# Postgraduate Programmes

**Course Structure and Syllabi**

For the specializations of

**(1) MACHINE LEARNING IN MATERIALS ENGINEERING**

(2) **MATERIALS SCIENCE AND ENGINEERING**

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उत्तिष्ठत जाग्रत प्राप्य वरान् निबोधत

INDIAN INSTITUTE OF ENGINEERING SCIENCE AND TECHNOLOGY, SHIBPUR

भारतीय अभियांत्रिकी विज्ञान एवं प्रौद्योगिकी संस्थान, शिवपुर

**Department of Metallurgy and Materials engineering**

Indian Institute of Engineering Science and Technology (IIEST), Shibpur

Botanic Garden, Howrah

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# COURSE STRUCTURE FOR M. TECH. IN
# MACHINE LEARNING IN MATERIALS ENGINEERING

## First Semester

| Sl. No. | Type | Course Name | Course code | Class Load/Week | | | Credit | Class load/ week | Marks |
|---|---|---|---|---|---|---|---|---|---|
| | | | | L | T | P | | | |
| 1 | PC | Materials Technology | MM5101N | 3 | 0 | 0 | 3 | 3 | 100 |
| 2 | PC | Advanced Characterization of Materials | MM5102N | 3 | 0 | 0 | 3 | 3 | 100 |
| 3 | PC | Advanced Thermodynamics and Kinetics | MM5103N | 3 | 0 | 0 | 3 | 3 | 100 |
| 4 | PSE | Machine Learning in Materials Discovery/Atomistic Simulation of Materials | MM5123N/ MM5124N | 3 | 0 | 0 | 3 | 3 | 100 |
| 5 | OE | Mechanical Behaviour of Engineering Materials/Selection of Engineering Materials | MM5161N/ MM5162N | 3 | 0 | 0 | 3 | 3 | 100 |
| | | **Theory Sub-total** | | **15** | **0** | **0** | **15** | **15** | **500** |
| 6 | PC | Materials Technology Lab. | MM5171N | 0 | 0 | 3 | 2 | 3 | 50 |
| 7 | PC | Materials Characterization Lab. | MM5172N | 0 | 0 | 3 | 2 | 3 | 50 |
| 8 | PC | Machine Learning in Materials Lab | MM5173N | 0 | 0 | 3 | 2 | 3 | 50 |
| | | **Practical Sub-total** | | **0** | **0** | **9** | **6** | **9** | **150** |
| | | **First Semester Total** | | **15** | **0** | **9** | **21** | **24** | **650** |

## Second Semester

| Sl. No. | Type | Course Name | Course code | Class Load/Week | | | Credit | Class load/ week | Marks |
|---|---|---|---|---|---|---|---|---|---|
| | | | | L | T | P | | | |
| 1 | PC | Manufacturing Processes | MM5201N | 3 | 0 | 0 | 3 | 3 | 100 |
| 2 | PC | Mechanical Behaviour of Materials | MM5202N | 3 | 0 | 0 | 3 | 3 | 100 |
| 3 | PC | Multiscale Material Modeling | MM5203N | 3 | 0 | 0 | 3 | 3 | 100 |
| 4 | PSE | Deep learning for materials engineering/Microstructure modelling for metallic systems | MM5224N/ MM5225N | 3 | 0 | 0 | 3 | 3 | 100 |
| 5 | OE | Nanostructures and nanomaterials/Biomedical Materials and Devices | MM5261N/ MM5262N | 3 | 0 | 0 | 3 | 3 | 100 |
| | | **Theory Sub-total** | | **15** | **0** | **0** | **15** | **15** | **500** |
| 6 | P | M.Tech. Thesis Part-I (Term-paper) | MM5291N | 0 | 0 | 3 | 2 | 3 | 50 |
| 7 | O | Seminar/Viva Voce | MM5292N | 0 | 0 | 3 | 2 | 3 | 50 |
| | | **Practical Sub-total** | | **0** | **0** | **6** | **4** | **6** | **100** |
| | | **Second Semester Total** | | **15** | **0** | **6** | **19** | **21** | **600** |

# COURSE STRUCTURE FOR M. TECH. IN
# MATERIALS SCIENCE AND ENGINEERING

## First Semester

| Sl. No. | Type | Course Name | Course code | Class Load/Week | | | Credit | Class load/ week | Marks |
|---|---|---|---|---|---|---|---|---|---|
| | | | | L | T | P | | | |
| 1 | PC | Materials Technology | MM5101N | 3 | 0 | 0 | 3 | 3 | 100 |
| 2 | PC | Advanced Characterization of Materials | MM5102N | 3 | 0 | 0 | 3 | 3 | 100 |
| 3 | PC | Advanced Thermodynamics and Kinetics | MM5103N | 3 | 0 | 0 | 3 | 3 | 100 |
| 4 | PSE | Functional Materials/Composite Materials | MM5121N/ MM5122N | 3 | 0 | 0 | 3 | 3 | 100 |
| 5 | OE | Mechanical Behaviour of Engineering Materials/Selection of Engineering Materials | MM5161N/ MM5162N | 3 | 0 | 0 | 3 | 3 | 100 |
| | | **Theory Sub-total** | | **15** | **0** | **0** | **15** | **15** | **500** |
| 6 | PC | Materials Technology Lab. | MM5171N | 0 | 0 | 3 | 2 | 3 | 50 |
| 7 | PC | Materials Characterization Lab. | MM5172N | 0 | 0 | 3 | 2 | 3 | 50 |
| 8 | PC | Machine Learning in Materials Lab | MM5173N | 0 | 0 | 3 | 2 | 3 | 50 |
| | | **Practical Sub-total** | | **0** | **0** | **9** | **6** | **9** | **150** |
| | | **First Semester Total** | | **15** | **0** | **9** | **21** | **24** | **650** |

## Second Semester

| Sl. No. | Type | Course Name | Course code | Class Load/Week | | | Credit | Class load/ week | Marks |
|---|---|---|---|---|---|---|---|---|---|
| | | | | L | T | P | | | |
| 1 | PC | Manufacturing Processes | MM5201N | 3 | 0 | 0 | 3 | 3 | 100 |
| 2 | PC | Mechanical Behaviour of Materials | MM5202N | 3 | 0 | 0 | 3 | 3 | 100 |
| 3 | PC | Multiscale Material Modeling | MM5203N | 3 | 0 | 0 | 3 | 3 | 100 |
| 4 | PSE | Design and selection of Materials/Surface treatment and Modifications | MM5221N/ MM5223N | 3 | 0 | 0 | 3 | 3 | 100 |
| 5 | OE | Nanostructures and nanomaterials/Biomedical Materials and Devices | MM5261N/ MM5262N | 3 | 0 | 0 | 3 | 3 | 100 |
| | | **Theory Sub-total** | | **15** | **0** | **0** | **15** | **15** | **500** |
| 6 | P | M.Tech. Thesis Part-I (Term-paper) | MM5291N | 0 | 0 | 3 | 2 | 3 | 50 |
| 7 | O | Seminar/Viva Voce | MM5292N | 0 | 0 | 3 | 2 | 3 | 50 |
| | | **Practical Sub-total** | | **0** | **0** | **6** | **4** | **6** | **100** |
| | | **Second Semester Total** | | **15** | **0** | **6** | **19** | **21** | **600** |

## Syllabus: First Semester

### Core Subject (Machine Learning in Materials Engineering & Materials Science and Engineering)

| Course Code | MM5101N | Course Name | Materials Technology | Course Category | PC | L | T | P |
|---|---|---|---|---|---|---|---|---|
| | | | | | | 3 | 0 | 0 |

| Pre-requisite Courses | *NIL* | Co-requisite Courses | *NIL* | Progressive Courses | Materials Technology Lab. |
|---|---|---|---|---|---|
| **Course Offering Department** | | Metallurgy and Materials Engineering | | **Data Book / Codes/Standards** | *NIL* |

| Course Objective | To gain an in-depth understanding of the structure, classification, and behavior of engineering materials by exploring crystallography, phase diagrams, solidification, diffusion, and solid-state transformations, enabling them to analyze microstructural evolution and apply materials principles to the design, processing, and performance optimization of advanced engineering materials. |
|---|---|

| Module | Syllabus | Duration (h) | Module outcome |
|---|---|---|---|
| *Module-I* | **Engineering Materials: Classification and Structure**<br>Classification of engineering materials; Elements of crystallography: Atomic packing, Stacking sequence; Bravais lattice & Miller indices; Crystal imperfections. | 5 | Able to classify engineering materials, interpret crystal structures using Bravais lattices and Miller indices, analyze atomic packing, and identify crystal imperfections and their effects on material properties. |
| *Module-II* | **Phase diagram and Transformation**<br>Phase rule; Types and construction of phase diagrams; Free energy-composition diagrams; Lever Rule; Isomorphous and phase diagrams with invariant reactions; Introduction to ternary system. | 6 | Interpret and construct phase diagrams, apply phase and lever rules, analyze free energy-composition curves, and understand invariant reactions and ternary systems to predict phase stability and transformations in multi-component materials. |
| *Module - III* | **Steel and Cast Iron**<br>Fe-C system; Steel and cast-iron microstructures with phase relations. | 5 | Understand the Fe-C phase diagram, analyze steel and cast-iron microstructures based on composition and thermal history to predict phase transformations and properties. |
| *Module -1V* | **Solidification**<br>Homogeneous and Heterogeneous nucleation, and growth; Planar, Columnar | 6 | Analyze nucleation types, solidification growth modes, solute segregation, and casting defects to understand and control microstructure evolution during solidification. |

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|---|---|---|---|
| | and dendritic solidification; Segregations; Casting defects. | | |
| *Module-V* | **Diffusion**<br>Diffusion laws; Kirkendall effect; activation energy; Diffusion mechanisms; uphill diffusion *etc.* | 6 | Apply diffusion laws and mechanisms, interpret the Kirkendall effect, calculate activation energy, and analyze phenomena like uphill diffusion to understand mass transport and its impact on microstructural evolution in materials. |
| *Module -VI* | **Solid-state phase transformation**<br>Thermodynamics and Kinetics of nucleation and growth; Mechanisms; T-T-T and C-C-T diagrams. | 6 | Analyze the thermodynamics and kinetics of nucleation and growth, understand transformation mechanisms, and interpret T-T-T and C-C-T diagrams to predict microstructural evolution during solid-state phase transformations. |
| *Module - VII* | **Diffusional and diffusion less transformation processes**<br>Polymorphic transformation; Pearlite, bainite and martensite transformations; Massive and order-disorder transformation; Precipitation; Recrystallization | 8 | Understand and analyze diffusional and diffusionless transformations, including polymorphic changes, pearlite, bainite, martensite, massive and order-disorder transformations, as well as precipitation and recrystallization, to evaluate microstructural evolution and material properties in solid-state phase transformations. |
| | **Total** | **42** | |

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| **Course Outcome** | Upon successful completion, students will:<br>CO1: Recognize and categorize engineering materials based on their structural attributes, properties, and applications.<br>CO2: Describe the connection between material microstructures and their mechanical behaviors.<br>CO3: Evaluate properties such as strength, hardness, toughness, and corrosion resistance utilizing standardized testing procedures. |

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| ***Learning Resources*** | **Materials Science and Engineering**: W.F. Smith, J. Hashemi and R Prakash, McGraw Hill<br>**The Science and Engineering of Materials**, D.R. Asheland, Springer Science<br>**Fundamentals of Materials Science and Engineering** : W.D. Callister, Jr, John Wiley & Sons, Inc.<br>**Science and Engineering - A First Course**, V. Raghavan, PHI |

| Course Code | MM5102N | Course Name | Advanced Characterization of Materials | Course Category | PC | L | T | P |
|---|---|---|---|---|---|---|---|---|
| | | | | | | 3 | 0 | 0 |

| Pre-requisite Courses | *NIL* | Co-requisite Courses | *NIL* | Progressive Courses | *NIL* |
|---|---|---|---|---|---|
| Course Offering Department | | Metallurgy and Materials Engineering | | Data Book / Codes/Standards | *NIL* |

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|---|---|
| **Course Objective** | To provide a thorough understanding of advanced characterization techniques for materials at micro- and nano-scales.<br>To develop the ability to select and apply appropriate characterization tools for analyzing structure, morphology, composition, and properties.<br>To prepare students for research and industrial problem-solving using modern materials characterization methods. |

| Module | Syllabus | Duration (h) |
|---|---|---|
| I | Introduction to Advanced material characterization techniques | 02 |
| II | x-ray diffraction pattern analysis: Determination of crystal structure, crystal size, lattice parameter, quantitative phase analysis and defect analysis. | 08 |
| III | Advanced optical Microscopy: Interference, Phase contrast, polarized light and near field scanning optical microscopy | 04 |
| 1V | Electron Microscopes: Scanning Electron Microscopes and Transmission Electron microscopes, Electron diffraction and diffraction pattern analysis | 10 |
| V | Scanning probe Microscope : Scanning tunneling microscope,Atomic force microscope, Magnetic force microscope | 05 |
| VI | Spectroscopy: Principle and application of Energy dispersive spectroscopy, Auger electron spectroscopy, X ray photo electron spectroscopy, x-ray fluorescence spectroscopy, Raman spectroscopy. Fourirer transform Infrared spectroscopy | 08 |
| VII | Thermal Characterization techniques: DSC, DTA-TGA, principles and applications | 05 |
| | **Total contact hours** | **42** |

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| **Course Outcome** | At the end of this course, students will be able to:<br>• Understand the principles and working mechanisms of various advanced characterization techniques.<br>• Interpret experimental data obtained from XRD, microscopy, and spectroscopic methods.<br>• Select appropriate techniques for specific materials analysis problems.<br>• Critically analyze microstructural, compositional, and surface properties of materials. |

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| **Learning Resources** | B.D Cullity: **Elements of x- ray diffraction**<br>Yang Leng: **Materials Characterization: Introduction to Microscopic and Spectroscopic Methods**<br>David B Williams, C. Barry Carter: **Transmission Electron Microscopy** |

| Course Code | MM5103N | Course Name | Advanced Thermodynamics and Kinetics | Course Category | PC | L | T | P |
|---|---|---|---|---|---|---|---|---|
| | | | | | | 3 | 0 | 0 |

| Pre-requisite Courses | *Nil* | Co-requisite Courses | *Nil* | Progressive Courses | |
|---|---|---|---|---|---|
| Course Offering Department | | *Metallurgy and Materials Engineering* | | Data Book / Codes/Standards | |

| Course Objective | |
|---|---|
| | 1. **Deepen understanding of classical and statistical thermodynamics** as applied to materials and chemical systems.<br>2. **Explore advanced thermodynamic models** for multicomponent, multiphase systems, including solutions and phase equilibria.<br>3. **Develop knowledge of kinetics** including rate theories, diffusion, and phase transformation mechanisms.<br>4. **Apply thermodynamic and kinetic principles** to real-world processes such as alloy solidification, corrosion, catalysis, and materials degradation.<br>5. **Enhance critical thinking skills** for interpreting complex phase diagrams and reaction mechanisms. |

| Module | Syllabus | Duration (class-hour) | Module Outcome |
|---|---|---|---|
| I | Review of Classical Thermodynamics: Laws of thermodynamics (Zeroth, first, second and third), Thermodynamic potentials: Basics and appllications (U, H, A, G), Maxwell's relations and their applications, Stability criteria and phase equilibrium | 08 | Understanding the need and challenges of thermodynamics for materials engineering applications. |
| II | Basics of Statistical Thermodynamics: Microstates, macrostates, and partition functions, Maxwell-Boltzmann, Fermi-Dirac, and Bose-Einstein statistics, Connection between statistical and classical thermodynamics, Configurational entropy and mixing. | 08 | Basics of statistical mechanics and its application for derivation of thermodynamic parameters. |
| III | Thermodynamics of Solutions and Phases: Ideal, regular, and real solutions, Partial molar quantities and chemical potential, Activity, fugacity, and excess properties, Gibbs phase rule and phase equilibria. | 06 | Understanding about the thermodynamics of solutions and its applications for the materials design. |
| IV | Diffusion and Mass Transport: Fick's laws and atomic mechanisms of diffusion, Diffusion in solids, liquids, and gases, Interdiffusion, Darken's equations, Kirkendall effect and tracer diffusion. | 06 | Understanding about the diffusion phenomena and its basics. |
| V | Reaction Kinetics and Mechanisms: Rate laws and reaction order, Arrhenius equation and activation energy, Transition state theory and reaction coordinate diagrams, Catalysis and surface reactions. | 06 | Application of kinetics for the chemical reactions and catalytic phenomena. |

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|---|---|---|---|
| VI | Applications and Case Studies: Thermo-kinetics in alloy design, Corrosion and oxidation and thin film growth | 07 | Application of thermodynamic and kinetic principles to industrial relevant phenomena. |
| | **Total contact hours** | **42** | |

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| **Course Outcome** | 1. Explain advanced thermodynamic concepts, including chemical potential, Gibbs energy minimization, and entropy production.<br>2. Analyze multicomponent phase equilibria using analytical methods.<br>3. Apply kinetic theories (e.g., transition state theory and diffusion mechanisms) to describe reaction rates and phase changes.<br>4. Conduct and critique thermodynamic and kinetic analyses in academic or industrial research contexts. |

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| **Learning Resources** | 1. Statistical mechanics: A survival guide, A. M. Glazer and J. S. Wark, Oxford University Press.<br>2. Textbook of Materials and Metallurgical Thermodynamics, Ahindra Ghosh, PHI Eastern Economy edition.<br>3. Introduction to the Thermodynamics of Materials, David R. Gaskell, Taylor and Francis Learning Resources<br>4. A Textbook of Metallurgical Kinetics, Sudipto Ghosh and Ahindra Ghosh, PHI Eastern Economy edition. |

## PSE: Machine Learning in Materials Engineering

| Course Code | MM5123N | Course Name | Machine Learning in Materials Discovery | Course Category | PSE | L | T | P |
|---|---|---|---|---|---|---|---|---|
| | | | | | | 3 | 0 | 0 |

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|---|---|---|---|---|---|
| **Pre-requisite Courses** | *Nil* | **Co-requisite Courses** | *Nil* | **Progressive Courses** | |
| **Course Offering Department** | | ***Metallurgy and Materials Engineering*** | | **Data Book / Codes/Standards** | |

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| **Course Objectives** | ▪ To provide students with a foundational understanding of machine learning principles, algorithms, and workflows, with a focus on supervised, unsupervised, and reinforcement learning.<br>▪ To foster the ability to integrate knowledge of materials science with data science to solve complex industrial challenges innovatively and efficiently. |

| Module | Syllabus | Duration (class-hour) | Module Outcome |
|---|---|---|---|
| I | **Mathematical Foundations for Machine Learning:** Vectors, matrices, and tensors, Matrix operations: addition, multiplication, transpose, inverse; Eigenvalues and eigenvectors, Singular Value Decomposition (SVD), Vector spaces, span, linear independence, Orthogonality and projections. Partial derivatives and multivariable calculus, Chain rule and the gradient descent algorithm; Optimization methods: gradient ascent/descent, Taylor series and approximations; Probability theory basics (conditional probability, Bayes' theorem), Random variables and distributions (Normal, Binomial, Poisson, etc.), Expectation, variance, and covariance, Maximum likelihood estimation (MLE), Hypothesis testing, Confidence intervals and p-values; | 7 | The Students will be able to demonstrate foundational knowledge in linear algebra, calculus, probability theory, and optimization as they pertain to machine learning algorithms. |
| II | **Machine Learning Fundamentals:** Linear regression and classification algorithms, Feature extraction, Evaluation metrics for machine learning models (accuracy, precision, recall, F1 score, etc.) | 4 | The Students will be able to explain the foundational principles of machine learning, including supervised, unsupervised, and reinforcement learning paradigms. |
| III | **Supervised Learning for Property Prediction:** Predicting material properties using regression models (e.g., elastic moduli, band gaps, melting points), Case study: | 7 | The Students will be able to implement and utilize common supervised learning algorithms (e.g., Linear Regression, |

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|---|---|---|---|
| | predicting the electronic properties of materials, Techniques: Random Forest, Support Vector Machines, k-Nearest Neighbors, and Gradient Boosting. | | Support Vector Machines, Decision Trees, Random Forests, Neural Networks, Graph Neural Networks) for both regression and classification tasks. |
| IV | **Deep Learning in Materials Discovery:** Neural networks and their application in materials science, Convolutional Neural Networks (CNNs) for image-based data, Recurrent Neural Networks (RNNs) for sequence prediction (e.g., material design through molecular structure), Transfer learning in material property prediction. | 6 | The Students will be able to utilize common deep learning architectures such as Convolutional Neural Networks (CNNs), Recurrent Neural Networks (RNNs), Graph Neural Networks (GNNs), and Transformer networks for materials-related tasks. |
| V | **Unsupervised Learning and Clustering:** Clustering techniques (e.g., k-means, hierarchical clustering) for materials discovery, Dimensionality reduction (e.g., PCA, t-SNE) for high-dimensional materials data, Identifying trends in materials datasets: finding novel materials based on clustering. | 6 | The Students will be able to implement unsupervised learning algorithms using popular programming languages (e.g., Python) and libraries (e.g., scikit-learn, SciPy). |
| VI | **Materials Genome Initiative and High-Throughput Screening:** The Materials Genome Initiative (MGI): an overview and its impact on materials discovery, High-throughput computational screening and Machine Learning-based optimization. | 6 | The Students will be able to navigate and leverage prominent materials databases for accessing existing materials data and properties |
| VII | **Reinforcement Learning for Materials Discovery:** Introduction to reinforcement learning (RL) and its application in materials science, RL for material design: agent-based modeling and reward structures, Case study: RL in the discovery of alloys and polymers. | 6 | The Students will be able to explain the core components of an RL problem: agents, environments, states, actions, rewards, and policies, specifically as they apply to materials design and discovery |

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| **Course Outcome** | The Students will be able to<br>1. Explain the core concepts of supervised, unsupervised, and reinforcement learning relevant to metallurgical processes and materials.<br>2. Identify and articulate specific challenges and opportunities for applying machine learning within the metallurgical industry (e.g., complex process parameters, material property variations, data sparsity, sensor noise).<br>3. Apply techniques for data cleaning, handling missing values, outlier detection, and data integration specific to metallurgical datasets.<br>4. Apply machine learning techniques for predicting structure-property relationships in alloys, ceramics, and composites |

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| **Learning Resources** | "Machine Learning for Materials Scientists: An Introduction to the Application of Machine Learning Algorithms in Materials Science" by James A. Pask, Malgorzata K. S. K. and Shreyas Shinde |


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|---|---|
| **Learning Resources** | **"Machine Learning for Materials Scientists: An Introduction to the Application of Machine Learning Algorithms in Materials Science" by** James A. Pask, Malgorzata K. S. K. and Shreyas Shinde. |

| Course Code | MM5124N | Course Name | Atomistic Simulation of Materials | Course Category | PSE | L | T | P |
|---|---|---|---|---|---|---|---|---|
| | | | | | | 3 | 0 | 0 |

| Pre-requisite Courses | *Nil* | Co-requisite Courses | *Nil* | Progressive Courses | |
|---|---|---|---|---|---|
| Course Offering Department | | *Metallurgy and Materials Engineering* | | Data Book / Codes/Standards | |

| Course Objectives | |
|---|---|
| | • Provide the theoretical foundations of molecular dynamics (MD), Density Functional Theory (DFT) and Monte Carlo (MC) simulations, including their statistical mechanical basis.<br>• Provide understanding how atomistic simulations complement experimental observations and higher-scale computational methods in materials research |

| Module | Syllabus | Duration (class-hour) | Module Outcome |
|---|---|---|---|
| I | **Mathematical Background for Atomistic Simulation of Materials**: Ordinary Differential Equations (ODEs),Partial Differential Equations (PDEs),Probability distributions (Gaussian, Poisson, etc.), Random variables and expectation values, The concept of ensembles in statistical mechanics (micro-canonical, canonical, grand canonical); Partition function and its connection to thermodynamic quantities, Relation between macroscopic observables and microscopic states; Bose-Einstein and Fermi-Dirac statistics; Quantum gases and their equations of state; Bose-Einstein condensation, Fermi surfaces, Time-dependent and time-independent Schrödinger equation, Perturbation theory (time-independent and time-dependent), Interaction picture and path integrals | 6 | Students will be able to formulate and analyze the mathematical equations underlying classical molecular dynamics (Newton's laws of motion) and Quantum Chemical Calculations. |
| II | **Introduction to Atomistic Simulation Methods** Overview of Atomistic Simulation: Introduction to the field, significance in materials science, and applications in industry and research. Material Properties and Modeling: Connection between atomistic models and macroscopic material properties. Overview of Computational Tools: Introduction to software packages. | 8 | Students will be able to know atomistic simulation techniques and their roles in materials engineering |
| III | **Classical Simulation Techniques** Molecular Dynamics (MD): Principles of MD simulations: Newton's equations of motion, time integration, and boundary conditions. Interatomic potentials (Lennard-Jones, embedded atom model (EAM), etc.). Thermodynamic properties from MD simulations (temperature, pressure, heat capacity). | 10 | Students will be able to set up, run, and analyze basic molecular dynamics (MD) and/or Monte Carlo (MC) simulations using an industry-standard atomistic simulation software package, |

| | | | |
|---|---|---|---|
| | Applications of MD: Diffusion, phase transitions, defect formation, etc.<br>Monte Carlo (MC) Simulations: Introduction to probabilistic methods and the Monte Carlo approach. Applications in simulating equilibrium states, thermodynamic properties, and material behavior. | | and interpret the resulting material properties and atomic behaviors. |
| IV | **Quantum Mechanical Simulations**<br>**Density Functional Theory (DFT):** Basic principles and the Hohenberg-Kohn theorems. Kohn-Sham equations and self-consistent field methods. Applications in calculating electronic structure, total energy, and forces. Exchange-Correlation Functionals:LDA, GGA, and hybrid functionals.Plane-Wave and Pseudopotential Methods: Use of plane waves and pseudopotentials in solving DFT equations.Quantum simulations using codes like VASP and Quantum ESPRESSO. Applications of DFT: Structural optimization, band structure calculations, and defect studies. | 8 | Students will be able to set up and perform Density Functional Theory (DFT) calculations using a widely-used computational package to predict fundamental electronic and structural properties of materials (e.g., band structure, density of states, equilibrium lattice parameters), and critically interpret the results. |
| V | **Simulation of Material Properties**<br>**:** Calculation of stress-strain relationships. Defects and Dislocations: Study of point defects, dislocations, and grain boundaries in materials. Impact of defects on mechanical properties. Phase Transitions and Material Behavior: Simulation of phase changes, crystallization, melting, and amorphization. Nucleation and growth mechanisms in materials. | 10 | Students will be able to perform atomistic simulations to predict and analyze the elastic constants, physical and mechanical properties of materials. |

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| **Course Outcome** | • The Students will be able to<br>• Design and set up simulation cells, including defining atomic positions, boundary conditions, and initial velocities/temperatures.<br>• Calculate and interpret various material properties from simulation trajectories, such as radial distribution functions, diffusion coefficients, elastic constants, thermal conductivity, and phase transitions.<br>• Simulate phenomena such as diffusion, phase transformations, defect interactions, mechanical deformation, and thermal transport at the atomic level.<br>• Predict material properties that are challenging or expensive to obtain experimentally |

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| **Learning Resources** | 1. "Atomistic Simulations of Materials" by Zhiqiang Wang<br>2. "Molecular Dynamics Simulation of Nanostructured Materials: An Understanding of<br>Mechanical Behavior" By Snehanshu Pal, Bankim Chandra Ray<br>3. "Molecular Dynamics for Materials Modeling: A Practical Approach Using LAMMPS Platform" By Snehanshu Pal, K. Vijay Reddy |

## PSE: Materials Science and Engineering

| Course Code | MM5121N | Course Name | Functional Materials | Course Category | PSE | L | T | P |
|---|---|---|---|---|---|---|---|---|
| | | | | | | 3 | 0 | 0 |

| Pre-requisite Courses | Physics of Materials | Co-requisite Courses | Thermodynamics | Progressive Courses | |
|---|---|---|---|---|---|
| Course Offering Department | | Metallurgy and Materials Engineering | | Data Book / Codes/Standards | |

| Course Objective | The course objectives include understanding fundamental concepts of different classes of functional materials. Understanding different synthesis approaches and characterization techniques. Exploring the diverse applications of functional materials. |
|---|---|

| Module | Syllabus | Duration (class-hour) |
|---|---|---|
| I | Overview of functional Materials, structure properties and their classification. | 02 |
| II | Ferroelectric, Piezoelectric and Piezoelectric Materials: Perovskite structure and spontaneous polarization, relationship of ferroelectrics and piezoelectric to crystal symmetry, Devices based on piezoelectric property, Piezoelectric composites, pyroelectric materials and devices | 10 |
| III | **Shape Memory Alloys:** Structural Thermo-elastic Phase Transition in Shape Memory Alloys, Dependency Between Microstructure and Elastic Behavior of SMA, Discontinuous Change of Physical Properties— Martensitic Phase Transition, Different Approaches to Describe the Shape- Memory Effect, Quantitative Models for Shape Memory Alloys | 08 |
| IV | **Magnetorheological and Electrorheological Fluids:** Viscoelastic Properties and Basic Rheology, Some Rheological Models, Understanding the Microscopic Structure of ERF and MRF, ER- and MR-effect Explained by the Interaction of Induced Dipoles, Applications—Switchable Fluid Acting as a Valve | 08 |
| V | **Nanostructured functional materials:** Semiconducting oxide films, Metallic nanoparticles, Carbon-based nanostructured materials for energy storage and conversion | 06 |
| VI | Functionally graded materials and their applications. | 06 |
| | Total contact hours | **42** |

| Course Outcome | ➢ After the completion of the course the students will be able will be able to apply their knowledge to solve problems related to functional materials, including designing, synthesis and characterization of functional materials for devices.<br>➢ Students will also develop critical thinking skills to evaluate and understand the scientific literature related to nanomaterials. |
|---|---|

| Learning Resources | ➢ The Physics of Multifunctional Materials Concepts, Materials, Applications, Martin Gurka |
|---|---|

| | |
|---|---|
| | ➢ Nanostructure Multifunctional Materials by Esteban A. Franceschini |

| Course Code | MM5122N | Course Name | Composite Materials | Course Category | PSE | L | T | P |
|---|---|---|---|---|---|---|---|---|
| | | | | | | 3 | 0 | 0 |
| Pre-requisite Courses | NIL | Co-requisite Courses | | NIL | Progressive Courses | NIL | | |
| Course Offering Department | | Metallurgy and Materials Engineering | | Data Book / Codes / Standards | | | NIL | |

| | |
|---|---|
| **Course Objective** | The objective is to equip students with the advanced knowledge of fundamentals of composite materials, design and analysis, innovation and newer applications, problem-solving and project development. They can work in industries that develop and apply composite materials, such as aerospace, automotive, or energy and apply knowledge to consulting or entrepreneurial ventures related to composite materials. In summary, this course aims to produce highly skilled professionals who can contribute to the advancement of composite materials and their applications in various industries. |

| Module | Syllabus | Duration (h) | Module Outcome |
|---|---|---|---|
| I | **Introduction**<br>Definition of composite material, Classification of composite materials, Reinforcements and matrices, Types of reinforcements, Types of matrices, Types of composites, Dispersion strengthened, particle reinforced and fiber reinforced composites, applications. | 04 | Understanding the basics of composite materials |
| II | **Design of Composites**<br>In-situ and ex-situ composites; Interfaces between reinforcements and matrices in composites; Bonding Mechanisms, Bond Strength, Interfacial Toughness. | 04 | Understanding the design and bonding mechanisms of composite materials |
| III | **Manufacturing Methods**<br>Polymer Matrix Composites: Polymer Matrices, Processing Techniques, Glass Reinforced Plastics, Carbon Fiber Composites; Metal Matrix Composites; Metal Matrices, Processing Techniques, Interfacial Controls, Discontinuously Reinforced Composites, Fiber Composites; Ceramic Matrix Composites: Ceramic Matrices, Processing Techniques, Alumina Matrix Composites, Glass Matrix Composites. | 08 | Understanding the manufacturing methods of various composites |
| IV | **Mechanical Properties**<br>Strengthening mechanisms, Properties of composites: Elastic Properties, Strength and toughness, Geometrical aspects – volume and weight fraction. Unidirectional continuous fibre, discontinuous fibers, Short fiber systems, woven reinforcements – Mechanical Testing: Determination of stiffness and strengths of unidirectional composites; tension, compression, flexure and shear. | 08 | Understanding the mechanical properties of composite materials |
| V | **Laminates**<br>Plate Stiffness and Compliance, Assumptions, Strains, Stress Resultants, Plate Stiffness and Compliance, Computation of Stresses, Types of Laminates -, Symmetric Laminates, Antisymmetric Laminate, Balanced Laminate, Quasi-isotropic Laminates, Cross-ply Laminate, Angle-ply Laminate. Orthotropic Laminate, Laminate Moduli, Hygrothermal Stresses | 08 | Understanding the different laminates and their stress-strain behaviour |
| VI | **Joining Methods and Failure Theories**<br>Joining – adhesive and mechanically fastened joints, advantages and disadvantages. Typical bond strengths and test procedures. | 06 | Understanding the joining methods and failure theories of composite joints |

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|---|---|---|---|
| VII | **Recent Developments**<br>Self-healing (Repairing) composites, Nano-composites, Bio-composites and their usefulness. | 04 | Understanding the recent developments in composites |
| **Total contact hours** | | **42** | |

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| **Course Outcome** | Upon completing a course in Composite Materials, students are expected to apply knowledge to design, analyse and develop innovative solutions to complex problems to achieve common goals related to composite materials. The learners will be well-equipped to pursue careers in research, industry, or academia, and make significant contributions to the field of composite materials. |

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| **Learning Resources** | 1. | F. L. Mathews and R. D. Rawlings: Composite Materials: Engineering and Science, Woodhead Publishing Limited. |
| | 2. | K. K. Chawla: Composite Materials: Science and Engineering, Springer. |
| | 3. | T. W. Clyne and D. Hull: An Introduction to Composite Materials, Cambridge University Press. |

## Open Elective

| Course Code | MM5161N | Course Name | Mechanical Behaviour of Engineering Materials | Course Category | OE | L | T | P |
|---|---|---|---|---|---|---|---|---|
| | | | | | | 3 | 0 | 0 |

| Pre-requisite Courses | NIL | Co-requisite Courses | NIL | Progressive Courses | NIL |
|---|---|---|---|---|---|
| Course Offering Department | | Metallurgy and Materials Engineering | | Data Book / Codes/Standards | NIL |

| Course Objective | To develop an in-depth understanding of the mechanical properties, deformation behavior, and failure mechanisms of engineering materials, enabling students to analyze the influence of microstructure, loading conditions, and environmental factors on strength, toughness, fatigue, and fracture for advanced material design and application. |
|---|---|

| Module | Syllabus | Duration (h) | Module Outcome |
|---|---|---|---|
| I | **Introduction to deformation and failure**<br>Concept of stresses and strains; Engineering and true stresses and strains; Different types of loading and temperatures encountered in engineering applications; Mechanical behaviour and failure of metals, alloys, ceramics, polymer and composites materials. | **4** | Understand stress-strain behavior under various loading, temperature and application conditions, and evaluate the mechanical response and failure mechanisms of various engineering materials. |
| II | **Elastic deformation**<br>State of stress and strain; Principal stress and strain; elastic stress-strain relation; Elastic behaviour of engineering materials. | **6** | Analyze elastic deformation in engineering materials by understanding stress and strain states, principal stresses and strains, and elastic stress-strain relationships to evaluate material response under elastic loading conditions. |
| III | **Plastic deformation**<br>Plastic stress-strain relation; Hydrostatic and deviatoric stress; Octahedral stress; Effective stress and strain; Yield criteria; Mohr circle. | **6** | Explain plastic stress-strain behavior, distinguish hydrostatic and deviatoric stress components, interpret octahedral and effective stress-strain, apply yield criteria, and construct Mohr's circle to understand material response under complex loading conditions. |
| IV | **Mechanisms of plastic deformation**<br>Crystal defects; Dislocation; Geometrical and statistical dislocations; Dislocation multiplication; Dislocation reactions; Slip and twinning; Critical resolved shear stress; Strain hardening; Hall-Petch relationship. | **6** | Explain the mechanisms of plastic deformation by analyzing crystal defects, dislocation behavior, slip and twinning, strain hardening, and the Hall-Petch relationship to understand how microstructural features influence the strength and deformation of engineering materials. |
| V | **Fatigue**<br>Types of dynamic loading; S-N curves; Classification of fatigue; Fatigue of engineering materials; Mechanisms of | **6** | Understand types of dynamic loading, interpret S-N curves, classify fatigue, understand fatigue behavior in engineering materials, and apply |

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|---|---|---|---|
| | fatigue failure; Fatigue life prediction | | failure mechanisms to predict fatigue life and enhance material performance under cyclic loading conditions. |
| VI | **Creep**<br>Time dependent deformation; Different stages of creep; Creep and stress rupture; Creep mechanisms and maps; Design of materials for high temperature applications | **6** | Explain time-dependent deformation, stages of creep, stress rupture behavior, underlying creep mechanisms and maps, and apply this knowledge to select and design materials suitable for high-temperature applications. |
| VII | **Fracture**<br>Fracture in engineering materials; Modes and mechanisms of fractures; Linear elastic fracture mechanisms; Elastic-plastic fracture mechanisms; Measurement of fracture toughness. | **8** | Analyze fracture behavior in engineering materials, including fracture modes and mechanisms, apply linear elastic and elastic-plastic fracture mechanics principles, and evaluate fracture toughness to assess material reliability and failure resistance. |
| | **Total** | **42** | |

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| **Course Outcome** | Upon successful completion, students will:<br>CO1: Understand stress-strain behavior under various loading and temperature conditions, and evaluate elastic and plastic deformation of different engineering materials.<br>CO2: Analyse plastic deformation mechanisms including dislocation dynamics, strain hardening, and yield criteria, and assess their influence on material strength and ductility.<br>CO3: Understand fatigue, creep, and fracture mechanisms in engineering materials, and apply this knowledge to predict material performance and failure under long-term or cyclic loading in critical applications. |

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|---|---|
| **Learning Resources** | Dieter, G.E. (1988) ***Mechanical Metallurgy***. 3rd edn. London: McGraw-Hill.<br>Hertzberg, R.W., Vinci, R.P. and Hertzberg, J.L. (2020) ***Deformation and Fracture Mechanics of Engineering Materials***. 6th edn. Hoboken, NJ: Wiley.<br>Hosford, W.F. (2010) ***Mechanical Behavior of Materials***. 2nd edn. Cambridge: Cambridge University Press.<br>Meyers, M.A. and Chawla, K.K. (2009) ***Mechanical Behavior of Materials***. 2nd edn. Cambridge: Cambridge University Press.<br>Hosford, W.F. (2010) ***Mechanical Behavior of Materials***. 2nd edn. Cambridge: Cambridge University Press.<br>Suresh, S. (1998) ***Fatigue of Materials***. 2nd edn. Cambridge: Cambridge University Press.<br>**Dyson, B.F. and McLean, M. (2003)** ***Creep Deformation and Fracture*****.** Warrendale, PA: ASM International. |

| Course Code | MM5162N | Course Name | Selection of Engineering Materials | Course Category | OE | L | T | P |
|---|---|---|---|---|---|---|---|---|
| | | | | | | 3 | 0 | 0 |

| Pre-requisite Courses | *NIL* | Co-requisite Courses | *NIL* | Progressive Courses | *NIL* |
|---|---|---|---|---|---|
| **Course Offering Department** | | Metallurgy and Materials Engineering | | **Data Book / Codes/Standards** | *NIL* |

| Course Objective | The main objective of the course is to allow students to develop a systematic procedure for selecting materials for structural, thermal, electrical and magnetic applications |
|---|---|

| Module | Syllabus | Duration (class-hour) | Duration (h) |
|---|---|---|---|
| I | Classification of materials and introduction to material property charts | 3 | Students will be able to classify materials, and have preliminary understanding of material property charts |
| II | Design-linked strategy of selecting materials and processes | 3 | Students will be able to understand the strategies for selecting materials and processes |
| III | Review of Mechanical properties of materials: concepts of stress and strain, stress versus strain curve of elastoplastic materials, | 6 | Students will review mechanical properties of materials associated with elastoplastic deformation |
| IV | Structural or Load-bearing materials: Stiffness-limited design, Strength-limited design, Material indices for yield-limited design | 6 | Students will be able to derive material indices associated with different mechanical responses. |
| V | Thermal materials: Review of thermal properties of materials, Thermal property charts, Case studies of material selection based on thermal properties | 6 | Students will review thermal properties and will be able to select materials based on thermal requirements of the product/application. |
| VI | Electrical materials: Review of electrical properties, Charts for electrical properties, Case studies of selection of materials using electrical properties | 6 | Students will review electrical properties and will be able to select materials based on electrical requirements of the product/application. |
| VII | Magnetic materials: Review of magnetic properties, Charts for magnetic properties, Case studies of materials selection for magnetic design | 6 | Students will review magnetic properties and will be able to select materials based on magnetic requirements of the product/application. |

| Course Outcome | CO1: On completion of the course, the students should gain an understanding of material selection as an integral part of the design process<br>CO2: On completion of the course, the students should be able to interpret material property charts and use appropriate material indices based on the requirement of design |
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| | CO3: On completion of the course, the students should be able to select appropriate materials for applications that involve mechanical deformation or are subject to temperature fields/electrical fields/magnetic fields. |

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| **Learning Resources** | **Materials: Engineering, Science, Processing and Design**, Michael Ashby, Hugh Shercliff, and David Cebon, Butterworth-Heinemann, 4th edition<br><br>**Materials Selection in Mechanical Design**, Michael F. Ashby, Butterwoth-Heinemann, 6th edition<br><br>**Materials Science and Engineering: An Introduction**, William D. Callister Jr. and David G. Rethwisch, Wiley, 10th edition |

**Practical Subject (**Machine Learning in Materials Engineering & Materials Science and Engineering**)**

| *Course Code* | MM5171N | *Course Name* | Materials Technology Lab. | *Course Category* | PC | L | T | P |
|---|---|---|---|---|---|---|---|---|
| | | | | | | 0 | 0 | 3 |

| *Pre-requisite Courses* | *NIL* | Co-requisite Courses | *Nil* | Progressive Courses | MM5101N |
|---|---|---|---|---|---|
| Course Offering Department | | **Metallurgy and Materials Engineering** | | Data Book / Codes/Standards | **ASTM E407-23, E384-23,** E8M-23, **E23-18** |

| **Course Objective** | To develop practical skills in metallographic sample preparation, microstructural characterization, mechanical testing, and fracture analysis to evaluate the structure–property relationship of ferrous and non-ferrous engineering materials using standard laboratory techniques. |
|---|---|

| Lab. | Syllabus | Duration (h) | Lab. Outcome |
|---|---|---|---|
| *I* | ***Metallographic Sample preparation -I:*** Sectioning, Mounting, Grinding, and Polishing. | 3 | **Prepare metallographic samples** using sectioning, mounting, grinding, and polishing to obtain smooth, defect-free surfaces for microstructural analysis. |
| *II* | ***Metallographic Sample preparation -II:*** Fine polishing, Electropolishing, and Etching | 3 | **Apply various polishing and etching** techniques to reveal microstructural features essential for accurate metallographic analysis of engineering materials. |
| *III* | **Optical Microscope and microstructural characterization** | 3 | **Use optical microscopy** to examine microstructures and identify phases, grain boundaries, and features relevant to material properties and processing. |
| *IV* | **Macro- and micro-structure of cast alloys** | 3 | Examine and interpret the macro- and microstructural features of cast alloys to understand solidification patterns, phase distribution, and structural integrity. |
| *V* | **Microstructure of ferrous materials** | 3 | Identify and interpret the microstructural features of ferrous materials, including phases and phase transformations, to understand their influence on mechanical properties and processing behavior. |
| *VI* | **Microstructures of non-ferrous materials** | 3 | Interpret microstructures of non-ferrous materials to assess their composition, phases, and processing history using standard metallographic and microscopy techniques. |
| *VII* | **Image Analyses: Measurement of Grain size and Phase content** | 3 | Perform image analysis to accurately measure grain size and phase content, enabling quantitative evaluation of microstructural characteristics in engineering materials. |
| *VIII* | **Hardness Test-I:** | 3 | Conduct Rockwell and Brinell tests to assess |

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| | **Rockwell and Brinell** | | material hardness and select appropriate indenter, load, and scale. |
| *IX* | **Hardness Test-I: Vickers** | 3 | Perform the Vickers hardness test and interpret the results to evaluate material hardness and understand its correlation with microstructure and mechanical properties. |
| *X* | **Microhardness Test** | 3 | Conduct Vickers microhardness testing to evaluate phase-specific hardness variations in multiphase materials |
| *XI* | **Tensile Test** | 3 | Perform tensile tests on materials like mild steel and copper, and interpret stress-strain data to determine yield strength, tensile strength, elongation, and strain hardening exponent. |
| *XII* | **Impact Test** | 3 | Analyze the influence of heat treatment and steel composition on Charpy impact toughness to understand the ductile-to-brittle transition temperature |
| *XIII* | **Analyses of Fractured surfaces** | 3 | Interpret SEM fracture surfaces to distinguish ductile and brittle modes and relate features to failure mechanisms. |
| *XIV* | **Test and Viva** | 3 | Assess practical understanding of material characterization techniques and mechanical testing methods through structured oral examination. |
| | **Total contact hours** | **42** | |

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| **Course Outcome** | On completion of the course, the students should be able to<br>**CO1:** Develop practical skills in metallographic sample preparation and use optical microscopy with image analysis to evaluate grain size, phase distribution, and microstructural features in ferrous and non-ferrous alloys.<br>**CO2:** Conduct mechanical tests including hardness, tensile, and impact testing, and interpret fractured surfaces to understand material behavior and failure mechanisms.<br>**CO3**: **Demonstrate critical thinking,** collaborative laboratory work, **and** effectively communicate findings through technical reports. |

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| **Learning Resources** | ASTM International (2023) ***Annual Book of ASTM Standards: Metals Test Methods and Analytical Procedures***. West Conshohocken, PA: ASTM International.<br>Vander Voort, G.F. (ed.) (2004) ***Metallography and Microstructures***. ASM Handbook, Vol. 9. Materials Park, OH: ASM International.<br>**In-house Laboratory Manuals**<br>**Virtual Labs** (NPTEL/VTU Virtual Lab) |

| *Course Code* | MM5172N | *Course Name* | Material Characterization Lab. | *Course Category* | *PC* | L | T | P |
|---|---|---|---|---|---|---|---|---|
| | | | | | | 0 | 0 | 2 |
| *Course Offering Department* | | Metallurgy and Materials Engineering | | *Requisite Courses* | | | *Nil* | |

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|---|---|
| **Course Objective** | • To provide hands-on experience with advanced material characterization equipment and techniques.<br>• To teach experimental design, data acquisition, and interpretation related to material structure, composition, and morphology.<br>• To bridge the gap between theoretical knowledge and real-world applications of characterization tools. |

| Module | Syllabus | Duration (h) |
|---|---|---|
| *I & II* | X-ray diffraction pattern analysis: Crystal structure, size and precise lattice parameter determination. | 06 |
| *III & IV* | Optical microscopy: Sample preparation and microstructural characterization. | 09 |
| *V & VI* | Electron Microscopes: Scanning Electron Microscopes and Transmission Electron microscopes, Image and diffraction pattern analysis | 09 |
| *VII & VIII* | Scanning probe Microscope: Scanning tunnelling microscope, Atomic force microscope, Magnetic force microscope demonstration | 09 |
| *IX & X* | Thermal Characterization techniques: DSC, DTA-TGA demonstration and analysis | 06 |
| *XI* | Test and Viva | 3 |
| | **Total contact hours** | **42** |

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|---|---|
| **Course Outcome** | At the end of this course, students will be able to:<br>• Basic knowledge about operating key characterization instruments like<br>• XRD, SEM, AFM, and spectrometers.<br>• Prepare samples and perform measurements.<br>• Analyze and interpret real experimental data.<br>• Choose suitable characterization methods for various material systems. |

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| **Learning Resources** | B.D Cullity: Elements of x- ray diffraction<br>Yang Leng: Materials Characterization: Introduction to Microscopic and Spectroscopic Methods<br>David B Williams, C. Barry Carter, Transmission Electron Microscopy |

| *Course Code* | **MM5173N** | *Course Name* | **Mini Project/Machine Learning in Materials Lab** | *Course Category* | *PC* | L | T | P |
|---|---|---|---|---|---|---|---|---|
| | | | | | | 0 | 0 | 2 |
| *Course Offering Department* | | **Metallurgy and Materials Engineering** | | *Requisite Courses* | | *NIL* | | |

| **Course Objective** | |
|---|---|
| | 1. Students will learn data preprocessing and feature engineering specific to materials datasets (e.g., crystallographic, spectroscopic, mechanical properties).<br>2. Students will learn to use ML algorithms to predict material properties, discover new materials, and optimize processing parameters.<br>3. Students will learn to use tools and programming environments (e.g., Python, scikit-learn, TensorFlow, Matminer) commonly used in materials informatics. |

| Module | Syllabus | Duration (h) |
|---|---|---|
| *I & II* | Setting up a Python environment (Anaconda/Google Colab), Writing basic Python scripts, Loading and visualizing materials datasets using Pandas and Matplotlib. | 06 |
| *III & IV* | Work with materials databases (e.g., Materials Project), Perform data cleaning and visualize distributions of key material properties, Identify key features affecting material properties (e.g., composition, structure) | 06 |
| *V & VI* | Predict material properties (e.g., hardness, conductivity) from composition and structure, Implement and compare models for prediction using scikit-learn, Hyperparameter tuning and cross-validation. | 06 |
| *VII & VIII* | Use SVM to classify materials based on performance (e.g., brittle vs. ductile materials). | 06 |
| *IX & X* | Build a simple neural network for regression or classification (e.g., predicting material properties from structure/composition). | 06 |
| | **Total contact hours** | **30** |

| **Course Outcome** | |
|---|---|
| | 1. Students will be able to Apply machine learning algorithms to analyze and interpret materials science data sets.<br>2. Develop predictive models for material properties using supervised learning techniques.<br>3. Implement unsupervised learning methods (e.g., clustering, dimensionality reduction) to explore and classify materials data.<br>4. Use open-source ML libraries (e.g., Scikit-learn, Matplotlib, Pandas, Matminer) to build reproducible data-driven workflows.<br>5. Evaluate model performance using appropriate metrics and improve models through hyperparameter tuning and feature selection. |

# Syllabus: Second Semester

## Core Subject (Machine Learning in Materials Engineering & Materials Science and Engineering)

| Course Code | MM5201N | Course Name | Manufacturing Processes | Course Category | PC | L | T | P |
|---|---|---|---|---|---|---|---|---|
| | | | | | | 3 | 0 | 0 |

| Pre-requisite Courses | *NIL* | Co-requisite Courses | *NIL* | Progressive Courses | *NIL* |
|---|---|---|---|---|---|
| Course Offering Department | | Metallurgy and Materials Engineering | | Data Book / Codes/Standards | *NIL* |

| Course Objective | Equip students with a deep understanding of scientific principles in manufacturing processes relevant to metallurgy and materials engineering, enabling analysis of material-process interactions. Introduce advanced technologies like Semi-conductor manufacturing and additive manufacturing, focusing on their applications. |
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| Module | Syllabus | Duration (class-hour) |
|---|---|---|
| I | Overview of manufacturing science, materials behaviour, processing-structure-property relationships, classification of manufacturing processes | 4 |
| II | Principles of casting, solidification mechanisms, casting processes (sand, die, investment), defects and quality control | 6 |
| III | Plastic deformation, bulk forming (rolling, forging, extrusion), sheet metal forming, | 8 |
| IV | Powder metallurgy processes: Metal powder production & characterization, powder blending, powder compaction, sintering, applications | 4 |
| V | Joining Process: Arc Welding, Resistance welding, High energy beam welding, solid state welding, brazing, adhesive bonding | 8 |
| VI | Semiconductor manufacturing: Crystal growth and wafer preparation, Ion Implantation, Photolithography, Thin Film Deposition, Etching, Metallization, Packaging | 6 |
| VII | Additive manufacturing: Fundamentals of additive manufacturing VAT photopolymerization, Material Jetting, Material extrusion, direct energy deposition | 4 |

| Course Outcome | Students will learn and analyze the scientific principles and material-process interactions in manufacturing processes like casting, forming, powder metallurgy, and additive manufacturing, evaluating and designing processes for specific applications. They will apply advanced techniques, such as additive manufacturing, to address modern engineering challenges, optimizing performance, cost, and sustainability. |
|---|---|

| Learning Resources | 1. Materials Processing and Manufacturing Science,<br>Authors: Rajiv Asthana, Ashok Kumar, Narendra B. Dahotre<br>2. Manufacturing Technology: Materials, Processes, and Equipment<br>Authors: Helmi A. Youssef, Hassan A. El-Hofy, Mahmoud H. Ahmed |
|---|---|

| Course Code | MM5202N | Course Name | Mechanical Behaviour of Materials | Course Category | PC | L | T | P |
|---|---|---|---|---|---|---|---|---|
| | | | | | | 3 | 0 | 0 |

| Pre-requisite Courses | *NIL* | Co-requisite Courses | *NIL* | Progressive Courses | *NIL* |
|---|---|---|---|---|---|
| **Course Offering Department** | | Metallurgy and Materials Engineering | | **Data Book / Codes/Standards** | *NIL* |

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|---|---|
| **Course Objective** | 1. **Analyze the elastic and plastic response** of materials using fundamental elasticity and plasticity theories<br>2. **Explain the microstructural basis of plasticity** utilising the concepts of resolved shear stress in single crystals and the role of defects in crystalline materials<br>3. **Evaluate and analyze the role of Strengthening Mechanisms,** including strain hardening, grain boundary effects (Hall-Petch), solid solution strengthening, and second-phase/precipitation hardening.<br>4. **Analyze fracture behaviour** in materials in light of fracture mechanics and toughening mechanisms |

| Module | Syllabus | Duration (h) |
|---|---|---|
| I | **Review of Basic Mathematics**<br>Vectors and tensors, dot and cross products; rotation of vectors and tensors; calculation of eigenvalues and eigenvectors; introduction to programming using MATLAB | 04 |
| II | **Theory of Elasticity**<br>Definition of stress and strain in 2-dimensions and in 3-dimensions; Mohr's circle of stress in two-dimensions; hydrostatic and deviatoric components of stress and strain; conversion of stresses to strains and vice-versa in elastic regime; Definition of elastic stiffness tensor for anisotropic materials; Micromechanics of linear elastic composites | 08 |
| III | **Theory of Plasticity**<br>Yield criteria in metals, ceramics and polymers; yield locus in 2D and in 3D; Octahedral stresses and strains; Levi-Mises and Prandtl-Reuss equations; yielding of anisotropic materials; | 08 |
| IV | **Microstructural Aspects of Plasticity**<br>Plasticity in single crystals; calculation of critical resolved shear stress; use of stereographic projection; Dislocations, interaction of dislocations; Twins; Stacking Faults | 08 |
| V | **Strengthening Mechanisms**<br>Strain hardening, grain boundary strengthening, solid solution strengthening, second phase strengthening | 04 |
| VI | **Fracture**<br>Fracture mechanisms, linear elastic fracture mechanics, toughening mechanisms | 08 |
| | **Total contact hours** | 40 |

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| **Course Outcome** | 1. **Apply Mathematical Frameworks** employing computational tools like MATLAB for analyzing material behaviours<br>**2. Analyze and study material behaviour** applying the theory of elasticity and plasticity under practical applications.<br>**3. Design microstructure and materials** to improve mechanical properties utilising the knowledge of various strengthening mechanisms<br>**4. Analyze failures in materials** across length scales |

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| ***Learning Resources*** | **Mechanical Behaviour of Materials**, T. H. Courtney, Waveland Press Deformation and **Fracture Mechanics of Engineering Materials**: R.W. Hertzberg, John Wiley and Sons **Mechanical Metallurgy, G.E. Dieter**, McGraw-Hill<br>**Mechanical Behavior of Materials**: M.A. Meyers, K K. Chawla, Cambridge Press Physical Properties of Crystals: Their Representation by Tensors and Matrices, J. Nye, Clarendon Press<br>**Getting Started with MATLAB,** R. Pratap, Oxford University Press |

| Course Code | MM5203N | Course Name | Multiscale Materials Modelling | Course Category | PC | L | T | P |
|---|---|---|---|---|---|---|---|---|
| | | | | | | 3 | 0 | 0 |

| Pre-requisite Courses | *Nil* | Co-requisite Courses | *Nil* | Progressive Courses | *Nil* |
|---|---|---|---|---|---|
| Course Offering Department | | Metallurgy and Materials Engineering | | Data Book / Codes/Standards | |

| Course Objective | |
|---|---|
| | 1. **Understand the fundamentals** of materials modeling across different length and time scales (from electronic to continuum).<br>2. **Explore computational techniques** such as ab initio (first principles), molecular dynamics (MD), Monte Carlo (MC), and finite element methods.<br>3. **Develop skills in coupling methods** that integrate different scale models (e.g., quantum–atomistic, atomistic–mesoscopic).<br>4. **Apply multiscale modeling tools** to analyze mechanical, thermal, electrical, and optical properties of materials.<br>5. **Interpret simulation results** and correlate them with experimental data. |

| Module | Syllabus | Duration (class-hour) | |
|---|---|---|---|
| I | Mathematical description of physical phenomena-basics of partial differential equations, statistical techniques and numerical analysis. Basics of optimization schemes: Simplex method, Steepest-descent Method, Conjugate Gradient Method, Newton-Raphson Method and Genetic Algorithm based schemes. | 06 | Basics of mathematical tool as applicable to the materials modelling. |
| II | Schemes of modelling- empirical, phenomenological and mechanistic approach of modelling. Deterministic, stochastic and probabilistic modelling approach of materials modelling. | 06 | Hierarchy of mathematical modelling and simulations for the problem formulation. |
| III | Quantum mechanics-based materials modelling approach – Applications of Density Functional Theory in materials modelling. Issue of convergence in Density Functional Theory calculations. | 03 | Basics of the quantum mechanics-based materials modelling. |
| IV | Atomistic modelling approaches. Classical interatomic potentials and their application for simulation of materials. Basics of Molecular Dynamics and Monte Carlo approach. | 02 | Understanding of atomistic modelling approach and its applications in materials engineering. |
| V | Mesoscale approach for materials modelling- Basics of Finite Difference and Finite Element Method. Application of Finite Element Method for studying multi-physics phenomena. Cellular Automata and its application in Materials Engineering. | 03 | Understanding about mesoscale materials modelling approach and their application for modelling the microstructural phenomena. |

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| VI | Coupling of scales for development of multiscale materials models for structure-property correlation in materials science and manufacturing. Uncertainty quantification in multiscale modelling-traditional and Bayesian approaches. | 05 | Basics of the bridging between various modelling schemes at range of spatiotemporal scale and error propagation schemes. |
| VII | Case-studies:<br>1. Integrated Computational Materials Engineering (ICME) approach for studying plasticity in materials.<br>2. Multiscale modelling of design of high temperature material for turbine applications. | 05 | Application of various modelling and simulation schemes for the industrial relevant applications. |

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| **Course Outcome** | 1. **Explain key concepts** of different modeling approaches and their applicable scales (e.g., DFT at quantum scale, MD at atomistic scale).<br>2. **Select appropriate models** and techniques for analyzing a given materials problem across multiple scales.<br>3. **Analyze and interpret simulation data**, identifying limitations and sources of error across scales.<br>4. **Implement coupling strategies** to link models at different scales (e.g., quantum-to-continuum approaches).<br>5. **Demonstrate problem-solving ability** in case studies involving real-world material systems (e.g., metals, polymers, composites). |

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| **Learning Resources** | 1. Multiscale materials modelling: Fundamentals and applications, Z. Xiao Guo, CRC press.<br>2. Multiscale Modelling: A Bayesian Perspective, Springer.<br>3. Integrated Computational Materials Engineering (ICME) for Metals: Using multiscale modelling to invigorate engineering design with science, M.E. Horstemeyer, Wiley.<br>4. Molecular Modelling: Principles and Applications, Andrew R. Leach, Pearson |

## PSE: Machine Learning in Materials Engineering

| Course Code | MM5224N | Course Name | Deep learning for materials engineering | Course Category | PSE | L | T | P |
|---|---|---|---|---|---|---|---|---|
| | | | | | | 3 | 0 | 0 |

| Pre-requisite Courses | *NIL* | Co-requisite Courses | *NIL* | Progressive Courses | *NIL* |
|---|---|---|---|---|---|
| Course Offering Department | | Metallurgy and Materials Engineering | | Data Book / Codes/Standards | *NIL* |

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| **Course Objective** | 1. Students will grasp the core concepts of deep learning, including neural networks, backpropagation, activation functions, and optimization techniques.<br>2. Students will implement machine learning and deep learning models to analyze experimental and computational materials datasets.<br>3. Students will use deep learning to discover and predict relationships between material structures, processing parameters, and resulting properties.<br>4. Students will employ deep learning frameworks for inverse design and property optimization in materials engineering.<br>5. Students will develop the ability to work in interdisciplinary teams, bridging materials science, computer science, and data analytics. |

| Module | Syllabus | Duration (h) |
|---|---|---|
| I | **Introduction to Deep Learning:** Role of Data Science and Machine Learning in MSE, Basics of Deep Learning: Neural Networks, Activation Functions, and Backpropagation, Introduction to Python for Deep Learning (libraries: Tensor Flow, Keras, PyTorch). | 05 |
| II | **Materials Data Representation**: Types of Materials Data: Experimental Data, Simulation Data, Databases, Feature Engineering for Materials Science: Atomic Structures, Crystal Graphs, and Descriptors, Data Preprocessing: Normalization, Scaling, and Encoding, Data Splitting, Cross-validation, and Performance Metrics (Accuracy, Precision, F1-score) | 05 |
| III | **Neural Networks and Architectures for Materials Science**: Multi-layer Perceptrons (MLP) for Materials Property Prediction, Convolutional Neural Networks (CNNs) for Image-based Materials Data (e.g., microscopy images), Recurrent Neural Networks (RNNs) for Time-series Data (e.g., material degradation over time), Transfer Learning and Fine-tuning for Materials Data | 05 |
| IV | **Generative Models for Materials Design**: Introduction to Generative Adversarial Networks (GANs), Variational Autoencoders (VAEs) for Material Generation,<br>Application of Generative Models for Predicting New Materials, Case Studies: Designing Novel Alloys, Polymers, or Catalysts | 05 |
| V | **Deep Learning for Microstructure and Process-Property Relations**: Image Analysis of Microstructures: CNNs for Material Characterization, Predicting Process-Property Relations (e.g., temperature, pressure effects), Multi-scale Modeling with Deep Learning, Case Study: Predicting the Effect of Processing on Microstructure and Mechanical Properties | 8 |
| VI | **Transfer Learning in Materials Science**: The theory of transfer learning: source and target domains. Types of transfer learning: inductive, trans-ductive, and unsupervised. Domain adaptation and domain generalization. | 4 |
| VII | **Integration of Deep Learning with Quantum Mechanics and Molecular Simulations**: Deep learning for electronic structure predictions (e.g., predicting HOMO-LUMO gaps, charge densities), Deep learning for electronic structure calculations (energy, wave functions) | 4 |

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|---|---|---|
| VIII | **AI-driven Materials Engineering in Industry**: AI in manufacturing: additive manufacturing, casting, forging, Process optimization using AI: predictive modeling and process control, Industry 4.0 and smart factories in materials engineering | 4 |
| | **Total contact hours** | **40** |

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| **Course Outcome** | 1. Students will be able to describe the foundational principles of deep learning and their relevance to materials engineering problems.<br>2. Students will be able to preprocess, analyze, and visualize materials datasets for input into deep learning models.<br>3. Students will be able to design, train, and evaluate deep neural networks using libraries such as TensorFlow or PyTorch.<br>4. Students will be able to apply deep learning models to predict material properties, classify material phases, or simulate microstructural evolution.<br>5. Students will be able to develop and implement inverse design models for discovering materials with targeted properties. |

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| **Learning Resources** | "Deep Learning" by Ian Good fellow, Yoshua Bengio, and Aaron Courville<br>"Neural Networks and Deep Learning: A Textbook" by Charu Aggarwal<br>"Materials Informatics: Data-Driven Discovery in Materials Science" by Rajiv S. Mishra and Akash M. Srivastava<br>"Machine Learning for Materials Informatics: Data-Driven Discovery in Materials Science" by S. S. Pandey, A. A. Hassan, and B. G. Sumpter |

<table>
<tr><td rowspan="2">Course Code</td><td rowspan="2">MM5225N</td><td rowspan="2">Course Name</td><td rowspan="2">Microstructure Modelling for metallic system</td><td rowspan="2">Course Category</td><td rowspan="2">Open Elective</td><td>L</td><td>T</td><td>P</td></tr>
<tr><td>3</td><td>0</td><td>0</td></tr>
<tr><td colspan="3">Course Offering Department</td><td>Metallurgy and Materials Engineering</td><td colspan="3">Pre-requisite Courses</td><td colspan="2">NIL</td></tr>
</table>

| | |
|---|---|
| **Course Objective** | 1. Students will learn fundamental and practical understanding of microstructure evolution in metallic systems through computational modeling techniques.<br>2. Students will learn to simulate and analyze microstructural changes—such as grain growth, phase transformations, and precipitation—using theoretical concepts and numerical methods |

| Module | Syllabus | Duration (h) |
|---|---|---|
| I | **Thermodynamics of Phase Transformation:** Solution thermodynamics, Introduction to CALPHAD thermodynamic modelling, Irreversible Thermodynamics | 8 |
| II | **Modeling of precipitation:** Nucleation, Diffusion controlled growth, Sharp interface theory, Interface controlled growth, JMAK kinetics, Application in Multiparticle precipitation kinetics. | 8 |
| III | **Monte Carlo Potts Model**: Hamiltoninan and dynamics, Ising model, Q-state Potts Model, Application in Grain growth and Recrystallisation | 8 |
| IV | **Phase-field Model:** Concept of diffuse interface, Allen-Cahn equation, Multiphase-field model, Diffusion coupled phase-field model, Application in Solidification, Cahn-Hilliard Model for Phase Separation. | 12 |
| V | **Cellular Automata:** Basic algorithm of Cellular Automata, Coupling of diffusion, Application in Phase Transformation. | 6 |
| | **Total contact hours** | **42** |

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| **Course Outcome** | 1. Students will be able to apply theoretical models such as phase-field, Monte Carlo, and cellular automata to simulate microstructural processes.<br>2. Students will be able to use computational tools to model grain growth, recrystallization, and phase transformations in metals.<br>3. Students will be able to design and optimize microstructures to achieve desired properties in engineering applications using modeling approaches |

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| **Learning Resources** | **Computational Materials Engineering** by Koenraad G. F. Janssens, Dierk Raabe, Ernst Kozeschnik, Mark A Miodownik, Britta Nestler; Elsevier.<br>**Continuum Scale Simulation of Engineering Materials** by Dierk Raabe, Franz Roters, Frederic Barlat, Long-Qing Chen; Wiley-VCH. Methods. |

## PSE: Materials Science and Engineering

| Course Code | MM5221N | Course Name | Design and Selection of Materials | Course Category | PSE | L | T | P |
|---|---|---|---|---|---|---|---|---|
| | | | | | | 3 | 0 | 0 |

| **Pre-requisite Courses** | *NIL* | **Co-requisite Courses** | *NIL* | **Progressive Courses** | *NIL* |
|---|---|---|---|---|---|
| **Course Offering Department** | | Metallurgy and Materials Engineering | | **Data Book / Codes/Standards** | *NIL* |

| **Course Objective** | The main objective of the course is to allow students to develop a systematic procedure for selecting materials that best match the requirements of a product design. |
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| Module | Syllabus | Duration (class-hour) | |
|---|---|---|---|
| I | Classification of materials and processes, Introduction to material property charts | 3 | Students will get a basic understanding of material property charts |
| II | Design-linked strategy of selecting materials and processes | 3 | Students will understand the underlying mechanism for selecting materials and processes for different products/applications |
| III | Review of Mechanical properties of materials: atomic/molecular origin of stiffness, yield criteria, strengthening mechanisms, fracture mechanics, fatigue | 6 | Students will refresh concepts associated with mechanical properties of materials. |
| IV | Selection of materials based on mechanical properties: Stiffness-limited design, Strength-limited design, Material indices for yield-limited design, Material property charts for toughness, Material property charts for fatigue, Fracture-limited design, Material property charts for friction and wear and associated case studies | 9 | Students will understand different material property charts associated with mechanical properties of materials. |
| V | Selection of materials based on thermal properties: Review of thermal properties of materials, Thermal property charts, Case studies of design using thermal properties | 3 | Students will review concepts associated with thermal properties of materials. Students will be able to interpret thermal property charts |
| VI | Selection of creep-resistant materials: Review of creep behaviour and deformation mechanism maps, Charts for creep behaviour, Case studies of design to cope with creep | 6 | Students will review high temperature deformation behaviour and understand material charts for creep |
| VII | Selection of materials based on electrical properties: Review of electrical properties, Charts for electrical properties, Case studies of design using electrical properties | 5 | Students will review basic electrical properties and understand charts associated with electrical properties. |

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| VIII | Selection of materials based on magnetic properties: Review of magnetic properties, Charts for magnetic properties, Case studies of materials selection for magnetic design | 5 | Students will review basic magnetic properties and understand charts associated with magnetic properties. |
| | **Total contact hours** | 40 | |

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| **Course Outcome** | CO1: On completion of the course, the students should gain an understanding of the concept of product design and how material selection is an integral part of the design process<br>CO2: On completion of the course, the students should be able to interpret material property charts and use appropriate material indices based on the requirement of design<br>CO3: On completion of the course, the students should be able to select appropriate materials for applications that involve mechanical deformation or are subject to temperature fields/electrical fields/magnetic fields. |

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| **Learning Resources** | **Materials: Engineering, Science, Processing and Design**, Michael Ashby, Hugh Shercliff, and David Cebon, Butterworth-Heinemann, 4th edition<br>**Materials Selection in Mechanical Design**, Michael F. Ashby, Butterwoth-Heinemann, 6th edition<br>**Materials Science and Engineering: An Introduction**, William D. Callister Jr. and David G. Rethwisch, Wiley, 10th edition |

| Course Code | MM5223N | Course Name | Surface Treatment and Modification | Course Category | PSE | L | T | P |
|---|---|---|---|---|---|---|---|---|
| | | | | | | 3 | 0 | 0 |

| Pre-requisite Courses | *NIL* | Co-requisite Courses | *NIL* | Progressive Courses | *NIL* |
|---|---|---|---|---|---|
| Course Offering Department | | Metallurgy and Materials Engineering | | Data Book / Codes/Standards | *NIL* |

| Course Objective | The students will learn the fundamental of surface treatment and modification techniques that enhance material performance. The students will understand possible techniques to improve properties such as wear resistance, corrosion resistance, and fatigue strength, enabling students to select appropriate processes for extending the life of engineering components in service. |
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| Module | Syllabus | Duration (h) | Module Outcome |
|---|---|---|---|
| I | **Introduction**<br>Conventional Surface Engineering, Types of Surface Modifications, Physical Modifications, Chemical Modifications, Applications of Surface Engineering towards Nanomaterials, Structure, Defects in solids, Bonds and Bands in Materials, Thermodynamics of Materials, Kinetics, Nucleation | 06 | Gain knowledge of surface engineering methods, material structures, thermodynamics, kinetics, and their applications |
| II | **Vacuum Science and Technology**<br>Kinetic Theory of Gases, Gas Transport and Pumping, Vacuum Technology | 06 | Understand kinetic theory, gas transport mechanisms, and vacuum technologies for scientific and industrial applications. |
| III | **Thin-film Evaporation Processes**<br>Physics and Chemistry of Evaporation, Film Thickness Uniformity, Evaporation Processes and Applications | 06 | Understand evaporation physics and chemistry, achieve uniform film thickness, and explore thin-film applications and processes. |
| IV | **Discharges, Plasma, and Ion-Surface Interactions**<br>Plasma Discharges and Arcs, Fundamentals of Plasma Physics, Reactions in Plasmas, Physics of Sputtering, Ion bombardment modification of growing films | 06 | Understand plasma physics, discharges, sputtering, and ion-surface interactions for thin-film growth and material modifications. |
| V | **Chemical Vapor Deposition**<br>Reaction types, Thermodynamics of CVD, Gas transport, Film growth kinetics, Thermal CVD, Plasma-enhanced CVD | 08 | Understand CVD reaction types, thermodynamics, gas transport, and film growth kinetics in thermal and plasma-enhanced processes. |
| VI | **Substrate Surface and Thin-film Nucleation**<br>Atomic view of substrate surface, Thermodynamic aspects of nucleation, Kinetic processes in nucleation and growth | 08 | Learn substrate structure, nucleation thermodynamics, and kinetics of thin-film growth. |
| | | **40** | |

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| **Course Outcome** | Students will be able to understand and analyse various surface treatment techniques, select suitable methods for specific applications, and evaluate their effectiveness in enhancing surface properties like hardness, corrosion and wear resistance, thereby improving the performance and durability of engineering materials. |

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| **Learning Resources** | Materials Science of Thin Films by Milton Ohring<br>Handbook of Surface Improvement and Modification Hardcover – Import, 1 March 2023 by George Wypych<br>Chemical Modification of Solid Surfaces by the Use of Additives, by Ranjan Kumar Mohapatra, Debadutta Das, Md. Azam |

## Open Elective

| Course Code | MM5261N | Course Name | Nanostructures and Nanomaterials | Course Category | OE | L | T | P |
|---|---|---|---|---|---|---|---|---|
| | | | | | | 3 | 0 | 0 |

| Pre-requisite Courses | Physics of Materials | Co-requisite Courses | Thermodynamics | Progressive Courses | *Nil* |
|---|---|---|---|---|---|
| Course Offering Department | | Metallurgy and Materials Engineering | | Data Book / Codes/Standards | |

| Course Objective | Course objectives include understanding fundamental nanoscience concepts, exploring synthesis methods, learning characterization techniques, and examining the diverse applications of nanomaterials. |
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| Module | Syllabus | Duration (class-hour) | Module Outcome |
|---|---|---|---|
| I | Introduction to nanostructures and nanomaterials | 02 | The students will be get an historical overview about the evolution of nanostructures, nanomaterials and its importance for potential application in various advanced technologies. |
| II | Classification of nanomaterials. Effect of size on the properties of materials and nanomaterials. Microstructural features of nanomaterials. Characterization of nanostructures and nanomaterials. | 08 | The students will be able to understand and differentiate between nanostrucutures, nanomaterials and traditional materials. The students will also develop an understanding about the functionalities of this class of materials from the viewpoint of their crystal structure and size effects on the properties of the material. |
| III | Preparation of Nanomaterials by Physical Methods: Inert gas condensation, Arc discharge, Plasma arc technique, Laser ablation, Ball Milling, Chemical vapour deposition, Electro deposition | 06 | The students will be introduced to the different physical techniques for preparing nanomaterials. They will also learn to classify different top down and bottom up approaches |
| IV | Synthesis of Nanomaterials via chemical routes: Chemical precipitation and co-precipitation; Metal nanocrystals by reduction, Sol-gel synthesis; Solvothermal synthesis; Thermolysis, Microwave heating synthesis; Sono-chemical synthesis; Electrochemical synthesis; Photochemical synthesis, Synthesis in supercritical fluids | 08 | The students will be introduced to the different chemical techniques and other advanced processing techniques. |
| V | Properties of nanowires, quantum wells and quantum dots | 06 | The students will learn how quantum confinement affect material properties and impart unique functionalities. |

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| VI | Carbon nanostructures: Synthesis and properties of fullerenes, carbon nanotubes, Graphene | 08 | This module will equip students with the knowledge and skills to understand, the structure property relations of carbon nanostructures. The module will also highlight the need for developing an economical technique for bulk production of different types of carbon nanostructures. |
| VII | Application of Nanostructures and nanomaterials | 02 | The student will become acquainted with the examples and methods of improving material properties, device performance across different fields |
| Total contact hours | | 40 | |

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| **Course Outcome** | The student will be able to understand nano-length scales and the properties of size-dependent materials and also will be able to correlate properties of nanomaterials and nanostructures with their size, shape and surface characteristics.<br>The course will offer a robust foundation for continued learning and involvement in nanoscience and nanotechnology, encompassing both research and development. |

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| **Learning Resources** | Nanostructures and nanomaterials: Synthesis, properties & applications by Guozhong Cao<br>Chemistry of nanomaterials: Synthesis, properties and applications by CNR Rao et.al. |

| Course Code | MM5262 | Course Name | Biomedical Materials and Devices | Course Category | OE | L | T | P |
|---|---|---|---|---|---|---|---|---|
| | | | | | | 3 | 0 | 0 |

| Pre-requisite Courses | Physics of Materials | Co-requisite Courses | Thermodynamics | Progressive Courses | *Nil* |
|---|---|---|---|---|---|
| **Course Offering Department** | | **Metallurgy and Materials Engineering** | | **Data Book / Codes/Standards** | |

| **Course Objective** | To introduce the fundamental concepts of biomaterials, their properties, interactions with biological systems, and the principles behind biomedical devices.<br>To provide knowledge on materials selection, design strategies, and fabrication techniques for biomedical applications.<br>To develop an understanding of the regulatory, ethical, and clinical challenges associated with biomedical materials and devices. |
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| Module | Syllabus | Duration (h) |
|---|---|---|
| I | Basics:<br>Materials and Biology: Metal, Ceramic, Polymer, Composite; Bioresorbale and bioerodable materials | 04 |
| II | Biomaterials Surfaces:<br>Physics; Surface Structure and Properties; Surface Energy; Adsorption, Segregation, and Reconstruction at Surfaces; Reactions at surfaces; Protein-Surface Interactions; Host Response to Biomaterials; Cell Adhesion Mechanisms; Coagulation Cascade | 08 |
| III | Testing of biomaterials:<br>In vitro and in vivo assessment; evaluation of blood material interactions; Microscopic techniques; Spectorscopic Techniques | 06 |
| IV | Degradation of Materials: Degradation of polymers; Degradation effect on metals and ceramics | 06 |
| V | Materials in medicine, biology and artificial organs :<br>Cardiovascular Medical Devices; Implantable Cardiac Assist Devices; Orthopedic Applications; Dental Implantation; Intraocular Lens Implants; Drug Delivery Systems; Biomedical Sensors and Biosensors | 12 |
| VI | Case studies :<br>Fiber Optic Biosensors, Nanobarcodes; Drug Delivery: Controlled Release; Mechanical Pumps; Artificial Pancreas, Cartilage, Nerve Regeneration | 06 |
| | **Total contact hours** | **42** |

| **Course Outcome** | • Understand the structure-property relationships of various biomaterials.<br>• Select appropriate materials for specific biomedical applications.<br>• Analyze the interaction of materials with tissues and biological fluids.<br>• Design and evaluate biomedical devices considering biocompatibility and mechanical performance.<br>• Familiarize themselves with clinical, ethical, and regulatory frameworks. |
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| **Learning Resources** | Ratner, Buddy D., et al. ***Biomaterials Science: An Introduction to Materials in Medicine***<br>B.Basu, D.Katti and Ashok Kumar; Advanced Biomaterials: Fundamentals, Processing |
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| | and Applications; John Wiley & Sons, Inc., USA (ISBN: 978-0-470-19340-2), September, 2009. |