal production processes. CO3: To identify the major challenges encountered in severe plastic deformation (SPD) is the industrial production of ultrafine-grained (UFG) and nanograined (NG) metals.						
Topics Covered	The ultrafine-grained and nanostructured materials,First approach: Bottom-Up: Inert Gas Condensation, Spray Conversion Processing, Chemical Vapor Condensation,Top-Down methods: High-Energy Ball Milling, Physical Vapor Deposition, Sputtering,Severe Plastic Deformation Methods. (4 hours) **Fundamentals of Severe PlasticDeformation:**History: The Ancient Age,The Scientific Age and The Microstructural Age, Basic Principles of Severe Plastic Deformation Methods, Difference between Severe Plastic Deformation and Conventional Metal-Forming Processes, Grain Refinement Mechanisms under Severe Plastic Deformation conditions: Face-Centered Cubic (FCC) Metals an Hexagonal Close-Packed (HCP) Metals. (4 hours) **Severe Plastic Deformation Methods for Bulk Samples:** High-Pressure Torsion, Equal-Channel Angular Pressing, Dual Equal Channel Lateral Extrusion, Channel Angular Pressing With ConvergingBillets, Nonequal Channel Angular Pressing, Torsion Extrusion,Multiple Direct Extrusion, Accumulated Extrusion, Pure Shear Extrusion, Equal Channel Forward Extrusion, C-Shape Equal Channel Reciprocating Extrusion, Twist Extrusion, Multidirectional Forging, Multiaxial Incremental Forging And Shearing, Repetitive Forging, Repetitive Upsetting, Cylinder Covered Compression, Repetitive Upsetting And Extrusion, Cyclic Extrusion Compression, Cyclic ExpansionExtrusion, Accumulative Back Extrusion, Cyclic ForwardBackward Extrusion, Half-Channel Angular Extrusion, Accumulative Channel-Die CompressionBonding, Machining, The Combined Methods. (8 hours) **Severe Plastic Deformation Methods For Sheets:** Accumulative Roll-Bonding, Cone-Cone Method, Constrained Groove Pressing,Friction Stir Processing, Equal Channel Angular Rolling, Repetitive Corrugation And Straightening, Epetitive Corrugation And Straightening By Rolling, Asymmetric Rolling, Continuous Frictional Angular Extrusion, Continuous Cyclic Bending. (4 hours) **Severe Plastic Deformation Methods for Tubular Samples**: Equal Channel Angular Pressing For Hollow Parts, High-Pressure Tube Twisting, Tube High-Pressure Shearing, Modified High-Pressure Tube Twisting, Accumulative Spin Bonding, Tubular Channel							

	Angular Pressing, Parallel Tubular Channel Angular Pressing, Combined Ptcap, Tube Channel Pressing, Cyclic Flaring And Sinking, Tube Cyclic ExtrusionCompression, Tube Cyclic ExpansionExtrusion, Rubber Pad Tube Straining, Other Combined Methods, General Limitations Of UFG TubeManufacturing Methods. (5 hours) **Severe Plastic Deformation for Industrial Applications:**Integrated Extrusion And Equal Channel Angular Pressing, Ecap-Conform, Equal Channel Angular Drawing, Ecap With Rolls, Incremental Ecap, Porthole-Equal Channel Angular Pressing, Continuous Confined Strip Shearing, Conshearing, Continuous Cyclic Bending, Caliber Rolling, Ring High-Pressure Torsion, High-Pressure Sliding, High-Pressure Sliding, Continuous High-Pressure Torsion, Severe Torsion Straining, Integrating Forward Extrusion And Torsion Deformation, Kobo Process, Cryo-Rolling. (4 hours) **Effective Parameters For The Success of Severe Plastic Deformation Methods:**Grain Size, Equivalent Plastic Strain And Hydrostatic Stress, Dislocations And Disclinations, Grain Boundaries, Multiphase Materials, Texture. (4 hours) **Mechanical Properties of Ultrafine-Grained and Nanostructured Metals:** Superior Strength And Ductility, Mechanical Anisotropy, Young's Modulus, Fracture Toughness, Hardness, Fatigue Properties, Wear Resistance. (3 hours) **Physical, Chemical, and Functional Properties of UFG and NS Metals:** Electrical Conductivity, Thermal Conductivity,Thermal Stability, Thermoelectricity, Hydrogen Storage Capability, Magnetic Properties, Corrosion, Biocorrosion, Biocompatibility, Cryogenic Properties. (3 hours) **Applications of Ultrafine-Grained and Nanograined Metals:** Biomedical, Structural Examples, Hydrogen Storage Capacity Of Nanostructured Mg Alloys, Sputtering Targets for The SemiconductorIndustry,Superplastic Properties, Military Applications, Sport, Microforming, Nanostructured Magnets, Anostructured Al And Cu Alloys With High Conductivity and Strength, UFG Metals for Semisolid Forming. (3 hours)
Text Books, and/or reference material	Text Books: 1. Severe Plastic Deformation Technology-ARosochowski, Whittles Publishing, 2017. 2. Severe Plastic Deformation: Methods, Processing and Properties- GhaderFaraji, H.S. Kim, and HessamTorabzadehKashi, Elsevier, 2018. 3. Severe Plastic Deformation: Toward Bulk Production of Nanostructured Materials-BurhanettinAltan, Nova Science Publishers, Inc., New York, 2006. Reference Books: 1. Investigations and Applications of Severe Plastic Deformation-Terry C. Loweand Ruslan Z. Valiev, Springer, 2000.

Mapping of COs with POs and PSOs

POs / COs	PO1	PO2	PO3	PSO 1	PSO 2
CO1	2	1	2	2	2
CO2	2	1	2	2	2
CO3	3	1	2	2	2

Correlation levels 1, 2 or 3 as defined below:

1: Slight (Low) 2: Moderate (Medium) 3: Substantial (High)

Department of Metallurgical & Materials Engineering							
Course Code	Title of the course	Program Core (PCR) / Electives (PEL)	Total Number of contact hours				Credit
			Lecture (L)	Tutorial (T)	Practical (P)	Total Hours	

MM9056	Raw Materials Characterization	PCR	3	0	0	3	3
Pre-requisites		Course Assessment methods (Continuous (CT), mid-term (MT) and end assessment (EA))					
Iron Making		CT+EA					

Course Outcomes	• CO1: To learn about the standard testing procedure for characterization of ores • CO2: To understand the standard testing procedure for characterization of coal/coke • CO3: Apply the knowledge to choose proper raw material for a iron making process
Topics Covered	Introduction – Minerals and ores, Classification of ore, Feed materials for Iron making, Ore preparation, Sintering and pelletization [8] Ferrous ore characterization: [15] • Chemical characterization - Chemical analysis, LoI measurement • Physical characterization –Apparent Porosity, Specific gravity, Bulk density, True density, Apparent density, Angle of repose, sieve analysis, Blain number, Green compressive strength, Dry compressive strength, Drop number, Compressive strength, Shatter test, Tumbler test, Decrepitation test • Physico-chemical characterization - RI, RDI, Swelling Index, High temperature softening melting Coal/Coke characterization – [15] • Occurrence of coal - types, ranks, classification, petrography, , Mineral Matter; Preparation of coke – coking process, carbonization; Coal/Coke analysis- Proximate and ultimate analysis; Physical Properties – Density, Porosity, Reflectance, Specific Resistance; Thermal Properties – Calorific Value, Heat Capacity, Agglomerating Index, Free-Swelling Index, Ash Fusibility, Thermal Conductivity: Mechanical properties – grindability, tumbler, shatter, Micum Index, CSR-CRI Quality of raw materials required for various iron making process. [4]
Text Books, and/or reference material	Suggested Text Books: 1. Laboratory Experiments in Ferrous Metallurgy, R. C. Gupta, PHI Publication 2. HANDBOOK OF COAL ANALYSIS, James G. Speight, A JOHN WILEY & SONS, INC., PUBLICATION 3. Agglomeration of Iron Ores, Ram Pravesh Bhagat, CRC Press 4. Pelletizing of iron ores, Kurt Meyer, Springer-Verlag

Mapping of COs with POs and PSOs

POs / COs	PO1	PO2	PO3	PSO 1	PSO 2
CO1	2	1	3	3	2
CO2	1	1	2	2	1
CO3	3	1	3	1	3

Correlation levels 1, 2 or 3 as defined below:

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Course Code	Title of the course	Program Core (PCR) / Electives (PEL)	Total Number of contact hours				Credit
			Lecture (L)	Tutorial (T)	Practical (P)	Total Hours	
MM9057	Production of Critical Minerals	PCR	3	0	0	3	3
Pre-requisites		Course Assessment methods (Continuous (CT), mid-term (MT) and end assessment (EA))					
		CT+EA					
Developer		A. K. Mandal + S. Ghorai					

Course Outcomes	CO1: To Identify the sources, occurrence, and importance of critical minerals and metals in technological applications. CO2: To Evaluate current and emerging extraction and processing technologies for sustainable production of critical metals. CO3: To Analyze global supply chain challenges, policy frameworks, and innovative solutions for securing critical metal resources
Topics Covered	**Introduction to Critical Minerals and Metals (4 Hours):** Definition and importance of critical minerals/metals, Global reserves, supply chain, and geopolitical issues, Standard classification of critical minerals (e.g., USGS, EU list), Role in emerging technologies and industries **Occurrence and Geological Aspects (4 Hours):** Geology and mineralization processes, Types of deposits: magmatic, hydrothermal, sedimentary, etc., Identification and exploration techniques Case studies of major deposits. **Processing and Beneficiation of Critical Minerals (4 Hours**): Crude ore processing technologies, Flotation, leaching, and other beneficiation techniques, Recovery efficiencies and techno-economics, Environmental impacts and mitigation. **Extraction of Critical Metals (6 Hours):** Hydrometallurgy, pyrometallurgy, and electrometallurgy methods, Innovations in low-temperature processing, Novel extraction techniques (e.g., bioleaching, solvent extraction), Case studies of extraction from secondary sources like recycling. **Recovery of Metals from Secondary Resources (2 Hours):** Metal recycling and urban mining, E-waste recycling technologies, Circular economy and sustainability in critical metal recovery. **Challenges, Future Trends, and Policy Aspects (4 Hours):** Supply chain vulnerabilities and geopolitics, Technological challenges and R&D directions, Policy frameworks and strategic reserves, Emerging trends and global initiatives **Extractive Processes of Key Critical Elements/Metals (12 hrs).** 1. Lithium (Li):Saline brine extraction methods (solar evaporation ponds), Hard-rock mineral extraction (spodumene, lepidolite), Hydrometallurgical processing (acid leaching, purification) 2. Cobalt (Co): Copper-cobalt sulfide ore processing, Hydrometallurgy: leaching, solvent extraction, and electrowinning, Bioleaching using bacteria 3. Rare Earth Elements (REEs): Bastnäsite, Monazite, and Xenotime mineral processing, Flotation and magnetic separation techniques, Combined hydrometallurgical processes (acid digestion, solvent extraction), Separation and purification of individual rare earths. 4. Tungsten (W): Tungsten ore deposits (wolframite, scheelite), Gravity separation, flotation, and magnetic separation, Hydrometallurgical extraction (acid leaching, solvent extraction), Carbide and metallic tungsten production. 5. Gallium (Ga): Extraction from bauxite residues (red muds), Recovery from zinc ore processing, Hydrometallurgical methods. 6. Indium (In): Recovery from zinc sulfide ores, Processing of LCD and semiconductor waste, Hydrometallurgical recovery techniques, 7. Nickel (Ni) and Copper (Cu): Laterite vs. sulfide ore processing, High-pressure acid leaching (HPAL), Hydrometallurgical and pyrometallurgical methods, Solvent extraction and

	electro-winning. 8. Uranium (U): In-situ leaching (ISL), Conventional open-pit and underground mining, Hydraulic and acid leaching techniques
Text Books, and/or reference material	Textbooks 1. "Critical Metals: Materials and Emerging Technologies" by K. S. Kannan, Sivakumar Manickam, and Suresh K. Bhargava 2. "Introduction to Mineral Processing" by Mike D. Adams 3. "Extractive Metallurgy of Critical and Strategic Metals" by K. K. Chaturvedi 4. "Rare Earth Elements: Geology, Mining, Resources, and Processing" by David A. Rickard, et al. 5. "Lead-Zinc and Copper Processing" (Multiple volumes) by A.M. Neville 6. "Hydrometallurgy: Fundamentals, Materials, and Processes" by Michael L. Gross and David E. Williams 7. "Mining of Rare Earth Elements" by S. K. Sharma 8. Green Hydrometallurgy: Recovery of Critical Metals" edited by Ronald A. Ouangraoua et al. Reference book 1. "Critical Metals Resources in the United States—Rare Earth Elements, Platinum-Group Elements, and Other Selected Metals" by USGS 2. "Extraction of Critical Metals from Ores and Waste Materials" by S. B. Singh and P. K. Singh 3. "Critical Materials and Their Recycling" edited by S. K. Haldar and A. K. Sinha 4. "Rare Earth Elements: The Global Supply Chain" by Rajdeep Singh

Mapping of CO (Course Outcome) and PO (Programme Outcome)

POs / COs	PO1	PO2	PO3	PSO 1	PSO 2
CO1	2	1	3	3	2
CO2	1	1	2	2	1
CO3	3	1	3	1	3

Correlation levels 1, 2 or 3 as defined below:

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Department of Metallurgical & Materials Engineering							
Course Code	Title of the course	Program Core (PCR) / Electives (PEL)	Total Number of contact hours				Credit
			Lecture (L)	Tutorial (T)	Practical (P)	Total Hours	
MM9058	Secondary Refining of Steel	PCR	3	0	0	3	3
Pre-requisites		Course Assessment methods (Continuous (CT), mid-term (MT) and end assessment (EA))					
Materials Thermodynamics (MM1001)		CT+EA					
Developer		M. K. Mondal + S. Ghorai					
Course Outcomes	• CO1: Learn fundamentals of physico-chemical principles of Secondary steel making. • CO2: Identify and solve reaction kinetics and mechanisms. • CO3: Ability to analyze industrial processes to meet the current need.						

Topics Covered	Introduction: Brief review of primary steel making processes, composition of the crude steel, need for secondary refining, objective of secondary steel making, secondary steel making equipment and processes, preheating and recycling of ladles. [4 hours] Chemical equilibrium, Activity-Composition relationships: Concentrated solutions, Activity Composition relationships: dilute solutions, interaction coefficient, chemical potential and equilibrium, physico-chemical principles of Secondary steel making, Slag basicity and capacities. [4 hours] Fluid flow in steel melts in Gas-Stirred ladle. [3 hours] Mixing, Mass transfer and kinetics: Introduction, mixing in steel melts in Gas-stirred ladles, kinetics of reactions among phases, Mass transferin a Gas-Stirred ladle, Mixing Vs. Mass transfer control. [3 hours] Powder injection refining: Introduction, Advantages and disadvantages, transitory and permanent contact reaction, bubbling-jetting phenomena. [3 hours] Core wire injection: Introduction, Advantages and application [1 hours] Deoxidation of liquid steel: Introduction, slag Carry-over: Impact on Ladle Metallurgy, Thermodynamics of deoxidation of molten steel, Kinetics of deoxidation of molten steel, deoxidation in industry. [5 hours] Degassing and Decarburization in liquid steel: Introduction, thermodynamics of reactions in vacuum degassing, side reactions during degassing, fluid flow and mixing in vacuum degassing, rates of vacuum degassing and decarburization, decarburization for Ultra-low carbon (ULC) and stainless steel. [6 hours] Desulfurization in secondary steelmaking: Introduction, thermodynamics aspects, desulfurization with only top slag, injection metallurgy for Desulfurization. [4 hours] Gas absorption during tapping and teeming from surrounding atmosphere, temperature changes of molten steel during secondary steelmaking, phosphorus control in secondary steelmaking, Nitrogen control in steel making. [3 hours] Inclusions and inclusion modification: Introduction, origin of nonmetallic inclusions, Types and properties of inclusions, Influence of inclusions on the mechanical properties of steel, Inclusion identification and cleanliness assessment, formation of inclusions during solidification, inclusion modification. [3 hours] Clean steel technology: Introduction, refractories for secondary steelmaking, Tundish metallurgy for clean steel. [2 hours] Alloying of steel: Introduction, Dissolution mechanism, Methods of alloying [1 hours]
Text Books, and/or reference material	Text Books: 1. A. Ghosh, and A. Chatterjee, , Principles and Practices in Iron and Steel making, Prentice Hall of India, New Delhi, 2008. 2. A. Ghosh, Secondary Steelmaking, CRC Press, Boca Raton, 2000. Reference Books: 1. Making, Shaping and Treating of Steel (Steelmaking and Refining), 10th Edition, 1985, AISE, Pittsburgh

Mapping of COs with POs and PSOs

COs \ POs	PO1	PO2	PO3	PSO 1	PSO 2
CO1	2	1	2	2	2
CO2	2	1	3	2	2
CO3	3	1	3	3	3

Correlation levels 1, 2 or 3 as defined below:
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Department of __________								
Course Code	Title of the course	Program Core (PCR) / Electives (PEL)	Total Number of contact hours				Credit
			Lecture (L)	Tutorial (T)	Practical (P)	Total Hours	
MM9059	Agglomeration Techniques	PEL	3	0	0	3	3
Pre-requisites		Course Assessment methods (Continuous (CT) and end assessment (EA))					
Sustainable Metal Production Technology		CT+EA					

Course Outcomes	CO1: Ability to understand the fundamentals of different types Agglomeration techniques CO2: Ability to learn the fundamental basis of recent developments taking place in agglomeration technology. CO3: Ability to analyze and solve the utilization iron ore fines and wastes generated in iron and steel industry
Topics Covered	General Introduction: Need and scope, Different types of agglomerations techniques, Standard procedure for characterization of raw materials as well as agglomerates. [5] Sintering: Introduction to Sintering Process, Raw materials requirements and Preparation of Charge, Fundamentals of sintering reactions, liquid phase formation and bonding mechanism, Heat transfer in sintering layers, Gas dynamics in sintering process, Sinter productivity, Sinter mineralogy and its effect on quality, Environmental aspects of sintering [12] Pelletization: General introduction to Pelletization, Raw materials requirements and Preparation of Charge, Different types of binders both inorganic and organic binders, Mechanism of green pellet formation and kinetics of ball growth, Reactions and Formation of Phases During Induration, Environmental aspects. [8] Briquetting: General Introduction to Briquetting, Raw materials requirements and Preparation of Charge, Basic Industrial Technologies of Briquetting, Metallurgical Properties requirements of Briquettes. [2] Advances in agglomeration: Utilization of other source of fines and wastes like slimes, Blue dust, LD sludge, BF dust and also slag, Micropelletization and sintering, Composite agglomeration techniques, Nonconventional pellet strengthening process. [15]
Text Books, and/or reference material	**Text Books:** 1. Agglomeration of Iron Ores, Ram Pravesh Bhagat, CRC Press 2. Pelletizing of iron ores, Kurt Meyer, Springer-Verlag **Reference Books:** 1. Agglomeration in Metallurgy By Aitber Bizhanov, Valentina Chizhikova, Springer Publication

Mapping of COs with POs and PSOs

POs / COs	PO1	PO2	PO3	PSO1	PSO 2
CO1	2	1	3	3	2

CO2	1	1	2	2	1
CO3	3	1	3	1	3

Correlation levels 1, 2 or 3 as defined below:
1: Slight (Low) 2: Moderate (Medium) 3: Substantial (High)

<table>
<tr><td colspan="9">Department of Metallurgical & Materials Engineering</td></tr>
<tr><td rowspan="2">Course Code</td><td rowspan="2">Title of the course</td><td rowspan="2">Program Core (PCR) / Electives (PEL)</td><td colspan="4">Total Number of contact hours</td><td rowspan="2">Credit</td></tr>
<tr><td>Lecture (L)</td><td>Tutorial (T)</td><td>Practical (P)</td><td>Total Hours</td></tr>
<tr><td>MM9060</td><td>Kinetics of Metallurgical Processes</td><td>PCR</td><td>3</td><td>0</td><td>0</td><td>3</td><td>3</td></tr>
<tr><td colspan="3">Pre-requisites</td><td colspan="5">Course Assessment methods (Continuous (CT), mid-term (MT) and end assessment (EA))</td></tr>
<tr><td colspan="3">Materials Thermodynamics (MM1001)</td><td colspan="5">CT+EA</td></tr>
<tr><td colspan="3">Developer</td><td colspan="5">S. Ghorai + M. K. Mondal</td></tr>
<tr><td>Course Outcomes</td><td colspan="7">• CO1: To learn reaction kinetics, including reaction rates, activation energies, and rate-limiting steps
• CO2: learn to analyze the transport kinetics of metallurgical processes
• CO3: Apply kinetics principles to analyze effect of process parameters on metallurgical process</td></tr>
<tr><td>Topics Covered</td><td colspan="7">Introduction: Role of kinetics, heterogeneous and homogeneous kinetics, Role of heat and mass transfer in metallurgical kinetics, rate expression, Effect of Temperature and concentration on reaction kinetics: effect of temperature (Arrhenius Equation), Effect of concentration (order of a reaction), significance and determination of activation energy. [11 hours]
Kinetics of solid-fluid reaction: kinetic steps, rate controlling step, definition of various resistances in series, shrinking core model, chemical reaction as rate controlling step, Product layer diffusion as rate controlling step, Mass transfer through external fluid film as rate controlling step, heat transfer as the rate controlling step, [10 hours]
Kinetics of fluid-fluid reaction - Ficks laws, diffusion coefficients, Slag-metal reaction kinetics, Gas-liquid metal reaction kinetics. [10 hours]
Kinetics of solid-state phase transformation - classification, nucleation and growth processes. homogeneous and heterogeneous nucleation kinetics, kinetics of growth, kinetics of alloy solidification. and classification, kinetics of homogeneous and heterogeneous nucleation, Overall transformation kinetics - Johnson-Mehl and Avrami s model, isothermal and non-isothermal kinetic analysis. [11 hours]</td></tr>
<tr><td>Text Books, and/or reference material</td><td colspan="7"><u>Suggested Text Books:</u>
1. Kinetics of Metallurgical Processes, Hem Shanker Ray • Saradindukumar Ray
2. A Textbook of Metallurgical Kinetics by Ahindra Ghosh and Sudipto Ghosh
3. Problems in Metallurgical Thermodynamics and Kinetics by G. S. Upadhyaya, R. K. Dube and D. W. Hopkins
4. Chemical Kinetics - Keith Laidler.
5. Any Chemical engineering kinetics book</td></tr>
</table>

Mapping of COs with POs and PSOs

POs / COs	PO1	PO2	PO3	PSO 1	PSO 2
CO1	2	1	2	2	2
CO2	2	1	2	2	2
CO3	3	1	3	3	3

Correlation levels 1, 2 or 3 as defined below:
1: Slight (Low) 2: Moderate (Medium) 3: Substantial (High)

Department of Metallurgical and Materials Engineering							
Course code	Title of the course	Program Core (PCR) / Electives (PEL)	Total Number of contact hours				Credit
			Lecture (L)	Tutorial (T)	Practical (P)	Total Hours	
MM9061	**Computational Materials Science**	PEL	3	0	0	3	3
Pre-requisites		Course assessment methods (continuous (CT) and end assessment (EA))					
Nil		CT+EA					
Developer		Dr. Madan Mohan Ghosh					
Course outcomes	CO1: To be familiar with the materials modelling approaches applicable to different length scale and time scale CO2: To study behaviour of materials under externally imposed variables and extract the relevant properties CO3: To study structure-property correlation of materials under different conditions CO4: To design materials for different applications						
Topics covered	**Introduction:** Concept of multiscale materials modelling and simulation; Its essence; Overview of the techniques of materials modelling applicable to different length scale and time scale; ICME. [3 h] **Atomistic Modelling and Simulation:** Basics of classical Newtonian mechanics based molecular dynamics (MD) simulation; statistical mechanics principles; N-body problem; ensembles and ergodicity; concept of microstate and macrostate; interatomic potentials-pair potentials, many body potentials; initialization, relaxation and thermal equilibration; boundary conditions; force calculation; potential energy cut-off and truncation schemes; integration algorithms with their relative merits and demerits; thermostatting; barostatting; evaluation of different physical, mechanical, structural, thermodynamic, and transport properties of materials using MD simulation technique; illustration of equilibrium MD and non-equilibrium MD techniques; Ab-initio molecular dynamics; exercises using LAMMPS, Atomsk and Ovito; MD simulation of plastic deformation, crack propagation, fracture, heat transfer, radiation damage of materials; overview of probability theory based Monte Carlo (MC) simulation; Metropolis algorithm; Kawasaki dynamics; kinetic Monte Carlo method; simulation of phase evolution and phase transformation using Monte Carlo method. [16 h] **Continuum Modelling and Simulation:** Outline of continuum modelling using FEM technique; discretization; element types; interpolation functions; continuity; finding the element properties using direct approach and Galerkin method; assembling the element properties to obtain the system equations; imposing the boundary conditions; solving the system equations; convergence analysis; illustration of solving structural mechanics and heat transfer problems using FEM simulation; exercises using Ansys/ABAQUS; FEM simulation of plastic deformation and heat transfer of						

	materials. [14 h **Multiscale Approaches:** Bridging the scale gaps using multiscale approaches; simultaneous integration of models; sequential integration of models (hierarchical approach); illustration of coupled MD-FEM model; materials design using computational materials modelling and simulation. [3 h]
Text books and/or reference materials	• Understanding Molecular Simulation*: D. Frenkel and B. Smit*, Academic Press, 2002 • The Art of Molecular Dynamics Simulation: *D.C. Rapaport*, Cambridge University Press, 2004 • Statistical Mechanics: *Donald A. Mcquarrie*, Harper Row, 1976 • Handbook of Materials Modeling: Ed.: *Sydney Yip*, Springer, 2005 • Monte Carlo Methods in Statistical Physics, *M.E.J. Newman and G.T. Barkema*, Clarendon Press, 1999 • An Introduction to the Finite Element Method, *J.N. Reddy*, Mc-Graw Hill, 2006

Mapping of COs with POs and PSOs

POs / COs	PO1	PO2	PO3	PSO 1	PSO 2
CO1	3	2	3	3	2
CO2	3	2	3	2	2
CO3	2	2	3	3	2
CO4	3	2	2	3	2

Correlation levels 1, 2 or 3 as defined below:
1: Slight (Low) 2: Moderate (Medium) 3: Substantial (High)

Department of Metallurgical and Materials Engineering							
Course code	Title of the course	Program Core (PCR) / Electives (PEL)	Total Number of contact hours				Credit
			Lecture (L)	Tutorial (T)	Practical (P)	Total Hours	
MM9062	**AI and ML in Materials Science and Engineering**	PEL	3	0	0	3	3
Pre-requisites		Course assessment methods (continuous (CT) and end assessment (EA))					
Nil		CT+EA					
Developer		Dr. Madan Mohan Ghosh					
Course outcomes	CO1: To develop a knowledge base on the use of AI/ML in materials science and engineering CO2: To design and develop new materials using AI/ML CO3: To apply AI/ML in different length scale and time scale needed for materials development						

Topics covered	**4.** Introduction to AI and ML; Why AI/ML in materials engineering?; Basics of materials engineering; Overview of different computational tools at different length scale and time scale; Materials design at different length scale. [10 h] **5.** Machine learning approaches for materials design; Accelerating materials development and deployment: Deep learning, Inverse design using AI/ML; Materials knowledge and materials data science; Overview of materials informatics. [26 h]
Text books and/or reference materials	• "Artificial Intelligence for Materials Science", by Y. Cheng, T. Wang and G. Zhang, Springer (2021) • "Materials Discovery and Design", by T. Lookman, S. Eidenbenz, F. Alexander and C. Barnes, Springer (2018) • "Informatics for Materials Science and Engineering", by K.R. Reddy, Butterworth-Heinemann Limited (2013)

Mapping of COs with POs and PSOs

POs / COs	PO1	PO2	PO3	PSO 1	PSO 2
CO1	3	2	3	3	3
CO2	3	2	3	2	3
CO3	3	2	2	3	3

Correlation levels 1, 2 or 3 as defined below:

1: Slight (Low) 2: Moderate (Medium) 3: Substantial (High)

Department of Metallurgical & Materials Engineering							
Course Code	Title of the course	Program Core (PCR) / Electives (PEL)	Total Number of contact hours				Credit
			Lecture (L)	Tutorial (T)	Practical (P)	Total Hours	
MM9063	Numerical Methods	PEL	3	0	0	42	3
Pre-requisites		Course Assessment methods (Continuous (CT), and end assessment (EA))					
NIL		CT+EA					
Developer		M. K. Mondal					

Course Outcomes	CO1: Calculate errors induced in the values by truncation of a series expansion. CO2: Fit polynomials to a given set of data points. CO3: Solve differential and integral equations numerically.
Topics Covered	**Linear Algebra:** Introduction, Linearity, Matrix Notation, The Determinant and Inverse, Elementary Row Operations, Rank and Row Echelon Form, Existence and Uniqueness of a Solution, Eigenanalysis, Error and their calculations, MATLAB Commands, problems. [4 hours] **Regression**: Introduction, Single Variable Linear Regression, The Variance of the Regression Coefficients, Multivariate Linear Regression, Polynomial Regression, Linearization of Equations, Confidence Intervals, Regression Subroutines, Problems. [6 hours] **Numerical Differentiation**: Introduction, Taylor Series Expansions, Finite Difference

	Formulae, Approximations for Partial Derivatives, Noise, Problems [5 hours] **Solution of a Single Nonlinear Algebraic Equation**: Introduction, Iterative Solutions and Convergence, Successive Approximations, Bisection Method of Rootfinding, Single Variable Newton-Raphson, Newton-Raphson with Numerical Derivatives, Solution in MATLAB, Existence and Uniqueness of Solutions, Rootfinding Subroutines, Problems. [5 hours] **Solution of a System of Nonlinear Algebraic Equations**: Introduction, Multivariate Newton-Raphson Method, Multivariate Newton-Raphson Method with Numerical Derivatives, Subroutine Codes, Problems. [6 hours] **Numerical Integration:** Introduction, Trapezoidal Rule, Second-Order Simpson's Rule, Higher Order Simpson's Rules, Quadrature, Example, Multidimensional Integrals, Subroutine Codes, Problems. [6 hours] **Solution of Ordinary Differential Equations:** Introduction, Initial Value Problems, Euler Method, Classical Fourth-Order Runge-Kutta Method, Application to Systems of Ordinary Differential Equations, Higher-Order ODEs, Boundary Value Problems, Subroutine Codes, Problems. [4 hours] **Optimization:** Introduction, Optimization vs Root-finding in One-Dimension, Other One Dimensional Optimization Techniques, Multivariate Nonlinear Optimization, Optimization vs Root-finding in Multiple Dimensions, Other Multivariate Optimization Techniques, Subroutine Codes, Problems. [6 hours]
Text Books, and/or reference material	Text Books and Reference Books: 1. R.H. Landau, M.J. Paez, and C.C. Bordeianu, Computational Physics: Problem soving with Computers Wiley VCH (2007) 2. S.C. Chopra and R.P. Canale, Numerical Methods for Engineers, Tata Mcgraw Hill (2002) 3. M.K. Jain, S.R.K. Iyengar, and R.K. Jain, "Numerical Methods for Scientific and Engineering Computation", New Age Pvt. Pub, New Delhi. 4. W. Y. Yang, W. Cao, T. Chung, S. Chung and J. Morris, Applied Numerical Methods Using MATLAB, John Wiley, 2005.

Mapping of COs with POs and PSOs

POs / COs	PO1	PO2	PO3	PSO 1	PSO 2
CO1	2	1	3	2	2
CO2	2	1	2	2	2
CO3	2	1	2	3	2

Correlation levels 1, 2 or 3 as defined below:

1: Slight (Low) 2: Moderate (Medium) 3: Substantial (High)

Department of Metallurgical & Materials Engineering							
Course Code	Title of the course	Program Core (PCR) / Electives (PEL)	Total Number of contact hours				Credit
			Lecture (L)	Tutorial (T)	Practical (P)	Total Hours	
MM9064	Advanced Materials Science	PEL	3	0	0	3	3

Pre-requisites	Course Assessment methods (Continuous (CT) and end assessment (EA))
NIL	CT+EA
Developer	D. Mandal
Course Outcomes	CO1: To understand the crystal structure, constitution of the phase and microstructure of materials CO2: To learn about liquid to solid and solid to solid phase transformation and phase diagram CO3: Apply the principle of physical metallurgy and phase transformation to design a sustainable engineering materials
Topics Covered	**Introduction:** Introduction and structure of materials: Crystal structure and Bravais Lattices, Lattice points, Directions, planes, Miller Indices, Reciprocal Lattice, The structure of crystalline solids. Different crystal structures, Single crystals, polycrystalline, Non-crystalline solids, Crystal defects, Vacancies, Interstitials, line defects, Geometry of dislocation - Surface imperfection, Importance of defects, Diffusion in solids, Fick's 1st and 2nd Laws, ideal solutions, Solid solutions and alloys - Phase diagrams, Gibbs phase rule, Single component systems, Isomorphous and Eutectic phase diagram, lever rule. Study of properties of phase diagrams - Phase transformation - Nucleation kinetics and growth. Microscopic techniques - grain size distribution. The iron-carbon phase diagram. Microstructure in Iron Carbon Alloys. [20 hours] **Materials:** Classification of Engineering materials, Metal, Ceramics, Polymer and Composites, Structure, Properties and application of Polymers, Crystallisation, melting and glass transition. Structure and properties of Ceramics, Ferrous and non-ferrous alloys. Structure, properties, production application, Heat Treatment and Life cycle. Applications and Processing of Metal and Alloys. Semiconductors, Biomaterials, composites, Advanced Materials, and Modern Materials – microstructure, properties and application [12 hours] **Properties of Materials:** Properties of materials? Mechanical properties, Stress, Strain, Elastic properties. Elastic deformation and plastic deformation. Hardness. Mechanisms of strengthening in metals. Dislocations strengthening. Failure of Materials. Relationship between structure and properties. Optical properties - Light interaction with solids, Atomic, and electronic interaction. Electrical Properties, Thermal Properties, Magnetic properties, Economic, Environmental and Social issues of Materials usage [13 hours]
Text Books, and/or reference material	Text Books: W. D. Callister, "Materials Science and Engineering: An Introduction", Tenth Edition, John Wiley & Sons, 2018. 2. K. Vijayamohanan Pillai and Meera Parthasarathi Functional Materials: A Chemist's Perspective by, Orient Blackswan (21 November 2013) 3. C. Kittel, "Introduction to Solid State Physics" Wiley Eastern Ltd, 2005. 4. V. Raghavan, "Materials Science and Engineering: A First Course", Prentice Hall, 2006 5. A.J. Dekker, "Solid State Physics", Macmillan & Co, 2000.

Mapping of COs with POs and PSOs

POs / COs	PO1	PO2	PO3	PSO 1	PSO 2
CO1	3	2	1	2	1
CO2	3	2	1	2	1
CO3	3	2	1	2	1

Correlation levels 1, 2 or 3 as defined below:
1: Slight (Low) 2: Moderate (Medium) 3: Substantial (High)

Department of Metallurgical & Materials Engineering							
Course Code	Title of the course	Program Core (PCR) / Electives (PEL)	Total Number of contact hours				Credit
			Lecture (L)	Tutorial (T)	Practical (P)	Total Hours	
MM9065	Fluid Flow Phenomena in Metallurgical Processes	PEL	3	0	0	3	3
Pre-requisites		Course Assessment methods (Continuous (CT), and end assessment (EA))					
NIL		CT+EA					
Developer		M. K. Mondal					

Course Outcomes	CO1: Understand the fundamentals of fluid flow theory in Metallurgical Processes CO2: Apply mass and momentum transfer principles in the extraction and refining of metals. CO3: Design an important component of the new process development of Metallurgical Processes.
Topics Covered	Introduction: Introduction, Definition of Some Basic Units and Concepts, The Newtonian Definition of Viscosity, Factors That Affect the Viscosity, Review of Elementary Vector and Tensor Notation, Problems. [4 hours] Integral Mass, Momentum, and Energy Balances: Introduction, The Integral Mass Balance, The Integral Momentum Balance, The Integral Mechanical Energy Balance (The Engineering Bernoulli Equation), The Friction Factor, Compressible Fluids, The Application of Overall Balances, Problems. [4 hours] The Differential Equations of Fluid Flow: The Equation of Continuity, The Equation of Motion, The Stream Function and Vorticity, Some Special Solutions of the Navier-Stokes Equations, Exact Solutions of the Navier-Stokes Equations, Problems. [5 hours] Turbulent Flow and Turbulence Phenomena: Some Physical Manifestations of Turbulent Flow Behavior, The Quantitative Characterization of Turbulent Flow, The Differential Equations of Turbulent Flow, Some Solutions of the Turbulent Equation of Motion, Problems. [4 hours] Electromagnetodynamics of Melts: Introduction, The Principal Parameters in Electrodynamics, MUD Applications in Metals Processing, Problems. [4 hours] Natural Convection and Surface Tension Driven Flows: Introduction, Convective Heat and Mass Transfer, Formulation of Convective Mass Transfer Problems, Surface Tension Driven Flows, Surface Tension Effects in Dynamic Systems, Problems. [5 hours] Solid Particle Fluid Systems: Single Particle Fluid Systems, Flow through Packed Beds, Fluidized Beds and Conveyed Systems, Sedimentation and Filtration, Problems. [4 hours] Gas Bubbles and Droplets in Melts: Introduction, Bubble Formation, The Motion of Gas Bubbles in Liquids, Dispersed Bubble Systems, The Formation and Behavior of Droplets, Problems. [4 hours] Gaseous and Liquid Jets: Free Jets, Confined Jets, Impinging Jet Systems, Submerged Jet Systems, Problems. [3 hours] Flow Measurements and the Physical Modeling of Metallurgical Flow Systems: Introduction, Measurement of Volumetric Flow Rates, Measurement of Fluid Velocity, The Physical Modeling of Fluid Flow Problems in Metals Processing, Problems. [5 hours]
Text Books, and/or reference material	Text Books and Reference Books: 1. Transport Phenomena in Materials Processing by David R. Poirier, G. Geiger, Springer. 2. Rate Phenomena in Process Metallurgy by J. Szekely and N. J. Themelis, Wiley, New

	York. 3. Fluid Flow Phenomena in Metals Processing by J. Szekely, Academic Press. 4. Treatise on Process Metallurgy, Volume 2: Process Phenomena, Edited by: S. Seetharaman, Elsevier.

Mapping of COs with POs and PSOs

POs / COs	PO1	PO2	PO3	PSO 1	PSO 2
CO1	2	1	3	2	2
CO2	3	1	2	2	3
CO3	2	2	3	3	2

Correlation levels 1, 2 or 3 as defined below:
1: Slight (Low) 2: Moderate (Medium) 3: Substantial (High)

Department of Metallurgical & Materials Engineering								
Course Code	Title of the course	Program Core (PCR) / Electives (PEL)	Total Number of contact hours				Credit
			Lecture (L)	Tutorial (T)	Practical (P)	Total Hours	
MM9066	Environmental Management in Metallurgical Industries	PCR	3	0	0	3	3
Pre-requisites		Course Assessment methods (Continuous (CT), mid-term (MT) and end assessment (EA))					
Sustainable Metal Proction Technology		CT+EA					
Course Outcomes	**CO1: Evaluate** the environmental impacts associated with metallurgical operations and identify pollution sources. **CO2: Apply** environmental management tools and technologies to develop sustainable metallurgical processes. **CO3: Analyze** policies, standards, and best practices for pollution control, waste management, and sustainable development in metallurgical industries.						
Topics Covered	Fundamentals of environmental management [4] A brief outline of the different metallurgical industries and its status [4] Sources and types of pollutants (wastes) from metal / minerals industries [4]. Gaseous emissions: control of SPM, hazardous gases, viz. sulphur dioxide, fluorides, nitrogen oxides.[4] Greenhouse gases: Greenhouse effect, global warming potential, Kyoto protocol, carbon trading [4] Emission and control from different ferrous and non-ferrous industries: Coal based DRI unit, Gas based DRI unit, Smelting reduction units, Ferro alloy plants, Foundry industries, Aluminium producing industries, Copper extraction industries, Zinc and led producing						

	industries, Other metallurgical industries [8] Liquid effluents: treatment of waste water, with examples from metal industries.[4] Solid wastes: types, disposal and utilization of slime, red mud and spent pot lining, iron and steel slags, Fly and bottom ash [8] Impact of pollutants on human health,[2] Management of radioactive wastes, e-waste, noise pollution, thermal pollution. [6]
Text Books, and/or reference material	**Text Books:** 1. R.C. Gupta: Energy and Environmental Management in Metallurgical Industries, PHI Learning 2. H.S. Ray. B.P. Singh, S. Bhattcharya, V. N. Misra,. Energy in Mineral and Metallurgical Industries, Allied Publisher 3. C. S. Rao: Environmental Pollution Control Engineering, Wiley Eastern Ltd. 4. J. A. Nathanson: Basic Environmental Technology, prentice-Hall India **Reference Books:** 1. R.C. Gupta(ed.): Proc. Environmental Management in Metallurgical Industries(EMMI-2010),Allied Publishers 2. Fathi Habashi: Pollution Problems in Mineral and Metallurgical Industries,Metallurgie Extractive Quebec. 3. H.S.Peavy et al.: Environmental Engineering, McGraw Hill

Mapping of CO (Course Outcome) and PO (Programme Outcome)

POs / COs	PO1	PO2	PO3	PSO 1	PSO 2
CO1	2	1	3	3	2
CO2	1	1	2	2	1
CO3	3	1	3	1	3

Correlation levels 1, 2 or 3 as defined below:

1: Slight (Low) 2: Moderate (Medium) 3: Substantial (High)

Department of Metallurgical and Materials Engineering							
Course Code	Title of the course	Program Core (PCR) / Electives (PEL)	Total Number of contact hours				Credit
			Lecture (L)	Tutorial (T)	Practical (P)	Total Hours	
MM9067	Human Resource Management	PEL	3	0	0	3	3
Pre-requisites	NIL	Course Assessment methods (Continuous (CT) and end assessment (EA))					
		CT+EA					

Course Outcomes	CO1: Ability to understand the involvement of human resource in alignment of organizational goals CO2: Ability to understand the goals of human resource for its own development CO3: Ability to develop practices for better output of the industries
Topics Covered	Role of HR in Organization, HR as a strategic partner , scope and importance in Business.(2 Hours)

	Talent Acquisition and Recruitment process (3 Hours) Employee Relations -employee engagement, workplace culture, and managing workplace conflict. (3 hours) Training and Development: Training needs assessment, learning methodologies, development programs, identifying skill gaps, designing training, and evaluation metrics. (4 hours) Compensation and Benefits: Wage and salary administration, incentive programs, employee benefits, and employee retention strategies. (4 hours) Performance Management: Setting objectives, performance appraisal methods, feedback, and coaching. (3 hours) HR Information Systems (HRIS): Implementation and management, data analytics for HR decision-making, and information security (2 hours) Organizational Behavior: Motivation theories, leadership styles, group dynamics, and teamwork. (2 Hours) Strategic HR Management: Aligning HR practices with organizational goals, HR planning, succession planning.(3 Hours) Legal Aspects of HRM: Labor laws, employment equity, and HR ethics. (2 Hours) Global HRM: Managing multinational teams, cross-cultural HR practices. (2 Hours) Change Management: Managing organizational change, employee engagement during transitions. (2 Hours) Human Resource Accounting: Valuing human resources, HR metrics. (2 Hours) HR Audit: Assessing the effectiveness of HR practices (2 Hours)
Text Books, and/or reference material	Text Books: • Koontz, Weirich &Aryasri, PRINCIPLES OF MANAGEMENT, Tata McGraw-Hill, NewDelhi,2004 • Tripathi & Reddy, PRINCIPLES OF MANAGEMENT, Tata McGraw-Hill, New Delhi,2008 • Laurie Mullins, MANAGEMENT AND ORGANISATIONAL BEHAVIOUR, Pearson, NewDelhi,2007 • Meenakshi Gupta, PRINCIPLES OF MANAGEMENT, PHI Learning, NewDelhi, 2009 • Stephen Robbins, ORGANISATIONAL BEHAVIOUR, Pearson, New Delhi

Mapping of CO (Course Outcome) and PO (Programme Outcome)

POs / COs	PO1	PO2	PO3	PSO1	PSO 2
CO1	2	3	3	3	2
CO2	2	2	2	2	1
CO3	3	2	3	2	3

Correlation levels 1, 2 or 3 as defined below:

1: Slight (Low)   2: Moderate (Medium)   3: Substantial (High)

Course Code	Title of the course	Program Core (PCR) / Electives (PEL)	Total Number of contact hours				Credit
			Lecture (L)	Tutorial (T)	Practical (P)	Total Hours	
MM9068	Hydrogen and Fuel Cells	PCR	3	0	0	3	3

Pre-requisites	Course Assessment methods (Continuous (CT), mid-term (MT) and end assessment (EA))
Materials Thermodynamics (MM1001)	CT+EA
Developer	S. Ghorai

Course Outcomes	CO1: To identify the potential of H2 as renewable and green fuel, and also to suitable production systems. CO2: To understand the thermodynamics and working principles of fuel cell. CO3: To describe the application of fuel cells in industrial and commercial areas
Topics Covered	Significances of hydrogen and fuel cells in current scenario, A History of Hydrogen Energy, Hydrogen energy – Hydrogen as a fuel, application. Hydrogen production methods – production of hydrogen from fossil fuels, electrolysis, thermal decompositions, photochemical and photocatalytic methods, issues related to scale up, Hydrogen storage methods – metal hydrides, metallic alloy hydrides, carbon nano-tubes, sea as source of deuterium. [15] Basic concepts of fuel cells, Fuel cell definition, difference between batteries and fuel cells, fuel cell history, components of fuel cells, principles of working and performance characteristics of fuel cells, efficiency of fuel cells, fuel cell electrochemistry – nearsnt equation, electrochemical kinetics, butler-volmer equation, Various types of fuel cells - Solid oxide cells, Acid and alkaline cells, Molten carbonate cells, Proton exchange membrane cells, Direct methanol and other non-hydrogen cells, Biofuel cells. Applications of fuel cells, Application related issues, Safety norms. [15] Cost calculations, Lifecycle analysis, opportunities and obstacles [12]
Text Books, and/or reference material	Suggested Text Books: 1. 'Principles of Fuel Cells', by Xianguo Li, Taylor & Francis 2. 'Fuel Cells, Principles and Applications', Viswanathan, B. and Scibioh, Aulice M, Universities Press 3. 'Hydrogen and Fuel Cells: Emerging Technologies and Applications', Bent Sørensen, Academic press 4. Hydrogen, Batteries and Fuel Cells, Bengt Sundén, Academic Press, Elsevier 5. Hydrogen and Fuel Cells: Emerging Technologies and Applications, Bent Sorensen, Giuseppe Spazzafumo, Academic Press, Elsevier 6. Fuel Cells and Hydrogen: From Fundamentals to Applied Research, Viktor Hacker and S. Mitsushima, Elsevier 7. I Dincer, C Zamfirescu, Sustainable Hydrogen Production, Elsevier 8. I Dincer, H Ishaq, Renewable Hydrogen Production, Elsevier,

Mapping of CO (Course Outcome) and PO (Programme Outcome)

POs / COs	PO1	PO2	PO3	PSO1	PSO2
CO1	2	1	3	2	2
CO2	2	1	2	2	2
CO3	2	1	3	2	2

Correlation levels 1, 2 or 3 as defined below:

1: Slight (Low) 2: Moderate (Medium) 3: Substantial (High)

Department of Metallurgical & Materials Engineering							
Course Code	Title of the course	Program Core (PCR) / Electives (PEL)	Total Number of contact hours				Credit
			Lecture (L)	Tutorial (T)	Practical (P)	Total Hours	
MM9069	Waste Management	PCR	3	0	0	3	3
Pre-requisites		Course Assessment methods (Continuous (CT), mid-term (MT) and end assessment (EA))					
Sustainable Metal Production Technology		CT+EA					
Course Outcomes	• CO1: To learn the legislation and polices for waste management • CO2: To identify the various kinds of wastes produced during metallurgical processing • CO3: To apply suitable methods to recycle the wastes						
Topics Covered	Importance of Solid Waste Management, Legislation and Policies Governing the Environmental and Health Impacts of Metallic Waste, Guidelines for Managing Mining and Metallurgical Waste, Environmental and Health Impacts, Principles of waste management, Various kind of wastes and their classification. [8] Mining and Beneficiation waste production. [4] Waste Production and Utilization of nonferrous metal extraction.[4] Recycling and reuse of blast furnace ironmaking slags, steel making dusts and sludges. [6] Utilization of steel making dusts and slags [6] Ferroalloys Waste Production and Utilization [4] E-waste and recovery of metals and useful things from e-waste. [6] Waste management and utilization options: zero waste process approach, synergy between residue produces and residue end users. Future outlook. [6]						
Text Books, and/or reference material	Suggested Text Books: 5. Ndlovu, S., G.S. Simate and E. Matinde, Waste production and utilization in the Metal Extraction Industry, CRC Press, 2017 6. Ramachandra Rao, Resource recovery and recycling from metallurgical wastes, Elsevier, 2006 7. K. Hieronymi, R. Kahhat, E. Williams, E-waste Management: From waste to resource, Routledge, New York,2013						

Mapping of CO (Course Outcome) and PO (Programme Outcome)

POs / COs	PO1	PO2	PO3	PSO 1	PSO 2
CO1	2	1	3	3	2
CO2	1	1	2	2	1
CO3	3	1	3	1	3

Correlation levels 1, 2 or 3 as defined below:

1: Slight (Low) 2: Moderate (Medium) 3: Substantial (High)