M.Tech. Program from Department of Mechanical Engineering

M. Tech. in Advanced Manufacturing Technology

Semester wise detailed syllabus

Sl. No.	Subject Code	SEMESTER I	L	T	P	C
1.	HS5111	Technical Writing and Soft Skill	1	2	2	4
2.	ME5101	Advanced Engineering Mathematics	3	1	0	4
3.	ME5103	Finite Element Analysis	3	0	0	3
4.	ME5108	Deformation-based Manufacturing	3	0	0	3
5.	ME5109	Manufacturing Lab - I	0	0	3	1.5
6.	ME61XX	DE-I	3	0	0	3
7.	ME61XX	DE-II	3	0	0	3
8.	XX61PQ	IDE	3	0	0	3
	TOTAL		**19**	**3**	**5**	**24.5**

Course Number	**ME5101**
Course Credit	L-T-P-C: 3-1-0-4
Course Title	**Advanced Engineering Mathematics**
Learning Mode	Hybrid
Learning Objectives	Complies with PLOs 1-5. • This course aims to train the students with the basic and advanced mathematical tools required to solve engineering problems. • Showcase the utility of mathematics towards the analysis of real-world engineering problems.
Course Description	This course is designed to fulfil the need for basic and advanced mathematics concepts often used in real-life engineering problems. Prerequisite: NIL
Course Outline	Linear Algebra: Matrix algebra; basis, dimension and fundamental subspaces; solvability of Ax = b by direct Methods; orthogonality and QR transformation; eigenvalues and eigenvectors, similarity transformation, singular value decomposition, Fourier series, Fourier Transformation, FFT. Vector Algebra & Calculus: Basic vector algebra; curves; grad, div, curl; line, surface and volume integral, Green's theorem, Stokes's theorem, Gauss-divergence theorem. Differential Equations: ODE: homogeneous and non-homogeneous equations, Wronskian, Laplace transform, series solutions, Frobenius method, Sturm-Liouville problems; PDE: separation of variables and solution by Fourier Series and Transformations, PDE with variable coefficient. Numerical Technique: Numerical integration and differentiation; Methods for solution of Initial Value Problems, finite difference methods for ODE and PDE; iterative methods: Jacobi, Gauss-Siedel, and successive over-relaxation. Complex Number Theory: Analytic function; Cauchy's integral theorem. Statistical Methods: Descriptive statistics and data analysis, correlation and regression, probability distribution.
Learning Outcome	• This course would enable the students to solve the mathematical governing equations of engineering problems. • The students would be able to realise the connection of Mathematics with Physics and Engineering.
Assessment Method	Mid Semester Examination, End Semester examination, Class test & quiz, Assignment, Class Performance and Viva

Suggested Readings:

Text Books:

1. H. Kreyszig, "Advanced Engineering Mathematics", Wiley, (2006).
2. Gilbert Strang, "Linear Algebra and Its Applications", 4th edition, Thomson Brooks/Cole, India (2006).
3. J. W. Brown and R. V. Churchill, "Complex Variables and Applications", McGraw-Hill Companies, Inc., New York (2004).
4. J. W. Brown and R. V. Churchill, "Fourier Series and Boundary Value Problems", McGraw-Hill Companies, Inc., New York (2009).
5. G. F. Simmons, "Differential Equations with Applications and Historical Notes", Tata McGraw-Hill Edition, India (2003).
6. S. L. Ross, "Differential Equations" 3rd edition, John Wiley & Sons, Inc., India (2004).
7. K. S. Rao, "Introduction to Partial Differential Equations", PHI Learning Pvt. Ltd (2005).
8. R. Courant and F. John, "Introduction to Calculus and Analysis, Volume I and II", Springer-Verlag, New York, Inc. (1989).

9. K. Atkinson and W. Han, “Elementary Numerical Analysis” 3rd edition, John Wiley & Sons, Inc., India (2004).
10. R. A. Johnson and G. K. Bhattacharya, “Statistics, Principles and Methods”, Wiley (2008).
11. Michael D Greenberg, “Advanced Engineering Mathematics”, 2^{nd} Edition, Pearson (1998).
12. R.K. Jain and S. R. K. Iyengar, “Advanced Engineering Mathematics” 4^{th} Edition, Narosa; 1st Edition (2002).

Course Number	**ME5103**
Course Credit	L-T-P-C: 3-0-0-3
Course Title	**Finite Element Analysis**
Learning Mode	Classroom Lecture
Learning Objectives	Complies with PLOs 1-5 This course aims to provide the mathematical concepts and detailed algorithm of finite element method and its applications in wide range of engineering problems.
Course Description	This course on FEM discusses all the important topics starting from fundamentals and mathematical modeling of boundary value problems, initial value problem and Eigenvalue problems in one and two-dimensional domains. Formulations for different element such as constant strain triangles, parametric elements and numerical integration, beams and frames, linear static analysis, and Eigenvalue problems in one and two-dimensional domains. Formulations for different elements such as constant strain triangles, isoparametric elements and numerical integration, beams and frames, linear static analysis, Dynamic analysis, Thermal analysis, Buckling analysis, scalar field problems, pre-processing and post processing
Course Outline	**Basic Concepts**: Introduction, weak formulations, variational formulations, weighted residual method, Rayleigh-Ritz and Galerkin's method. **One Dimensional Problems**: Second-order differential equations in one dimension, Basis steps, discretization, assembly, local and global stiffness matrix and its properties, boundary conditions, multipoint constraints, applications to: solid mechanics heat transfer and fluid mechanics, Electromagnetic problems, axisymmetric problems **Trusses, Beams and Frames**: Plane truss, local and global coordinate systems, stress calculations, temperature effect on truss members, Euler Bernoulli beam element, C^0 and C^1 elements, Hermite cubic spline functions, frame element, Numerical examples, Case Studies. **Eigen Value and Time dependent problems**: Formulation, FEM models, semidiscrete FEM models, method and Newmark scheme, Applications, problems, convergence and accuracy, Numerical examples **Scalar Field Problems**: Single variables in 2-D, heat transfer, potential flow problems, Electromagnetic, impositions of BCs, Numerical examples. **Convergence and error:** Energy and L_2 norm, accuracy and error, stability **Two Dimensional Problems**: Constant strain triangle, isoparametric formulation, master elements, higher order elements, serendipity elements, hybrid element, quaterpoint element, modelling considerations, mesh generation, numerical integration, reduced integration, *computer implementation*: heat transfer in thin fins, 2D plane stress/plain strain. **Modelling considerations:** Element Geometries, Mesh Generation, Load representation, Discussion on Plane stress, plane strain, plate, membrane, Thin Shell elements

	Post Processing Techniques: Viewing of results, Average and unaverage stress, Interpretation of results. **Limitations with FEM:** Introduction of Meshfree Methods, XFEM, Phase Filed Modelling, Application
Learning Outcome	• Ability to mathematically formulate and ***solve*** Multiphysics problem: Solid, Thermal, Fluid, etc. • Analytical ability to interpreter the results involving linear static analysis, Dynamic analysis, Thermal analysis, Buckling analysis etc. • Understanding and working of FEA commercial tools ANSYS/ABAQUES/COMSOL
Assessment Method	Class tests, quiz, Project (By using commercial software/developing own FEA code), Mid semester and End semester Examination.

Suggested Readings:

Text Book:

[1] Reddy, J.N., “An Introduction to Finite Element Methods”, 3rd Ed., Tata McGraw-Hill. 2005.

Reference Books:

[2] Zienkiewicz, O. C. “The Finite Element Method, 3rd Edition, Tata McGraw-Hill. 2002.
[3] Cook, K.D., Malkus, D.S. and Plesha, M.E., “Concept and Applications of Finite Element Analysis”, 3th Ed., John Wiley and Sons. 1989.
[4] Rao, S.S., “The Finite Element Method in Engineering”, 4th Ed., Elsevier Science. 2005.
[5] Reddy, J.N. and Gartling, D.K “The Finite Element Method in Heat Transfer and Fluid Dynamics”, 2rd Ed., CRC Press. 2001.
[6] Fish, J. and Belytschko, T., “A First Course in Finite Elements”, 1st Ed., John Wiley and Sons. 2007.
[7] Chaskalovic, J., “Finite Element Methods for Engineering Sciences”, 1st Ed., Springer. 2008.
[8] Bathe, K. J., “Finite Element Procedures”, 1st Ed., Cambridge Press

Course Number	**ME5108**
Course Credit	L-T-P-C : 3-0-0-3
Course Title	**Deformation-based Manufacturing**
Learning Mode	Classroom Lecture
Learning Objectives	Complies with PLOs 1, 2, 4 and 5 After attending the class, the students will be able to understand 1. Plastic deformation-based manufacturing processes: cutting and forming 2. Fundamental Mechanics in orthogonal and oblique cutting, including analysis of cutting temperature and its effect on surface roughness 3. The geometry and mechanics of single and multipoint cutting tool 4. Advanced machining, including hard machining, high-speed machining, diamond turning, minimum quantity lubrication, and cryogenic fluids 5. The use of cutting tool materials and various cutting fluids in cutting and forming 6. The fundamental aspects of material materials deformation process 7. Analysis of various bulk material forming processes using approaches like slab method, upper and lower bound, slip line field 8. Analysis of sheet metal forming processes
Course Description	The course will provide a fundamental of the metal cutting process including a thorough understanding of the tool geometry and mechanics of cutting. Additionally, this course is designed to fulfill the basic concepts of material yielding and plastic deformation, and analysis of various bulk and sheet metal forming operations. Prerequisite: NIL
Course Outline	**Module 1**: Single and multipoint tool geometry, Orthogonal and oblique cutting mechanics, Thermal aspects in machining, Tribology in metal cutting, Cutting tool materials and tool life, Surface roughness in machining, Recent advances in machining: hard turning, high seed machining, diamond turning, machining of advanced materials, machining with minimum quantity cutting fluids and cryogenic fluids; Mechanics of drilling, milling, grinding and broaching **Module 2**: Stress-strain relations in elastic and plastic deformations, Yield criteria for ductile materials; Analysis of bulk metal forming processes using Slab method, Upper and lower bound methods, Slip line field theory; Effects of temperature and strain rate in metal forming, Friction and lubrication in metal forming, Sheet metal forming processes, Forming limit diagram, anisotropy in sheet metal forming.
Learning Outcome	The course training enables with (a) Understanding of fundamental mechanics of cutting and forming processes (b) Analysis of various cutting and forming processes using commonly used analytical methods
Assessment Method	Mid Semester Examination (25%), End Semester examination (50%), Class test & quiz (15%), Assignment (10%)

Suggested Readings:

Text Books:

[1] M. C. Shaw, Metal Cutting, Tata McGraw Hill, New Delhi, 2004.

[2] William F. Hosford, Robert M. Caddell, Metal Forming: Mechanics and Metallurgy, Cambridge University Press
[3] G. W. Rowe, Principles of Industrial Metal working processes, CBS publishers and Distributors
[4] A. Ghosh and A. K. Malik, Manufacturing Science, East West Press, 2010.

Reference book

[1] G. Boothroyd and W. A. Knight, Fundamentals of Machining and Machine Tools, CRC-Taylor and Francis, 2006.
[2] P. N. Rao, Manufacturing Technology: Foundry, Forming and Welding, Volume 2, Tata McGraw Hill Education Private Limited (2018)
[3] P. H. Black, Metal Cutting Theory, McGraw Hill, 1961.
[4] G. K. Lal, Introduction to Machining Science, New Age International Publishers, 2007.
[5] R.H Wagoner, Metal Forming Analysis, Cambridge University Press
[6] J. Chakrabarty, Theory of Plasticity, McGraw Hill, 1998.
[7] Dieter, Mechanical Metallurgy, McGraw Hill. Inc

Course Number	**ME5109**
Course Credit	L-T-P-C : 0-0-3-1.5
Course Title	**Manufacturing Lab-I**
Learning Mode	Laboratory experiments
Learning Objectives	Complies with PLOs 1 and 5 This course aims to understand the fundamentals of metal cutting and metal forming analysis with hands-on training on several experimental setups, including the fabrication of single and multi-point cutting tool
Course Description	This course will provide hands-on training on several aspects of metal cutting analysis, starting from the fabrication of the cutting tool, understanding the chip removal mechanism, cutting mechanics, cutting temperature, and life. Additionally, this course will provide hands-on training on finding out the working load of various bulk deformation processes and sheet forming processes, including forming limit diagrams (FLD).
Course Outline	Fabrication of single point cutting tool, re-sharpening of twist drill, cutting force measurement using DAQ and Labview, measurement of cutting temperature using DAQ and Labview, Tool life. Extrusion, rolling, forging load estimation, deep drawing analysis, forming limit diagram, blanking, and piercing operation.
Learning Outcome	The students will be acquiring knowledge of handling sophisticated instruments and equipment related to deformation-based manufacturing processes including metal cutting and metal forming. They will also acquire knowledge on the phenomena pertaining to the deformation-based manufacturing processes
Assessment Method	Experiment (20%), Report (20%), Viva (60%)

Suggested Readings:

Texts Books:

[1] Bhattacharyya, A., Metal cutting: theory and practice, New Central Book, Kolkata, New Edition

[2] G. W. Rowe, Principles of Industrial Metalworking processes, CBS publishers and Distributors, New Edition.

Department Elective - I						
Sl. No.	**Subject Code**	**Subject**	**L**	**T**	**P**	**C**
1.	ME6102	Computational Fluid Dynamics	3	0	0	3
2.	ME6106	Mobile Robotics	3	0	0	3
3.	ME6107	Digital Manufacturing and Industry 4.0	3	0	0	3
4.	ME6108	Wear & Lubrication of Machine Components	3	0	0	3

Course Number	**ME6102**
Course Credit	L-T-P-C : 3-0-0-3
Course Title	**Computational Fluid Dynamics**
Learning Mode	Classroom Lecture/Hybrid
Learning Objectives	Complies with PLOs 1, 2 and 5 This course aims to lay the essential foundations of computational fluid dynamics and enable; (a) understanding of the governing equations of fluid dynamics and their classification, (b) understanding of different discretization methods to solve the governing equations numerically, (c) understanding of different types of grids involved in CFD, (d) understanding of popular CFD algorithms for solving incompressible flows.
Course Description	This course is designed to fulfil the basic concepts of computational fluid dynamics. The course first discusses the general background required for understanding the various numerical methods or discretization techniques involved in CFD. It is followed by a detailed understanding of the two of the popular discretization methods – Finite Difference Method (FDM) and Finite Volume Method (FVM). The course then concludes by proving an overview of other popular CFD methods. Prerequisite: Undergraduate Fluid Mechanics and Heat Transfer course
Course Outline	Concept of Computational Fluid Dynamics: Different techniques of solving fluid dynamics problems, their merits and demerits, governing equations of fluid dynamics and boundary conditions, classification of partial differential equations and their physical behavior, Navier-Stokes equations for Newtonian fluid flow, computational fluid dynamics (CFD) techniques, different steps in CFD techniques, criteria and essentialities of good CFD techniques. Finite Difference Method (FDM): Application of FDM to model problems, steady and unsteady problems, implicit and explicit approaches, errors and stability analysis, direct and iterative solvers. Finite Volume Method (FVM): FVM for diffusion, convection-diffusion problem, different discretization schemes, FVM for unsteady problems. Prediction of Viscous Flows: Pressure Poisson and pressure correction methods for solving Navier- Stokes equation, SIMPLE family FVM for solving Navier-Stokes equation, modelling turbulence. CFD for Complex Geometry: Structured and unstructured, uniform and non-uniform grids, different techniques of grid generations, curvilinear grid and transformed equations. Lattice Boltzman and Molecular Dynamics: Boltzman equation, Lattice Boltzman equation, Lattice Boltzman methods for turbulence and multiphase flows, Molecular interaction, potential and force calculation, introduction to Molecular Dynamics algorithms.
Learning Outcome	After attending this course, the following outcomes are expected: 1. Ability to classify the partial differential equations involved in fluid mechanics and heat flow and understanding of their physical behaviour.

	2. Ability to write CFD codes for the various algorithms covered in this course. 3. Understanding of discretization approach required for the unstructured grids.
Assessment Method	Mid Semester Examination, End Semester examination, Viva, Written and Coding Assignments

Suggested Readings:

Text Books:

1. J. D. Anderson, "Computational Fluid Dynamics", McGraw-Hill Inc. (New Edition).
2. S. V. Patankar, "Numerical Heat Transfer and Fluid Flow", Hemisphere Pub. (New Edition)
3. A. Sharma, "Introduction to Computational Fluid Dynamics Development, Application and Analysis", Ane Books, 1st edition 2016
4. K. Muralidhar, and T. Sundarajan, "Computational Fluid Flow and Heat Transfer", Narosa (New Edition)
5. D. A. Anderson, J. C. Tannehill and R. H. Pletcher, "Computational Fluid Mechanics And Heat Transfer", Hemisphere Pub. (New Edition)
6. M. Peric and J. H. Ferziger, "Computational Methods for Fluid Dynamics", Springer (New Edition).
7. H. K. Versteeg and W. Malalaskera, "An Introduction to Computational Fluid Dynamics", Dorling Kindersley (India) Pvt. Ltd. (New Edition).
8. C. Hirsch, "Numerical Computation of Internal and External Flows", ButterworthHeinemann, (New Edition).
9. J. M. Jaile, "Molecular Dynamics Simulation: Elementary Methods", Willey Professional, (New Edition).
10. A. A. Mohamad, "Lattice Boltzman Method: Fundamentals and Engineering Applications with Computer Codes, Springer (New Edition).

Course Number	**ME6106**
Course Credit	L-T-P-Cr : 3-0-0-3
Course Title	**Mobile Robotics**
Learning Mode	Classroom Lecture
Learning Objectives	Complies with PLOs 3, 4 and 5 • This course will present various aspects of design, fabrication, motion planning, and control of intelligent mobile robotic systems. • This course presents computational aspects and practical implementation issues and thereby leads to a well rounded training.
Course Description	This course is designed to introduce students to the concepts of Mobile Robotics. The course will provide theoretical background as well as expose the students to practical aspects of Mobile Robotics. Prerequisite: Engineering Mathematics, Linear Algebra
Course Outline	**Robot locomotion:** Types of locomotion, hopping robots, legged robots, wheeled robots, stability, manoeuvrability, controllability **Mobile robot kinematics and dynamics:** Forward and inverse kinematics, holonomic and nonholonomic constraints, kinematic models of simple car and legged robots, dynamics simulation of mobile robots **Perception:** Proprioceptive/Exteroceptive and passive/active sensors, performance measures of sensors, sensors for mobile robots like global positioning system (GPS), Doppler effect-based sensors, vision based sensors, uncertainty in sensing, filtering **Localization:** Odometric position estimation, belief representation, probabilistic mapping, Markov localization, Bayesian localization, Kalman localization, positioning beacon systems **Introduction to planning and navigation:** path planning algorithms based on A-star, probabilistic roadmaps (PRM), Markov Decision Processes (MDP), and stochastic dynamic programming (SDP).
Learning Outcome	After completing this course, the students will be able to design and fabricate a mobile robotic platform and program it to apply learned theoretical concepts in practice.
Assessment Method	Mid Semester Examination, End Semester examination, Class test & quiz, Assignment with simulation and hardware building exercises.

Suggested Readings:

Text / Reference Books:

[1] R. Siegwart, I. R. Nourbakhsh, “Introduction to Autonomous Mobile Robots”, The MIT Press, 2011.

[2] Peter Corke, Robotics, Vision and Control: Fundamental Algorithms in MATLAB, Springer Tracts in Advanced Robotics, 2011.

[3] S. M. LaValle, “Planning Algorithms”, Cambridge University Press, 2006. (Available online http://planning.cs.uiuc.edu/)

[4] Thrun, S., Burgard, W., and Fox, D., Probabilistic Robotics. MIT Press, Cambridge, MA, 2005.

[5] Melgar, E. R., Diez, C. C., Arduino and Kinect Projects: Design, Build, Blow Their Minds, 2012.

Course Number	**ME6107**
Course Credit	L-T-P-Cr : 3-0-0-3
Course Title	**Digital Manufacturing and Industry 4.0**
Learning Mode	Classroom Lecture
Learning Objectives	Complies with PLO 1-5 • This course will present various aspects of digital manufacture systems and industry 4.0 with smart and connected business perspective. • This course presents data analytics for digital manufacturing and practical implementation issues for cyber physical systems and thereby leads to a well-rounded training. • This course will also give theoretical and practical knowledge on unmanned aerial vehicle or drone technology, automatic guided vehicles and collaborative robotics essential for industry 4.0
Course Description	This course is designed to discuss t various aspects of digital manufacture systems and industry 4.0 with smart and connected business perspective. The course will describe required tools for cyber physical systems development. This course will also give theoretical and practical knowledge on unmanned aerial vehicle or drone technology, automatic guided vehicles and collaborative robotics essential for industry 4.0 Prerequisite: nil
Course Outline	Digital Manufacturing: theory and industrial applications; Project planning and project management with digital tools; Digital configuration and architecture; Digital manufacturing system modelling, simulation and analysis Industry 4.0: Globalization and emerging issues, the fourth revolution, LEAN production systems, smart and connected business perspective, smart factories; Cyber Physical Systems and next generation sensors; Collaborative platform and product lifecycle management; Augmented Reality and Virtual Reality; Machine Learning and Artificial Intelligence in Manufacturing; Industrial Sensing & Actuation; Industrial Internet Systems Automation and Robotic solution under the umbrella of Industry 4.0: Applications of Unmanned Aerial Vehicles (UAVs), Autonomous Guided Vehicles (AGV); Understanding the application scenarios of UAVs and AGVs for manufacturing; Key components of UAV and AGV - Sensor & Hardware, Understanding of Navigation and Path Planning.
Learning Outcome	After completing this course, the students will be able to develop digital twins of the physical system and program it to apply learned theoretical concepts for implementation of collaborative industry 4.0 platforms in practice.
Assessment Method	Mid Semester Examination, End Semester examination, Class tests, Assignments

Suggested Readings:

Reference Books:

[1] M.P. Groover, "Automation, Production Systems and Computer Integrated manufacturing", 4th Edition, Pearson Education (2016)

[2] Hamed Fazlollahtabar, Mohammad Saidi-Mehrabad, "Autonomous Guided Vehicles: Methods and Models for Optimal Path Planning", Springer, 2015.

[3] K Kumar, D Zindani and J P Davim, "Digital Manufacturing and Assembly Systems in Industry 4.0," CRC Press, 2019

[4] J P Davim, "Manufacturing in Digital Industries: Prospects for Industry 4.0", De Gruyter, 2020

[5] P. K. Garg, "Introduction To Unmanned Aerial Vehicles," New Age International Private Limited; First edition, 2020
[6] S.K., Pal, D. Mishra, A. Pal, S. Dutta, D. Chakravarty, S. Pal, "Digital Twin – Fundamental Concepts to Applications in Advanced Manufacturing", Springer, 2021

Course Number	**ME6108**
Course Credit	L-T-P-Cr : 3-0-0-3
Course Title	**Wear & Lubrication of Machine Components**
Learning Mode	Classroom Lecture
Learning Objectives	Complies with PLOs 3, 4 and 5 Surface failure due to rubbing is a critical problem that affects the life and reliability of modern machinery. The knowledge of surface interaction is interdisciplinary and essential to design for life and reliability and also enable innovation in electromechanical and material engineering design. The course focuses on theories of friction, wear, contact and lubrication, approaches to model basic tribological elements/systems, and methods to simulate tribological processes.
Course Description	This course is designed to fulfil understanding of theories of friction, wear, contact and lubrication, approaches to model basic tribological elements/systems, and methods to simulate tribological processes. Prerequisite: NIL
Course Outline	Definition Tribology, Significance for Maintenance and Reliability of Machines, Surface – Roughness, Mechanics of surface/solids contact – Hertzian, Non-Hertzian, Modeling of Rough surface contact, Laws of friction, Mechanisms of friction, Stiction, Stick slip, Surface temperature, Surface energy, micro and nano scale friction. Rolling/Sliding – Heathercote Model, Kalker, Wear – Adhesive Wear, Delamination Wear, Fretting Wear, Abrasive Wear, Erosive Wear, Corrosive Wear, Mild and Severe Oxidative Wear, Wear Mechanism Maps, Stribeck Curve, Reciprocatory, Rotary, Macro-pitting, Micro –pitting, Wear in mechanical/electrical contact, Lubrication – regimes: Boundary Lubrication, Solid Film Lubrication, Mixed Lubrication, Hydrodynamic Lubrication, Hydrostatic Lubrication, EHL, Lubrication in vacuum, Bearings – rolling elements, Journal bearing, Gears, Cams, reciprocatory applications – e.g. sliders, piston-cylinders, IC engines-valve-followers, Lubrications and wear control – coatings and material processing, Lubricants – composition, base fluids, rheology, Additives – boundary layer, Nano additives, Tribological tests – friction, Wear, Life tests, Standards, Reciprocatory, Rotary, rolling/sliding –spiral orbit, dry and Lubricated tests, Scaling up subscale tests, component tests, Nano scale testing
Learning Outcome	Understanding of surface contact failures and ways to prevent or increase life of such components. Design of test equipment for testing wear and friction at different scales.
Assessment Method	Assignments, Quiz, Mid term and end term exams

Suggested Readings:

Text Books:

[1] R.D. Arnell, P.B. Davies, J. Halling, T.L. Whomes, Tribology: principles and design applications, Macmillan Education Ltd, First edition 1991.

[2] B. Bhushan, Principles and Applications of Tribology, John Wiley, second edition, 2013.

[3] K.L. Johnson, Contact mechanics, Cambridge University Press, 1987.

[4] A. Cameron, Basic Lubrication Theory, E. Horwood, Halsted Press, 1976.

[5] I. Hutchings, P. Shipway, Tribology: friction and wear of engineering materials, Butterworth-heinemann, 2nd Edition, 2017.

[6] G, Stachowiak, A.W. Batchelor, Engineering tribology, Butterworth-heinemann, Fourth edition, 2013.

Department Elective - II						
Sl. No.	**Subject Code**	**Subject**	**L**	**T**	**P**	**C**
1.	ME6103	Continuum Mechanics	3	0	0	3
2.	ME6110	Biomechanics	3	0	0	3
3.	ME6111	Advanced Manufacturing Processes	3	0	0	3
4.	ME6112	Advanced Mechanical Characterisation of Alloys	3	0	0	3

Course Number	**ME6103**
Course Credit	**L-T-P-C:** 3-0-0-3
Course Name	**Continuum Mechanics**
Pre-requisites	Mechanics of Solids and Mechanics of Fluids
Learning Mode	Classroom lecture

Course Objectives

Complies with PLOs 1, 2 and 4

- This course targets students of solid and fluid mechanics, aiming to familiarize them with the fundamentals of continuum mechanics by enhancing their problem-solving skills for engineering problems like structural mechanics, fluid dynamics and heat transfer.

Course Content

1. **Mathematical Preliminaries**
   Introduction to Tensors: Vectors and second order tensors; Tensor operation; Properties of tensors; Invariants, Eigenvalues and eigenvectors of second order tensors; Tensor fields; Differentiation of tensors; Divergence and Stokes theorem.
2. **Kinematics of Deformation**
   Continuum hypothesis, Material (Lagrangian) and Spatial (Eulerian) descriptions of motion, Displacement field, Deformation gradient, Stretch ratios, Polar decomposition of deformation gradient, Velocity gradient, Rate of deformation, Vorticity, Length, area and volume elements in deformed configuration; Material and spatial time derivatives - velocity and acceleration, Cauchy stress tensor, state of stress, concept of first and second Piola-Kirchoff stress tensors.
3. **Fundamental Laws in Continuum Mechanics:**
   Material derivatives of Line, Surface and Volume Integrals, Conservation of mass, continuity equation, Conservation of linear and angular momentum, Conservation of energy; Continuum Thermodynamics: Basic laws of thermodynamics; Energy equation; Entropy; Clausius-Duhem inequality.
4. **Constitutive Relations and Material Models:**
   Constitutive Assumptions; Ideal Fluids; Elastic Fluids, Hyperelastic Material; Notion of Isotropy; Isothermal Elasticity - Thermodynamic Restrictions, Material Frame Indifference, Material Symmetry; Hooke’s law, Stokes problem, Newtonian and Non-Newtonian fluids.

Learning Outcomes:

- The students will understand the various theoretical elements of continuum mechanics, and how these elements apply to solids and fluids.
- The students will be able to derive and apply the equations of continuum mechanics in the following areas: stress and strain analysis, deformation, work and energy, theory of elasticity, viscoelasticity, theory of plasticity, fluid mechanics, and the basis for constitutive equations.
- The students will be able to use continuum theory descriptions in their research work. Furthermore, it will also be helpful for them to understand research or scientific articles with continuum formulations.

Assessment Method

Mid semester examination, End semester examination, Class test/Quiz, Assignments

Reference Books

1. Mase, G. T., and Mase, G. E., Continuum Mechanics for Engineers, CRC Press, 2nd Edition, 1999.
2. Malvern, L. E., Introduction to the Mechanics of a Continuous Medium, Prentice-Hall Inc., Englewood Cliffs, New Jersey, 1969.

3. Rudnicki, J. W., Fundamentals of Continuum Mechanics, John Wiley & Sons, 2015.
4. Lai, W. M., Rubin, D., and Krempl, E., Introduction to Continuum Mechanics, Butterworth-Heinemann, 4th edition, 2015.
5. Reddy, J.N., An introduction to continuum mechanics, Cambridge University Press, 2013.
6. Jog, C.S., Foundations and applications of mechanics: Volume I: Continuum mechanics, Narosa Publishing House, 2007.

Course Number	**ME6110**
Course Credit	L-T-P-Cr : 3-0-0-3
Course Title	**Biomechanics**
Learning Mode	Classroom Lecture
Learning Objectives	Complies with PLOs 4 and 5 The objectives of this course are: • Recognize different forces and couples acting on a Biological systems. • Should be able to unify the biological system as a Continuum and demarcate the different elements of biological system such as bone, tendon, cartilage and smooth muscle cells. • Analyze the growth, remodelling and residual stress. • Perform the experiment on RBC like system, viscosity measurement blood-like liquid, ECG, blood pressure, pressure distribution of human walk on the foot, determination of residual stress overgrowth. • Model some of the biological system through computational technique. • Able to identify a few of instrumentation technique like ECG, EEG, blood flow, respiratory systems • Should be able to mathematically analyse a simple injury of biological system from impact and able to perform the preventive design from the first principle.
Course Description	This course is designed to fulfil the requirement of designing biological systems from the engineering perspective by imparting the some knowledge of biological system through analytical way. Prerequisite: NIL
Course Outline	**Introduction to Biological System** Cell, Tissues and Connective Tissues and their Phenomenological Models: Bone, Tendon, Cartilage, Smooth Muscle cells, Musculo-Skeletal system as a tensegrity structure Gait Analysis: Locomotion and Control Modeling of Humanoid Robots Physiology and mechanical properties of muscles- Viscoelastic model of muscle Tentanization pulse in muscle fibers Physiology and mechanical properties of bones- Bones as bidirectional fibers-nets and its stress response **Circulation system** Composition and rheological properties of blood Construction of RBC Composition of Artery and Venus walls Operation of heart as a pump and electrical potential **Neural system and control** Central nervous system Auxiliary nervous system

	Experiment on Biological system- Experiment on RBC like system, viscocity measurement blood-like liquid, ECG, blood pressure, pressure distribution of human walk on the foot **Growth, Remodeling and Residual Stresses** Mathematical model of growth Mathematical model of tumor Remodeling of biological tissues like skin, artery- wrinkle of skin, ageing of artery Modeling of Residual stress **Experiment on Biological system-** Determination of residual stress in artery-like tissue Determination of ageing affect on arterial tissue **Instrumentation Technique in Biomechanics** Measurement of Biopotential – ECG, EMG, ENG,… Test on Respiratory Mechanism Ultrasonic measurement of Blood flow Drug Delivery Systems **Application of Biomechanics** Sports Biomechanics Artificial Limbs and organs Occupational Biomechanics- consideration in Machine Control and Workplace Design Injury Biomechanics – Analysis and optimal design **Biomaterial**
Learning Outcome	Following learning outcomes are expected after going through this course. a) Will be able to model a biological system both analytically and numerically. b) Will be able to apply the knowledge of Electro-Magnetic Interference to design different instruments like ECG, EEG and EMG. c) Will be able obtain the interpretation of biological system in growth, remodelling and residual stresses to predict through model the circulation system of human body. d) Will be able to identify the different sophisticated instrumentation technique like MRI, Colour Angiogram, Elastogram in qualitative and quantitative way to identify the diseased cells. e) Will be able to design and develop different biological instruments/actuators/device/artificial limbs needed for the society.
Assessment Method	Mid Semester Examination (30 %), End Semester examination (50%), Class test & quiz (10%), Assignment (10%)

Suggested Readings:
Text Books:

1.	Jay D. Humphrey and Sherry DeLange "An Introduction to Biomechanics: Solids and Fluids, Analysis and Design", Springer; 1st Edition	2004
2.	Roger Bartlett "Introduction to Sports Biomechanics: Analysing Human Movement Patterns" Routledge; 2nd Edition	2007

3.	STEPHEN C. COWIN AND JAY D. HUMPHREY Edt. , "Cardiovascular Soft Tissue Mechanics ", Kluwer Academic Publishers	2000
4.	Walter D. Pilkey, Dmitry V. Balandin, Nikolai N. Bolotnik, "Injury Biomechanics and Control: Optimal Protection from Impact ", 1st Edition., Wiley .	2009
5.	Don B. Chaffin, Gunnar B. J. Andersson, Bernard J. Martin "Occupational Biomechanics", Wiley-Interscience; 3rd Edition	1999
6.	John G. Webster, "Medical Instrumentation: Application and Design", Wiley; 3rd Edition	1997

Course Number	**ME6111**
Course Credit	L-T-P-Cr: 3-0-0-3
Course Title	**Advanced Manufacturing Processes**
Learning Mode	Classroom Lecture
Learning Objectives	Complies with PLOs 1, 3-5 This course aims to impart the essential fundamental concepts of various advanced machining processes and enable (a) to appraise mechanism of material removal, (b) understand and analyze the process performance, (c) identify the suitability of the processes for various materials and applications.
Course Description	This course is designed to fulfil the basic concepts of material removal mechanism, fundamental analysis, applications and suitability of various advanced machining processes required for different applications. Prerequisite: NIL
Course Outline	Advanced Engineering Materials & the limitations of Conventional manufacturing processes; Classification of advanced manufacturing processes; Water jet & abrasive water jet machining; Ultrasonic machining; Electrical discharge machining; Ion Beam, Electron Beam & Laser beam in manufacturing; PVD & CVD; Micro and Nano Manufacturing.
Learning Outcome	The course will enable the students to (a) analyse the process performance, (b) estimate the amount of material removal, and (c) select the suitable advanced machining process for various materials for different applications.
Assessment Method	Mid Semester Examination, End Semester examination, Assignments and Quiz

Suggested Readings:

Text Books:

[1] A Ghosh and A K Mallik, Manufacturing Science, Affiliated East-West Press Pvt Ltd, 2nd Edn, 2010.
[2] P. C. Pandey, H S Shan. Modern Machining Processes, Tata McGraw Hill, New Delhi, 2007.

Reference Books:

[1] James Brown, Modern Manufacturing Processes, Industrial Press Inc, 1991.
[2] William M. Steen, Laser Material Processing, 3rd edition, Springer, 2003.
[3] Mark J. Jackson, Microfabrication and Nanomanufacturing, Taylor & Francis, 2008.
[4] P. K. Mishra. Nonconventional Machining, Narosa Publishing House, New Delhi, 1997.
[5] J.A. McGeough, Advanced Methods of Machining, Springer, 2014
[6] G. F. Benedict, Nontraditional Manufacturing Processes, Marcel Dekker Inc, NY., 1987.

Course Name	Advanced Mechanical Characterisation of Alloys
Course Number	**ME6112**
L-T-P-C	3-0-0-3
Pre-requisites	Nil
Learning Mode	Class room lecture

Course objectives

Complies with PLOs 3, 4 and 5

- Impart a thorough understanding of the mechanical behaviour of materials under various conditions.
- Teach students how to interpret the results of mechanical tests.
- Apply this knowledge to solve real-world engineering problems.

Course Content

1. **Introduction**

Fundamentals of elastic and plastic deformation
Yield criteria, von Mises, Tresca, Hill 48, Hill 1993
Defects in materials
Role of dislocations, twinning, and slip in plastic deformation
Strengthening mechanisms in alloys
Ductile and brittle failure, intergranular and transgranular failure, GTN model
Influence of temperature, strain rate, and environment on plastic deformation
Application of mechanical properties in engineering design

2. **Monotonic Tests**

Tensile, compression, shear, and torsion tests
Bend test and notch tensile test
Macro, micro, and nano hardness tests
Wear testing
Hydrogen embrittlement evaluation

3. **Fatigue**

Oligocyclic fatigue, Low cycle fatigue, high cycle fatigue, and giga cycle fatigue
Concept of endurance limit, effect of mean stress
Basquin and Coffin-Manson laws, strain energy density laws for life prediction
Cyclic stress-strain curve analysis
Masing analysis
Cyclic hardening/softening
Notch fatigue
Thermo-mechanical fatigue
Rolling contact fatigue
Fretting fatigue
Effect of hydrogen embrittlement on fatigue
Influence of defects and microstructural inhomogeneity on fatigue

4. **Fracture**

Stress concentration factor and stress intensity factor
Griffith theory
Basics of linear elastic and elastoplastic fracture mechanics
Impact toughness and ductile to brittle transition
Fracture toughness and concepts of K_{1c} and J_{1c}, CTOD, Mode mixity,
Fatigue Crack Growth Rate (FCGR), and Paris law
Short crack growth and concept of K_{th}

5. **Creep**
   Creep and creep crack growth
   Stress relaxation tests
   Creep-fatigue interaction

6. **High Rate Deformation**
   Strain rate sensitivity
   Crash testing
   Crashworthiness of engineering components

7. **Sheet Metal Forming**
   Concept of planar anisotropy and texture
   Forming limit diagram, Wrinkling limit, fracture limit curve
   Hole expansion ratio
   Bauschinger effect and spring back
   r-ratio and deep drawing ratio

Learning Outcomes:
By the end of this course, undergraduate students should be able to:
- Demonstrate a comprehensive understanding of various advanced mechanical properties.
- Interpret various mechanical tests
- Apply knowledge of advanced mechanical properties to solve real-world engineering problems and enhance material performance.

Assessment Method
- Quiz, mid and end-semester examinations

Texts and References

Text Books:

1. George E. Dieter, Mechanical Metallurgy, McGraw Hill Education, 3rd Edition, 1 July 2017.
2. S. Suresh, Fatigue of Materials, Cambridge University Press, 2nd edition, June 2012.
3. T.L. Anderson, Fracture Mechanics: Fundamentals and Applications, CRC Press, 4TH EDN, 2017.
4. M.N. Shetty, Dislocation and mechanical behaviour of materials, PHI, 2013.

Reference Books:

1. Prashant Kumar, Elements of Fracture Mechanics, McGraw Hill Education, 2017.
2. J. Schijve, Fatigue of Structures and Materials, Springer, 2nd ed. 2009.
3. Bruno C. De Cooman and Kip O. Findley, Introduction to the Mechanical Behavior of Steel, Association for Iron & Steel Technology, 30 Nov 2017.

Sl. No.	Subject Code	SEMESTER II	L	T	P	C
1.	ME5201	Advanced Engineering Software Lab	1	0	4	3
2.	ME5203	Measurement and Instrumentation	3	0	0	3
3.	ME5207	Solidification-based Manufacturing	3	1	0	4
4.	ME5208	Manufacturing Lab - II	0	0	3	1.5
5.	ME62XX	DE-III	3	0	0	3
6.	ME62XX	DE-IV	3	0	0	3
7.	RM6201	Research Methodology	3	1	0	4
8.	IK6201	IKS	3	0	0	3
	TOTAL		**19**	**2**	**7**	**24.5**

Course Number	**ME5201**
Course Credit	L-T-P-C: **1-0-4-3**
Course Title	**Advanced Engineering Software Laboratory**
Learning Mode	Classroom Lectures and Practical
Learning Objectives	Complies with PLO 5 Exposure to industrial software used in Mechanical Engineering practices.
Course Description	This course is designed to make students understand commercial software along with the understanding of numerical al techniques.
Course Outline	**CAD/CAM**: 2D and 3D geometric transformation, Composite Transformation, Projections; Curves: Cubic, Bezier, Splines; Surfaces: Quadric, Coons patch, Super Quadric, Bezier, B-Splines. Process planning, CL data generation, Automatic CNC code generation. **FEM**: Solid model creation, different types of elements, chunking of model, meshing, mesh quality, different kinds of analysis: static, dynamic, transient, thermal, electro-magnetic, acoustics, sub- structuring and condensation, Error and convergence. Non-linear static and dynamic analysis, contact analysis, multi-physics problem, rigid body analysis of flexible element. **CFD**: Different types of CFD techniques, various stages of CFD techniques (i) pre-processor: governing equations, boundary conditions, grid generation, different discretization techniques (ii) processor: solution schemes, different solvers (iii) post-processing: analysis of results, validation, grid independent studies etc. Developing codes using commercial/open source software for solving few problems of laminar and turbulent flow with heat transfer applications. Engineering software's related to CAD/CAM, FEM, CFD, with both GUI and script like languages, are to be used for laboratory assignments.
Learning Outcome	At the end of the course, students will be able to use the industrial software for simulating industrial and research problems related to solid and fluid mechanics. A mature understanding of various numerical techniques and their advantages and disadvantages will develop with respect to the software used in the class.
Assessment Method	Class test & quiz, Assignment, Class Performance and Viva, Practical Exam

Suggested Readings:

1. D. F. Rogers and J. A. Adams, "Mathematical Elements for Computer Graphics", McGraw- Hill, 1990
2. M. Groover and E. Zimmers, "CAD/CAM: Computer-Aided Design and Manufacturing", Pearson Education, 2009.
3. Saxena and B. Sahay, "Computer Aided Engineering Design", Springer, 2007.
4. J. N. Reddy, "An Introduction to Finite Element Methods", 3rd Ed., Tata McGraw-Hill, 2005.
5. J. Fish, and T. Belytschko, "A First Course in Finite Elements", 1st Ed., John Wiley and Sons, 2007.
6. J. D. Anderson, "Computational Fluid Dynamics", McGraw-Hill Inc. (1995).
7. H. K. Versteeg and W. Malalaskera, "An Introduction to Computational Fluid Dynamics", Dorling Kindersley (India) Pvt. Ltd. (2008).
8. S. Biringen and C Chow, An Introduction to Computational Fluid Mechanics by Example.

Course Number	**ME5203**
Course Credit	L-T-P-C: 3-0-0-3
Course Title	**Measurement and Instrumentation**
Learning Mode	Classroom lecture
Learning Objectives	Complies with PLOs 2-4. The course aims to provide a basic understanding of the mechanical measurement systems and statistical analysis of experimental data.
Course Description	The course contains the generalized configuration and functional elements of measuring systems, static and dynamic characteristics of measuring instruments. The course also includes the instrumentation for displacement, strain, velocity, force, torque, power, pressure, sound, flow and temperature measurement.
Course Outline	Module-1 Basic concepts of measurement, functional elements of instruments, classification of measuring instruments, methods of correction for interfering and modifying inputs, static characteristics of measuring instruments Module-2 Static characteristics of measuring instruments, loading effect and impedance matching, statistical analysis, Chi-square test, least square method, Curve Fitting, Uncertainty analysis and error propagation Module-3 Generalized model of a measuring system, zero and first order system, second order system. First order system- ramp response, impulse response, frequency response, Second order system- step response, ramp response, impulse and frequency response, higher order systems, compensation, transducers Module-4 Flow measurement (hot wire anemometer, PIV systems, coriolis flow meter, etc.,) temperature measurement (thermocouple, RTD, Infra thermography etc.), heat flux sensors. Optical Methods- Shadowgraph, Schilieren and Interferometer. Module-5 Strain gauges, piezoelectric transducers pressure measurement, force and torque measurement, displacement and acceleration measurement Module-6 Sound measurement, thermophysical properties measurement, flow visualization, air pollution sampling and measurement, pollutants-Gas Chromatography.
Learning Outcome	• Students will be able to analyze and behavior and characteristics of various measuring instruments and record data • Students will be able to analyze and interpret the experimental data • Students will be able to perform uncertainty analysis in the measured and derived quantities.
Assessment Method	Mid Semester Examination, End Semester examination, Quiz, assignments seminar

Textbook

1. E.O. Doebelin, Measurement Systems: Application and Design.

Reference books

2. E.G.R. Eckert and R.G. Goldstein, Measurement Techniques in Heat Transfer.
3. T.P. Holeman, Experimental Methods for Engineers.
4. H.D. Young, Statistical Treatment of Experimental Data.

Course Number	**ME5207**
Course Credit	L-T-P-C : 3-1-0-4
Course Title	**Solidification-based Manufacturing**
Learning Mode	Classroom Lecture
Learning Objectives	Complies with PLOs 3, 4 and 5 This course aims to impart (a) the fundamental aspects of solidification-based manufacturing processes, (b) analysis of various casting, welding, and additive manufacturing processes, and (c) to train the students with the analytical, practical, and problem-solving skills related to solidification-based manufacturing processes.
Course Description	This course is designed to fulfill the basic concepts of solidification-based manufacturing processes and analysis of various casting, welding, and additive manufacturing processes. Prerequisite: NIL
Course Outline	**Module 1**: Introduction to solidification theory, Diffusion theory, Phase diagrams, Nucleation kinetics, Phase Transformation, Growth and Interface Stability, Effect of secondary phase precipitation **Module 2**: Overview of different casting processes, Rate of solidification for casting processes, Directional solidification and Progressive solidification: Solidification with constant casting surface temperature, Solidification with predominant interface resistance, Solidification with predominant resistance in mould and solidified Metal, CFR, Solidification Time and Chvorinov rule, Solidification shrinkage and linear contraction, pouring rate and Temperature, Padding, Use of exothermic materials, Chills, Feeding Aids, etc. **Module 3**: Overview of different fusion welding processes, Weld solidification, Heat transfer in welding processes, Welding solidification parameters, Correlation between solidification parameters and weld microstructures, control of weld solidification structure, solute redistribution during welding solidification, solidification modes and constitutional supercooling, solidification and liquation cracking, Hydrogen embrittlement, brief overview of NDT **Module 4**: Solidification in powder bed fusion and direct energy deposition fusion additive manufacturing technologies, Melt pool dynamics, Non-equilibrium solidification, Rapid solidification of multi-component alloys, Fusion zone geometries, cooling rates, and solidification parameters, Effect of solidification rate on micro-segregation, Solute trapping, case studies
Learning Outcome	The course training enables with (a) Fundamental concept of solidification-based manufacturing processes (b) Analysis of various casting, welding, and additive manufacturing processes
Assessment Method	Mid Semester Examination, End Semester examination, Assignments and Quiz

Suggested Readings:

Text Books:

[1] Carl R. Loper, Philip C. Rosenthal, Richard W. Heine, Principal of metal casting,
[2] D. J. Hoffman, K. R. Dahle, D. J. Fisher, Welding; Pearson publication, 2017.

[3] Igor Yadroitsev, Ina Yadroitsava, Anton Du Plessis, Eric MacDonald, Fundamentals of Laser Powder Bed Fusion of Metals, Elsevier, 1st Edition, 2021

Ref Books:

[1] Fundamental of Modem Manufacturing: Materials, Processes and Systems, Mikell P.Groover

[2] Materials &Processes in Manufacturing, E. P. DeGarmo, J. T. Black and Kohser

[3] Manufacturing Engineering &Technology, S. Kalpakjian, S.R. Schmid

[4] A. Ghosh and A. K. Malik, Manufacturing Science, East West Press, 2010.

[5] P. N. Rao, Manufacturing Technology: Foundry, Forming and Welding, 4e (Volume 1) Tata McGraw Hill Education Private Limited (2013)

[6] John O. Milewski. 'Additive Manufacturing of Metals: From Fundamental Technology to Rocket Nozzles, Medical Implants, and Custom Jewelry', Springer, 2017.

[7] A.C. Davies, The Science and Practice of Welding, Vol-2: The Practice of Welding; Cambridge University Press, 2002.

Course Number	**ME5208**
Course Credit	L-T-P-Cr : 0-0-3-1.5
Course Title	**Manufacturing Lab-II**
Learning Mode	Laboratory experiments
Learning Objectives	Complies with PLOs 1 and 5 This course aims to understand the fundamentals of solidification-based manufacturing processes and CAD and CAM of solid components with hands-on training on several experimental setups
Course Description	This course will provide hands-on training on solidification-based manufacturing processes, including additive manufacturing, robotic welding, casting, and CAD and CAM of solid components using CNC-controlled machining.
Course Outline	Dimensional analysis in sand casting, CAD and CAM of solid components using CNC Milling/ CNC Lathe / EDM / WEDM/ WJM, 3D printing, TIG/MIG welding, Friction Welding, CMM, Remote monitoring and control of Industry 4.0-enabled machine tools.
Learning Outcome	The students will be acquiring knowledge of handling instruments and equipment related to solidification-based manufacturing processes and CAD and CAM of solid components. They will also acquire knowledge of Industry 4.0-enabled machine tools.
Assessment Method	Experiment (20%), Report (20%), Viva (60%)

Suggested Readings:

Texts Books:

[1] M. Groover and E. Zimmers, CAD/CAM: Computer-Aided Design and Manufacturing, Publisher: Pearson Education, 2014.

[2] G. K. Lal & S. K. Choudhury, Fundamental of Manufacturing, Publisher: Narosa, 2010.

[3] A. Ghosh and A. K. Malik, Manufacturing Science, Publisher: East West Press, 2010

Department Elective - III						
Sl. No.	**Subject Code**	**Subject**	**L**	**T**	**P**	**C**
1.	ME6203	Laser Processing of Materials	3	0	0	3
2.	ME6208	Robot Motion Planning	3	0	0	3
3.	ME6214	Additive Manufacturing of Metals: Theory and Practice	3	0	0	3
4.	ME6215	Computer Numerical Controlled Machine Tools	3	0	0	3

Course Number	**ME6203**
Course Credit	L-T-P-C: **3-0-0-3**
Course Title	**Laser Processing of Materials**
Learning Mode	Classroom Lecture
Learning Objectives	Complies with PLOs 2, 3, 4 and 5 This course aims to (a) Understand the fundamentals of laser, laser-material interactions, and physics involved in the laser processing of materials. (b) Understand and analyze various laser machining processes used in manufacturing from macro-scale to micro-scale. (c) Understand and analyze various laser joining processes and surface modification techniques. (d) Understand laser-based 3D manufacturing techniques. (e) Acquainted with recent developments in the field of laser material processing.
Course Description	This course is designed to impart the necessary basic knowledge of laser, laser-material interaction, and a wide range of applications of laser material processing.
Course Outline	Module-I : Laser Fundamentals Stimulated Emission, Population Inversion and Amplification; Laser Beam Characteristics: Wavelength, Coherence, Polarization, Mode and Beam Diameter; Industrial Lasers: Solid-Sate Lasers, Gas Lasers, Semiconductor Lasers, Liquid Dye Lasers, etc; Laser Materials Interactions: Absorption of Laser Radiation, Absorption Characteristics of Materials; Thermal Effects - Heating, Melting, Vaporization and Plasma Formation; Time scales. Module-II: Laser Machining Laser Drilling: Melt Expulsion During Laser Drilling, Analysis of Laser Drilling Process, Laser Drilling Applications. Laser Cutting: Evaporative Laser Cutting, Laser Fusion Cutting, Reactive Laser Cutting, Controlled Fracture Technique; Underwater Cutting. Laser Micromachining: Laser Ablation, Laser-Assisted Chemical Etching; Laser Micromachining Techniques - Direct Writing Technique, Mask Projection Technique. Laser Micromachining Applications. Module-III: Laser Fabrication Laser Welding: Process Mechanisms - Keyholes and Plasmas, Analysis of Laser Welding Process. Laser Surface Modification: Heat Treatment, Rapid Solidification, Alloying and Cladding, Surface Texturing. Laser Rapid Prototyping: Classification of RP Processes, Laser Based RP Processes, Applications. Mathematical Modeling. Module-IV: Special Topics

	Laser Interference Processing; Laser Shock Processing; Biomedical Laser Processes, etc.
Learning Outcome	The course training will enable students to achieve the following learning objectives: (a) Basics of laser and laser parameters for various laser-based manufacturing processes. (b) The advantages and limitations of laser-based manufacturing processes with physical insights. (c) The effects of various process parameters in laser material processing. (d) Basic foundation knowledge and analytical skills to perform research on laser material processing.
Assessment Method	Mid Semester Examination, End Semester Examination, Assignments, Quiz, and Seminar.

Suggested Readings:

1. W. M. Steen and J. Mazumder, Laser Material Processing, 4’th Edition, Springer, 2010.
2. N. B. Dahotre and S P Harimkar, Laser Fabrication and Machining of Materials, Springer, 2008.
3. E. Kannatey-Asibu, Principles of Laser Materials Processing, , Wiley, 2009.
4. M. von Allmen and A . Blatter, Laser-Beam Interactions with Materials, 2’nd Edition, Springer, 1998.
5. John C. Ion, Laser Processing of Engineering Materials, Elsevier, 2005.
6. J. F. Ready (Editor), LIA Handbook of Laser Materials Processing, Springer, 2001.
7. Selected Journal Papers

Course Number	**ME6208**
Course Credit	L-T-P-Cr : 3-0-0-3
Course Title	**Robot Motion Planning**
Pre-requisite	Mobile Robotics
Learning Mode	Classroom Lecture
Learning Objectives	Complies with PLOs 3 and 4 • This course covers the prominent motion planning algorithms used in the area of mobile robotics. • The course will cover various motion planning algorithms and analyses.
Course Description	This course introduces students to motion planning algorithm theory and implementation which is a crucial enabling technology for imparting higher degree of autonomy to robots. Prerequisite: ME6106 Mobile Robotics
Course Outline	**Configuration space and topology:** Homeomorphism and diffeomorphism, differential manifolds, connectedness and compactness, parameterization of SO(3) **Potential functions:** Additive attractive/repulsive potential, distance computation using Brushfire algorithm, local minima problem, wave-front planner, navigation potential functions, sphere-space and star-space, potential function in non-Euclidean spaces **Roadmaps:** Visibility maps, Generalized Voronoi Diagram, Retract-like Structures, Canny’s Roadmap algorithm, opportunistic path planner **Cell decomposition:** Trapezoidal decomposition, Morse cell decompositions, Visibility-based decompositions for Pursuit/Evasion; **Sampling-based algorithms:** Probabilistic roadmaps, Expansive spaces trees, Rapidly-Exploring Random Trees, Analysis of PRM.
Learning Outcome	After completing this course, the students will be able to implement and analyse robot motion planning algorithms.
Assessment Method	Mid Semester Examination, End Semester examination, Class test and quiz, Programming Assignments

Suggested Readings:

Text Book:

[1] H. Choset, K. M. Lynch, S. Hutchinson, G. Kantor, W. Burgard, L. E. Kavraki and S. Thrun, Principles of Robot Motion: Theory, Algorithms, and Implementations, MIT Press, Boston, 2005.

Reference Book:

[1] S. M. LaValle, “Planning Algorithms”, Cambridge University Press, 2006. (Available online http://planning.cs.uiuc.edu/)

Course Number	**ME6214**
Course Credit	L-T-P-Cr : 3-0-0-3
Course Title	**Additive Manufacturing of Metals: Theory and Practice**
Learning Mode	Classroom Lecture
Learning Objectives	Complies with PLOs 3, 4 and 5 The course is suitable for UG/PG/Ph.D students. The main objective of the course is to make the student familiar with the recent emerging trends in the processing and fabrication methods of the metal based products. This course is designed to provide a comprehensive overview of the metal based additive manufacturing technologies, its current state and applications in various industries. Also, the numerical modelling approaches, hot deformation theory, and the mechanical metallurgy fundamentals will be dealt in depth in the proposed course.
Course Description	In the present state of the art, the additive manufacturing (AM) has become viable construction tools for fabricating a wide range of structures and complex geometries. The process consists of printing successive/additive layers of materials that are formed layer by layer build up approach. Due to its low material wastage, it has undergone a remarkable evolution over the past three decades. The technology allows combining various manufacturing processes for the production of a bespoke part that applied complex geometries, and has captured an increasing attention across various industrial sectors. The present course is designed to covers both the fundamental and advanced scientific approaches of the additive manufacturing technologies. Prerequisite: Knowledge of conventional manufacturing techniques (welding, powder metallurgy, etc.)
Course Outline	Recent scope in additive manufacturing technologies, Different additive manufacturing processes and relevant working principle/physics, Computer Aided Design for additive manufacturing – 3D model, slicing algorithms, Path planning, Computer Added manufacturing for additive manufacturing – CNC and robot based additive manufacturing, Hybrid additive manufacturing – rolling, friction stir processing, and other severe plastic deformation methods, Large scale additive manufacturing, concept of different auxiliary energies integrated hybrid additive manufacturing systems, process monitoring of additive manufacturing systems, Analytical and numerical modeling approaches in fusion based additive manufacturing methods, Theory of hot deformation mechanisms in severe plastic deformation methods, Materials science in additive manufacturing of metals, Introduction to characterization techniques (SEM, EBSD, TEM, Mechanical dynamic tests, etc.), Theory of microstructural evolution, correlation between microstructure and properties evolution, Industrial applications and future scope of additive manufacturing technologies in various industries.
Learning Outcome	To understanding the underlying scientific principles/physics of the different additive manufacturing techniques. From an applicability viewpoint, this course will help to understand the recent trends in the area of advanced manufacturing techniques and its applications across various industrial sectors such as biomedical, energy, automotive, and defense where the structural and the engineering uses require to achieve high-functionality at low cost. The present course is designed to covers both the fundamental and advanced scientific approaches used in the present state of the art.

Assessment Method	Mid Semester Examination (30 %), End Semester examination (40 %), Class test & quiz (20 %), Assignment (10 %)

Suggested Readings:

Texts and Reference Books:

[1] John O. Milewski. 'Additive Manufacturing of Metals: From Fundamental Technology to Rocket Nozzles, Medical Implants, and Custom Jewelry', Springer, 2017.

[2] Brian Baughman, Donald G. Godfrey, Francisco Medina, Keng Hsu, Li Yang, Mamballykalathil Menon, and Soeren Wiener. 'Additive Manufacturing of Metals: The Technology, Materials, Design and Production', Springer, 2017.

[3] David Ian Wimpenny, Pulak M. Pandey, L. Jyothish Kumar. 'Advances in 3D Printing & Additive Manufacturing Technologies', Springer, 1st Edn, 2017.

[4] Milan Brandt (Edited by). Laser Additive Manufacturing- Materials, Design, Technologies, and Applications, Woodhead Publishing, 2016.

[5] Salvatore Brischetto, Paolo Maggiore, Carlo Giovanni Ferro (Special Issue Editors). Additive Manufacturing Technologies and Applications, MDPI, 2017.

Course Number	**ME6215**
Course Credit	L-T-P-Cr : 3-0-0-3
Course Title	**Computer Numerical Controlled Machine Tools**
Learning Mode	Classroom Lecture
Learning Objectives	Complies with PLOs 1, 2 and 4 The objectives of this course, the student should be able: • To recognize the importance of CNC technology over conventional methods • To learn the fundamentals of CNC machine tools control systems with the help of binary logic circuits and solved numerical • To learn the fundamentals of various electrical and mechanical components of CNC machines with the help solved numerical • To learn about different work and tool holding devices for CNC machines • To write CNC part programming for CNC lathe and milling with the help of solved problems • To learn the fundamentals of writing CNC program for free form surfaces after acquiring knowledge on the mathematical modeling of few contour surfaces with solved numerical • To learn designing of a CNC machine, testing and maintenance
Course Description	This course is designed to introduce the fundamentals of CNC Machine tools to get them accustomed with the control systems used, mechanical and electrical components, work and job holding devices, CNC part programming and design and maintenance of CNC machine tools Prerequisite: NIL
Course Outline	Unit I: An overview of CNC Historical perspective, Introduction to NC/CNC/DNC and its role in FMS and CIMS, Is CNC suitable for mass production, basic elements of CNC machine tools, Machine axes designation, Advantages and disadvantages of CNC machine tools, Use of CNC technology for non-machining applications, CNC machines for industry 4.0 Unit II: Classification of CNC machine tools Point-to-point control (P-T-P), Continuous control, Open-loop control, Closed-loop control, 2 and 3 axes, and 4 and 5 axes CNC machine tools Unit III: Mechanical components of CNC machine tools Drive units of the carriages in CNC machine tools: Recirculating ball screw, Roller screw, Planetary roller screws, Recirculating roller screws Unit IV: Electrical and electronics components of CNC machine tools Power units: Working principle of stepper motors, servo motors, ac servo motors etc.; Encoders: Working principle of incremental, absolute, rotary and linear encoders; Working principle of position down counter (PDC), and decoding logic circuits, Interpolators: linear, circular etc., Digital differential analyzer (DDA) hardware-based linear and curvilinear interpolation Unit V: Tooling for CNC machine tools Tool changing arrangements: manual tool changer, automatic tool changer (ATC), tool turrets, tool magazines: chain magazine, circular magazine, and box magazine Unit VI: Work-holding for CNC machine tools Turning center work holding methods, Work holding for machining centers Unit VII: CNC part programming

	Introduction to part programming, advanced programming features and canned cycles, machining of free-form (3D) surfaces: curved surface geometries, cutter path generation for curved surfaces, CNC program generation using CAM software, Remote operation Unit VIII: Design, testing and maintenance of CNC machine tools Design of CNC machine tools for static, dynamic and thermal loads, Testing and calibration of CNC machine tools for geometric, kinematic and thermal errors, Maintenance and troubleshooting operation, Online inspection features
Learning Outcome	The student will be able to • Apply the knowledge of CNC technology taught in this course to develop laboratory scale CNC system • Apply the knowledge of part programming to manufacture any intricate surfaces using CNC machine tools
Assessment Method	Mid Semester Examination (25%), End Semester examination (50%), Class test & quiz (15%), Assignment and Mini Project (10%)

Suggested Readings:

References:

[1] CAD/CAM: Computer-Aided Design and Manufacturing, MP Groover, PTR Prentice-Hall, New Jersey
[2] CNC machining Technology, Graham T. Smith, Springer Verlag, London
[3] Computer Numerical Control Machines and Computer Aided Manufacturing, P Radhakrishnan, New Academic Science Limited, UK
[4] Machining and CNC Technology, Michael Fitzpatrick, McGraw Hill
[5] Computer Numerical Control of Machine Tools, G.E Thyer, NewNes, 1991
[6] CAD/CAM Theory and Practice, Ibrahim Zeid and R Sivasubramanian, Tata McGraw Hill, New Delhi, 2009.

Department Elective - IV						
Sl. No.	**Subject Code**	**Subject**	**L**	**T**	**P**	**C**
1.	ME6210	Robotics: Advanced Concepts & Analysis	3	0	0	3
2.	ME6211	Analysis of Welding Processes	3	0	0	3
3.	ME6212	Fracture and Fatigue	3	0	0	3

Course Number	**ME6210**
Course Credit	L-T-P-Cr : 3-0-0-3
Course Title	**Robotics: Advanced Concepts and Analysis**
Learning Mode	Classroom Lecture
Learning Objectives	Complies with PLOs 3, 4 and 5 • This course gives various aspects of kinematics, dynamics, motion planning, and control of robotic manipulators • This course presents computational aspects, control aspects and practical implementation of multi degree of freedom manipulators for industrial application
Course Description	This course is designed to fulfil the basic and advanced concepts of kinematics, dynamics, motion planning, and control of industrial Robotics. The course will provide theoretical background as well as expose the students to practical aspects of Robotic manipulators. Prerequisite: NIL
Course Outline	Introduction to robotics: brief history, types, classification and usage and the science and technology of robots. Kinematics of robot: direct and inverse kinematics problems and workspace, inverse kinematics solution for the general 6R manipulator, redundant and over-constrained manipulators. Velocity and static analysis of manipulators: Linear and angular velocity, Jacobian of manipulators, singularity, static analysis. Dynamics of manipulators: formulation of equations of motion, recursive dynamics, and generation of symbolic equations of motion by computer simulations of robots using software and commercially available packages. Planning and control: Trajectory planning, position control, force control, hybrid control Industrial and medical robotics: application in manufacturing processes, e.g. casting, welding, painting, machining, heat treatment and nuclear power stations, etc.; medical robots: image guided surgical robots, radiotherapy, cancer treatment, etc. Advanced topics in robotics: Modelling and control of flexible manipulators, wheeled mobile robots, bipeds, etc. Future of robotics.
Learning Outcome	• After completing this course, the students will be able to design and fabricate a robotic arm for some practical applications • Students will able to operate and control a robotic system using the theoretical concepts learned in this course
Assessment Method	Mid Semester Examination, End Semester examination, Class tests, Assignments, mini-projects

Suggested Readings:

Reference Books:

[1] M. P. Groover, M. Weiss, R. N. Nagel and N. G. Odrey, “Industrial Robotics-Technology, Programming and Applications”, McGraw-Hill Book and Company (1986).

[2] S. K. Saha, “Introduction to Robotics”, Tata McGraw-Hill Publishing Company Ltd. (2008).

[3] S. B. Niku, “Introduction to Robotics–Analysis Systems, Applications”, Pearson Education (2001).

[4] A. Ghosal, Robotics: “Fundamental Concepts and Analysis”, Oxford University Press (2008).

[5] Pires, “Industrial Robot Programming–Building Application for the Factories of the Future”, Springer (2007).

[6] Peters, “Image Guided Interventions – Technology and Applications”, Springer (2008).
[7] K. S. Fu, R. C. Gonzalez and C.S.G. Lee, “ROBOTICS: Control, Sensing, Vision and Intelligence”, McGraw-Hill (1987).
[8] J. J. Craig, “Introduction to Robotics: Mechanics and Control”, 2nd edition, Addison-Wesley (1989).

Course Number	**ME6211**
Course Credit	L-T-P-Cr : 3-0-0-3
Course Title	**Analysis of Welding Processes**
Learning Mode	Classroom Lecture
Learning Objectives	Complies with PLO 3, 4, 5 This course aims to impart (a) the fundamental concepts and process details of fusion and non-fusion welding processes, (b) analysis of the processes focusing the role of process parameters, heat generation, heat distribution and metallurgical aspects, (c) weld design and testing aspects of welded joints.
Course Description	This course is designed to fulfil the concepts, process behavior, and analysis of various fusion and non-fusion welding processes, metallurgical aspects, and quality, testing of welded joints. Prerequisite: Basic course on Manufacturing Processes that covers welding processes or equivalent course
Course Outline	Fundamentals of fusion welding – different arc welding techniques; Welding power source: behavior, characteristics, analysis; Physics of Arc; Heat generation, 2D/3D heat flow and heat transfer analysis; Physics and analysis of metal transfer in arc welding, forces on metal pool; Process characteristics of some common arc welding processes e.g. SMAW, TIG, GMAW, SAW etc.; Concepts of flux activated welding, pulsed current welding. Review of different non-fusion welding techniques; Analysis of heat generation during friction, friction stir welding techniques; Fundamentals and applications of other non-fusion welding etc. Welding metallurgy: Heat flow, cooling rate and metallurgical transformations, solidification and cracking; Phase transformations-weld CCT diagrams; Welding of steels – Schaffler and Delong diagrams, Weld metallurgy of Non-ferrous alloys. Welding symbols and concepts of joint design; Weld defects; Joint quality assessments by destructive and non-destructive testing.
Learning Outcome	After completing the course, the students will be able to (a) identify the process characteristics and behavior of fusion, non-fusion welding processes, (b) perform thermal analysis, and appraise the metallurgical changes in welded joints, (c) suitably design for the weld and assess the weld quality.
Assessment Method	Mid Semester Examination, End Semester examination, Assignments and Quiz

Suggested Readings:

Text Books:

[1] A.C. Davies, The Science and Practice of Welding, Vol-2: The Practice of Welding; Cambridge University Press, 2002.
[2] D. J. Hoffman, K. R. Dahle, D. J. Fisher, Welding; Pearson publication, 2017.

Reference Books:

[1] R.W. Messler, Principles of Welding: Processes, Physics, Chemistry, and Metallurgy; John Wiley & Sons, 1999.
[2] R. Little, Welding and Welding Technology, McGrawHill, 2017.
[3] S. Kou, Welding Metallurgy, Second Ed., John Wiley & Sons, 2003.
[4] Fundamentals of Welding, Welding Handbook, Part-I, American Welding Society, 1976.
[5] Metals and their Weldability, Welding Handbook, Part-4, American Welding Society, 1982.

Course Number	**ME6212**
Course Credit	L-T-P-Cr : 3-0-0-3
Course Title	**Fracture & Fatigue**
Learning Mode	Classroom Lecture
Learning Objectives	Complies with PLOs 3, 4 and 5 To provide the analytical and mathematical concepts of fracture mechanics and its applications in wide range of engineering problems.
Course Description	This course discusses topics starting from Griffith's theory of brittle failures, linear elastic fracture mechanics, Irwin's stress intensity factors; Linear elastic fracture mechanics: crack tip stress and deformation fields, Stress intensity factor (SIF) SIF and ERR; First order estimate of plastic zone using Irwin's and Dugdale approach; Elasto-plastic fracture: J-integral and CTOD, Mixed mode fracture; Experimental evaluation of Fracture Toughness, J integrals, Crack nucleation and growth, Fatigue crack growth theories, Fatigue life prediction. **Prerequisite:** Knowledge of solid mechanics or equivalent course
Course Outline	**Introduction**: Background; Griffith theory of fracture, energy release rate (ERR), conditions for stable and unstable crack growth, crack arrest **Linear elastic fracture mechanics**: Stress field at the tip of a crack, solution of stress and displacement field for plane cracks using complex methods in plane elasticity. Stress intensity factor (SIF) for plane and penny shaped cracks, Embedded Cracks, Equivalence of SIF and ERR, fracture toughness. **Elasto-plastic fracture mechanics**: First order estimate of crack tip plastic zone using Irwin's and Dugdle's approach, Plastic zone for plane stress and plane strain situation and effect on fracture toughness, Review of small strain plasticity, Crack tip fields in an elasto-plastic material (Discussion on HRR fields) J-integral as a fracture parameter and crack tip opening displacement. **Mixed mode fracture:** Prediction of crack path and critical condition for crack extension under mixed mode loading using Maximum tensile stress, Minimum strain energy density and Maximum energy release rate criteria. **Experimental measurement of SIF and fracture toughness:** Measurement of plain strain fracture toughness (K_{IC}), Measurement of J_{IC}, Measurement of Critical COD. **Fatigue crack growth:** Mechanism of crack nucleation and growth under cyclic loading, Crack closure, Determination of life of a cracked solid using Paris-Erdogan law and its variants, Variable amplitude cyclic loading.
Learning Outcome	• Understanding of fundamental concepts behind the failure of material and mathematical foundation from mechanics. • Ability to understand how material fails and ability to prevent such failures. • Laboratory testing procedure of fracture parameters. Ability to predict the remaining life of the specimen/component.
Assessment Method	Class tests, quiz, Project (Case Studies), Mid-semester and End semester Examination.
Suggested Readings:	

Text Books:

[1] T.L. Anderson, Fracture mechanics fundamentals and applications; CRC Press: Florida, Fourth Edition, 2017.

Reference Book

[1] C.T Sun and Z.H Jin, Fracture Mechanics; Elsevier: Oxford, First Edition, 2012.
[2] Prashant Kumar, Elements of Fracture Mechanics, Tata McGraw Hill, New Delhi, India, 2009.
[3] E. E. Gdoutos, Fracture Mechanics- An Introduction, Springer Netherlands,1990.
[4] D. Broek, Elementary Engineering Fracture Mechanics, Kluwer Academic Publishers, Dordrecht, 1986.
[5] M. Janssen, J. Zuidema and R.J.H Wanhill, Fracture Mechanics, Spon Press, New York, 2005.
[6] S. Suresh, Fatigue of Materials, Cambridge University Press, UK, 2003.