One Year Post Graduate Diploma in Additive Manufacturing

Course Structure

Semester I

Sr. No.	Course Code	Course Name	Teaching Scheme			Credits
			L	T	P	
1		Additive Manufacturing Processes, Machines and Applications	3	-	-	**3**
2		Lasers in Manufacturing Technology	3	-	-	**3**
3		Materials and Characterization Techniques	3	-	-	**3**
4		CAD for Additive Manufacturing	3	-	-	**3**
5		CAD Lab	-	-	2	**1**
6		AM Lab	-	-	2	**1**
		Total	**12**	**-**	**4**	**14**

Semester II

Sr. No.	Course Code	Course Name	Teaching Scheme			Credits
			L	T	P	
1		Metal Additive Manufacturing	2	1	-	**3**
2		Rapid Tooling and Industrial Applications	3	-	-	**3**
3		Reverse Engineering Lab	-	1	2	**2**
4		Mini Project	-	-	-	**5**
5		* Elective	2	1	-	**3**
		Total	**7**	**3**	**2**	**16**

List of Electives:

1. Micro and Nano Manufacturing
2. Product Design for Manufacturing and Assembly
3. Mathematical Modeling and Simulation of Manufacturing Systems

Semester III

Sr. No.	Course Code	Course Name	Teaching Scheme			Credits
			L	T	P	
1		Project Stage 1	-	-	-	2
2		Project Stage2	-	-	-	18
		Total				**20**

SEMESTER I

Additive Manufacturing Processes, Machines and Applications

1. **Introduction to Additive Manufacturing (AM):** Introduction to AM, AM evolution, Distinction between AM and CNC machining, Advantages of AM,
2. **AM process chain**: Conceptualization, CAD, conversion to STL, Transfer to AM, STL file manipulation, Machine setup, build , removal and clean up, post processing.
3. **Classification of AM processes:** Liquid polymer system, discrete particle system, molten material systems, solid sheet system.
4. **Design for AM:** Motivation, Design for manufacturing and Assembly concepts and objectives, AM unique capabilities, Exploring design freedoms, Design tools for AM, Part Orientation, Removal of Supports, Hollowing out parts, Inclusion of Undercuts and Other Manufacturing Constraining Features, Interlocking Features, Reduction of Part Count in an Assembly, Identification of markings/ numbers etc.
5. **Guidelines for process selection:** Introduction, selection methods for a part, challenges of selection, example system for preliminary selection, production planning and control
6. **AM Applications:** Functional models, Pattern for investment and vacuum casting, Medical models, art models, Engineering analysis models, Rapid tooling, new materials development, Bi-metallic parts, Re-manufacturing. Application examples for Aerospace, defense, automobile, Bio-medical and general engineering industries
7. **Post processing of AM parts:** Support material removal, surface texture improvement, accuracy improvement, aesthetic improvement, preparation for use as a pattern, property enhancements using non-thermal and thermal techniques.
8. **Future Directions of AM:** Introduction, new types of products and employment and digiproneurship.
9. **Construction of basic AM machines:** Construction of CNC Machine - Axes, Linear motion guide ways, Ball screws, Motors, Bearings, Encoders/ Glass scales, Process Chamber, Safety interlocks, Sensors
10. **Energy delivery, Material delivery, Nozzle and Heating Systems:** Lasers and electron beam, Laser scanning system and Fiber Delivery Systems, Powder feeding and Wire feeding systems, Multi-material processing, Co-axial and Lateral Nozzles.
11. **Optical and Optoelectronic components in AM:** Laser, basic laser optics, collimators, beam expanders, optic fibers, metal optics etc.
12. **CNC Controller and Process Controller:** CNC Controller, Process Controller – Process parameters, Scanning strategies – Raster scan, Patterned Vector Scanning and Hatching Patterns.
13. **Environmental control systems:** Environmental controller for temperature, oxygen level, humidity etc.

READING:

1. Chua Chee Kai, Leong Kah Fai, “Rapid Prototyping: Principles and Applications”, World scientific, 2003.
2. Ian Gibson, David W Rosen, Brent Stucker., “Additive Manufacturing Technologies: Rapid Prototyping to Direct Digital Manufacturing”, Springer, 2010
3. Ali K. Kamrani, Emand Abouel Nasr, “Rapid Prototyping: Theory and Practice”, Springer, 2006.
4. D.T. Pham, S.S. Dimov, Rapid Manufacturing: The Technologies and Applications of Rapid Prototyping and Rapid Tooling, Springer 2001

Lasers in Manufacturing Technology

1. **Introduction:** Electromagnetic Radiation, Energy Levels, Interaction of Radiation and Matter, Spontaneous and stimulated emission, Population Inversion, Resonant Cavity.
2. **Properties of Laser Light:** Linewidth, Beam Divergence Angle, Spatial Profiles of Laser Beams, Temporal Behavior of Laser Output, Coherence, Radiance, Focusing Properties of Laser Radiation, Power.
3. **Practical Lasers**: Gas Lasers – He-Ne lasers, Noble Gas Ion-lasers, CO2 Lasers, Excimer lasers; Solid state lasers. Semi-conductor diode lasers; Beam conditioning; High power diode lasers, Optically pumped lasers, Diode-Pumped Solid State Tunable Lasers.
4. Light beam deflectors, Q-switches, Optical isolators, Beam profilers, Beam homogenizers, Laser care and safety
5. Interaction of High Power Laser Radiation with Materials, Laser Applications in Material **Professing:** welding, Hardening, Laser alloying, cladding, Laser induced material removal: drilling, cutting, marking

READING:

1. K. Thyagarajan, Ajoy Ghatak, *Lasers: Fundamentals and applications*, 2nd Ed., Springer, 2010
2. Ready, J.F, *Industrial applications of Lasers*, Academic Press, 2nd Ed., 1997
3. Willium T Selfvast, *Laser Fundamentals*, Cambridge Univ. Press, 2008

Materials and Characterization Techniques

1. **General review of materials** in engineering and their relative positions in application in engineering fields. Metallic, ceramic and polymer based materials. Polymeric materials, general character and main applied groups of thermoplastic and thermosetting polymers.
2. **Characterization** of materials for engineering use and its evolution. Mechanical properties, chemical analysis, techniques for material constitution – metallography, optical and electron microscopy, X-ray methods- diffraction and fluorescence methods, constitution by cooling curves, phase diagrams, Thermal analysis and related methods. Electronic and magnetic properties. Assessment of average chain-length and average molecular weight in polymers. Gel chromatography,
3. **Powder Metallurgy and Powder Technology.** Characterization of powders. Alloys and materials based on powder metallurgy. Compacting and Sintering. Processes involved in sintering. Loose powder sintering. Selective laser sintering.
4. **Microscopy:** Optical microscopy, Transmission electron microscopy, Scanning electron microscopy. Specimen preparation, imaging modes, Applications, Limitations. Limitations of microscopic methods for polymeric materials. Atomic force microscopy and scanning probe microscopy.
5. **Thermal Analysis -** Introduction, Basi cs of thermodynamics and heat transfer, Common characteristics- Instrumentation, experimental parameters, Different types used for analysis, Differential thermal analysis, Differential Scanning Calorimetry, Thermogravimetry, Dilatometry, Dynamic mechanical analysis- Basic principles, Instrumentation, working principles, Applications, Limitations
6. **X- Ray Diffraction (XRD) -** Introduction, Basic principles of diffraction, X - ray generation, Instrumentation, Applications. Limitation of Diffraction methods for polymers. Small angle scattering methods for polymers.
7. **X- Ray Spectroscopy for Elemental Analysis –** Introduction, Wavelength Dispersive Spectroscopy and Energy Dispersive Spectroscopy - Instrumentation, Working procedure, Applications, Limitations. Electron Probe Micro Analyzer (EPMA)

READING:

1. ASM Handbook: Materials Characterization, ASM International, 2008.
2. P R Khangaonkar: Introduction to Materials Characterization, Penram Publishing (I) pvt. Ltd., 2010
3. Yang Leng: Materials Characterization-Introduction to Microscopic and Spectroscopic Methods, John Wiley and Sons (Asia) Pte Ltd., 2008.
4. Robert F. Speyer: Thermal Analysis of Materials, Marcel Dekker Inc., New York, 1994.
5. S.J.B. Reed: Electron Microprobe Analysis, Cambridge University Press, London, 1975.

CAD for Additive Manufacturing

1. **2D and 3D Transformations of geometry:** Translations, Scaling, Reflection, Rotation, Homogeneous representation of transformation, Concatenation of transformations, Perspective, Axonometric projections, Orthographic and Oblique projections.
2. **Design of Curves:** Analytic Curves, PC curve, Ferguson, Composite Ferguson, curve Trimming and Blending, Bezier segments, de Casteljau's algorithm, Bernstein polynomials, Bezier- subdivision, Degree elevation, Composite Bezier, Splines, Polynomial Splines, B-spline basis functions, Properties of basic functions, Knot Vector generation, NURBS.
3. **Design of Surfaces:** Differential geometry, Parametric representation, Curves on surface, Classification of points, Curvatures, Developable surfaces, Surfaces of revolution, Intersection of surfaces, Surface modeling, 16-point form, Coons patch, B-spline surfaces.
4. **Design of Solids:** Solid entities, Boolean operations, B-rep of Solid Modeling, CSG approach of solid modeling, advanced modeling methods.
5. **Reverse Engineering:** Introduction and Scope of Reverse Engineering, Co-ordinate Measuring Machine-Types of CMM, Probe used, Applications, 3D scanning and Digitizing Devices

READING:

1. Ibrahim Zeid: Mastering in CAD-CAM, Tata McGraw Hill Publication.
2. Mikel P. Groover and Emory W. Zimmers: Computer Aided Design and Manufacturing, Prentice Hall.
3. Paul C. Bave: CAD Principles and Applications
4. Co-ordinate Measurment and reverse engineering, Donald R. Honsa, ISBN 1555897, American Gear Manufacturers Association
5. Design Recovery for Maintenance and Reuse, T J Biggerstaff, IEEE Corpn. July 1991
6. Data Reverse Engineering, Aiken, Peter, McGraw-Hill, 1996
7. Reverse Engineering, Linda Wills, Kluiver Academic Publishers, 1996
8. Manuals of Co-ordinate measuring machines and systems.
9. Opto Electronics for Technology and Engineering - Robert G. Seippel Prentice Hall New Jersey – 1989

CAD Lab

1. **Introduction-** Scope and tasks of CAD Modelling, Assignments on Transformations etc.

2. **Tools for CAD –** Introduction to CAD Software, assignments on CAD Modelling for different components (Part Modeling, Assembly Modelling),

3. **STL -** Generation of STL File, STL File Problems, STL File Manipulation (Materialize Magics, and NETFAB)

4. **Generative Design :** Use of Fusion 360 Module for Generative Design

Additive Manufacturing Lab

1. **Rapid Prototyping**- Introduction to Additive Manufacturing, Classification of AM

2. **3D Printing Software :** Introduction of 3D Printing Software, process parameters for Additive Manufacturing Technology (CURA, GRABCAD)

3. **Assembly of AM Machines –** Assembly and Construction of FDM Technology 3D Printing Machine.

4. **Hands-On Experience -** Practicals on every technology machine in 3D Make Lab,

SEMESTER II

Metal Additive Manufacturing

1. **Introduction to Metal Additive Manufacturing (AM) Processes:** Metal AM Trends, Classification, Opportunities, Design for metal AM.
2. **Introduction to Powder Bed Fusion (PBF) processes:** SLM, DMLS, EBM, Binder jetting, subsystems, and their process parameters Advantages and limitations, Challenges and remedies in deposition, Applications.
3. **Introduction to Direct energy deposition processes:** Process Description, Material Delivery, LENS, WLAM, Plasma wire AM, TIG wire AM, Plasma powder AM, subsystems, and their process parameters Advantages and limitations, Challenges and remedies in deposition, Applications.
4. **Introduction to Sheet lamination process:** Ultrasonic consolidation, subsystems, and their process parameters Advantages and limitations, Challenges and remedies, Applications.
5. **Materials and their properties:** Factors affecting solidification in metal AM, Defects, Microstructural properties, Mechanical properties, Phases after post process, Materials such as Ferrous Alloys, Titanium alloys, Nickel Alloys, Aluminum Alloys
6. **Physical phenomena and governing equations during metal deposition:** Absorption, heat conduction, Surface convection and radiation
7. **Case studies:** Medical and dental, Aerospace and defense, Automobile, Cooling Channels, Topology optimizations.

READING:

1. Ehsan Toyserkani, Dyuti Sarker, Osezua Obehi Ibhadode, Farzad Liravi, Paola Russo, Katayoon Taherkhani, “Metal Additive Manufacturing” Wiley, 2022.
2. Richard Leach and Simone Carmignato, “Precision Metal Additive Manufacturing” CRC press, 2021.
3. Michael Gouge Pan Michaleris, “Thermo-Mechanical Modeling of Additive Manufacturing”, Elsevier, 2018.
4. Milan Brandt, “Laser Additive Manufacturing Materials, Design, Technologies, and Applications” Elsevier, 2017.

Rapid Tooling and Industrial Applications

1. **Introduction:** Convectional Tooling Vs. Rapid Tooling, Classification of Rapid Tooling, Direct and Indirect Tooling methods, Soft and Hard Tooling methods.
2. **Rapid Tooling Process Modeling:** Introduction to modeling, Concurrent Rapid Product and Process Development, Finite Element Modeling and Simulation, Injection-moulding, Die-casting, Blow-moulding, Theroforming Processes modeling
3. **Indirect Methods for Rapid Tool Production and Rapid Bridge Tooling**: Role of Rapid Soft Tooling methods in tool production, Introduction to Bridge tooling, CAFÉ Bridge tooling, DirectAIM Rapid Bridge tooling, RapidTool Rapid Bridge tooling, Shrinkage Variation, Random-noise Srinkage, Metal deposition tools, RTV tools, Epoxy tools, Ceramic tools, Cast Metal tools, Investment-cast Rapid Production tooling, Fusible metallic cores, Rapid Production tooling for Precision Sand Casting, Keltool process.
4. **Direct Method for Rapid Tool Production:** Role of direct methods in tool production, Direct ACES Injection moulds, Laminated Object Manufactured (LOM) tools, DTM Rapid Tool, RapidSteel 1.0, RapidSteel 2.0, Copper Polymide tools, SandForm tools, EOS Direct Tool Process, Direct Metal Tooling using 3DP, Topographic Shape Formation (TSF) tools.
5. **The Express Tool Process:** Introduction, High-Thermal-Conductivity Materials, Conformal Cooling Channels, The Express Tool Process, Finite-Element Analysis of Express Tools, Express Tool Process Characteristics, Case studies of Express Tools.
6. **The Role of Rapid Tooling in Investment-Casting Applications:** Introduction, Rapid Tool Making for investment Casting, Rapid Tooling for developing Casting Applications, BELL Helicopter 427 Program
7. **The Role of Rapid Tooling in Sand-Casting Applications:** Sand casting Process, Tool Design and Construction for Sand Casting, Sand Casting Dimensional Control, Tooling Alternative Selection Case Studies.
8. **Rapid Tooling in the Medical Device Industry:** Introduction, Investment Casting and Conventional Wax Pattern Tooling, Conventional Tooling Manufacture Vs. Rapid Tooling Manufacture, Medical Case studies like Hip Stem and Knee implants.
9. **Rapid Tooling in the Automotive Industry:** Approaching Niche Vehicle Markets, Accelerating Product Developments, Utilizing Rapid Prototyping and Manufacturing, Machining Laminates, Rapid Prototype Stages, Subsequent Casting Operations, Rapid Tooling Developments, Case Studies.
10. **The Future of Rapid Tooling and Rapid Manufacturing:** Factors influencing Accuracy of tools, Data Preparation Errors, Part Building Errors, Selection of Part Build Orientation, Post-processing methods.

READING:

1. D.T. Pham and S.S Dimov, Rapid Manufacturing: The Technogies and Applications of Rapid Prototyping and Rapid Tooling, Springer, 2001.
2. Peter Hilton and Paul F Jacobs, Rapid Tooling Technologies and Industrial Applications, Marcel Dekker Inc, New York, 2001
3. Wanlong Wang, Henry W. Stoll and James G. Conley, Rapid Tooling Guidelines for Sand Casting, Springer, 2010.
4. Andreas Gebhardt, Understanding Additive Manufacture: Rapid Prototyping, Rapid Tooling and Rapid Manufacture, Hanser Publishers, 2013.

Reverse Engineering (RE) Lab

1. **Introduction -** Introduction to Reverse Engineering Applications etc.

2. **Data Generation using Reverse Engineering -**
    a. CMM - Working principle and construction of CMM, Demonstration of CMM operations, Use of CMM for inspection and scanning a 3D object, etc.
    b. 2D Scanning - Demonstration and use of 'Rapid I' a vision based measurement system, Visual inspection and measurement of 2D features of parts, Metrological measurements of various features using Rapid I.
    c. 3D Scanners- Introduction to Photogrammeter, Types of 3D scanners - working principles, Setup and use of 3D scanners, 3D point cloud data collection and processing with the help of associated software Programmes like Artec, David, etc., Application oriented case study.

3. **Data handling using Reverse Engineering –** Point cloud data handling and reduction methods, Conversion of Point Cloud Data into .stl file.

List of Electives

Micro and Nano Manufacturing

1. **Introduction:** Importance of Nano-technology, Emergence of Nanotechnology, Bottom-up and Top-down approaches, challenges in Nanotechnology
2. **Nano-materials Synthesis and Processing:** Methods for creating Nanostructures; Processes for producing ultrafine powders- Mechanical grinding; Wet Chemical Synthesis of nano-materials- sol-gel process, Liquid solid reactions; Gas Phase synthesis of nano-materials- Furnace, Flame assisted ultrasonic spray pyrolysis; Gas Condensation Processing (GPC), Chemical Vapor Condensation(CVC)- Cold Plasma Methods, Laser ablation, Vapour – liquid –solid growth, particle precipitation aided CVD, summary of Gas Condensation Processing(GPC).
3. **Structural Characterization:** X-ray diffraction, Small angle X-ray Scattering, Optical Microscope and their description, Scanning Electron Microscopy (SEM), Scanning Probe Microscopy (SPM), TEM and EDAX analysis, Scanning Tunneling Microscopy (STM), Atomic force Microscopy (AFM).
4. **Spectroscopic characterizations:** Basic concepts of spectroscopy, operational principle and application for analysis of nano-materials, UV-VIS-IR Spectrophotometers, Principle of operation and application for band gap measurement, Raman spectroscopy.
5. **Surface Characterization:** X-ray Photoelectron Spectroscopy (XPS), Auger electron spectroscopy, Low Energy Ion Scattering Spectroscopy (LEISS), Secondary Ion Mass Spectroscopy (SIMS), Rutherford Backscattering Spectroscopy (RBS).
6. **Thermal Characterization of Nano-materials:** DTA, TGA, DSC (Principle and Applications), Determination of thermo physical parameters.
7. **Micro fabrication Techniques**: Lithography, Thin Film Deposition and Doping, Etching and Substrate Removal, Substrate Bonding, MEMS Fabrication Techniques, Bulk Micromachining, Surface Micromachining, High- Aspect-Ratio Micromachining
8. **Nanofabrication Techniques:** E-Beam and Nano-Imprint Fabrication, Epitaxy and Strain Engineering, Scanned Probe Techniques, Self-Assembly and Template Manufacturing.
9. **MEMS devices and applications**: Pressure sensor, Inertial sensor, Optical MEMS and RF-MEMS, Micro-actuators for dual-stage servo systems.

READING:

1. Mark James Jackson, Microfabrication and Nanomanufacturing, CRC Press, 2005.
2. Gabor L. Hornyak, H.F Tibbals, Joydeep Dutta and John J Moore, Introduction to Nanoscience and Nanotechnology, CRC Press, 2009.
3. Ray F. Egerton , Physical Principles of Electron Microscopy: An Introduction to TEM, SEM, and AEM , Springer, 2005.
4. Robert F Speyer, Thermal Analysis of Materials, Marcel Dekker Inc , New York, 1994.
5. B.D. Cullity - Elements of X-Ray Diffraction, 3rd edition, Prentice Hall , 2002.
6. Tai-Ran Hsu, “MEMS and Microsystems: Design and Manufacture,” McGraw- Hill, 2008

Product Design for Manufacturing and Assembly (PDFMA)

1. **Introduction to Product Design for Manufacturing and Assembly (PDFMA):** Working of DFMA, Reasons for Not Implementing DFMA, What Are the Advantages of Applying DFMA During Product Design, Typical DFMA Case Studies, Overall Impact of DFMA on Industry.
2. **Design for Manual Assembly**: General Design Guidelines for Manual Assembly, Development of the Systematic DFA Methodology, Assembly Efficiency, Effect of Part Symmetry, Thickness, Weight on Handling Time, Effects of Combinations of Factors, Application of the DFA Methodology.
3. **High speed Automatic Assembly and Robot Assembly:** Design of Parts for High-Speed Feeding and Orienting, Additional Feeding Difficulties, High-Speed Automatic Insertion, General Rules for Product Design for Automation, Design of Parts for Feeding and Orienting, Product Design for Robot Assembly.
4. **Design for Machining and Injection Molding:** Machining Using Single-Point and Multi point cutting tools, Choice of Work Material, Shape of Work Material, Machining Basic Component Shapes, Cost Estimating for Machined Components, Injection Molding Materials, The Molding Cycle, Injection Molding Systems, Molding Machine Size, Molding Cycle Time, Estimation of the Optimum Number of Cavities, Design Guidelines.
5. **Design for Sheet Metal working and Die Casting:** Dedicated Dies and Press-working, Press Selection, Turret Press working, Press Brake Operations, Design Rules, The Die Casting Cycle, Auxiliary Equipment for Automation, Determination of the Optimum Number of Cavities, Determination of Appropriate Machine Size, Die Casting Cycle Time Estimation, Die Cost Estimation, Design Principles.
6. **Design for Assembly Automation:** Fundamentals of automated assembly systems, System configurations, parts delivery system at workstations, various escapement and placement devices used in automated *as*sembly systems, Quantitative analysis of Assembly systems, Multi station assembly systems, single station assembly lines.

READING:

1. Geoffrey Boothroyd, Assembly Automation and Product Design, Marcel Dekker Inc., NY, 3rd Edition, 2010.
2. Geoffrey Boothroyd, Hand Book of Product Design, Marcel Dekker Inc., NY, 1992.

Mathematical Modeling and Simulation of Manufacturing Systems

1. **System Modelling**
   Concept of state: System, Environment and Variables. The state of a system, mathematical models of continuous line linear lumped parameter time invariant systems, Discrete time systems, Linear approximation of non-linear systems, Topological models of system, Block diagram representation, Signal flow graph, Mason's rule.
   A generalized approach to modelling: Principles of conservation and continuity, Physical laws, Mechanical systems, Electrical and electromechanical systems, Fluid systems, Thermal systems.
   Modelling of physical systems: The linear graph approach. Linear graph Terminology, Formulation of system equations.
2. **Discrete Event Simulation**
   Design (component and organization) of a simulation experiment. Rational selection of input distribution. Output data analysis. Variance reduction techniques, Model validation. Discrete event systems, Time advance mechanism, Simulation, Monte Carlo and stochastic simulation, Generation of random numbers, Pseudo random numbers, Test for random number, simulation of probability distributions, Discrete event simulation: Simulation of single server and multiple server queuing system, Simulation of PERT network, Analysis of an activity, Network, Simulation of inventory system and manufacturing system.
3. **Simulator Technology:** Motion systems, Instrumentation systems, Interface technology, Six degrees of freedom systems, Aural systems, Visual systems, Fidelity of man-machine systems with respect to simulation of one of the systems - land systems, air systems, submarine systems. Latest trends in simulators

READING:

1. Law A.M. and Kelton W.D, Simulation Modeling and Analysis
2. Narasingh Deo, System Simulation with Digital Computer, Prentice Hall,1979.
3. Kheir N.A, System Modelling and Computer Simulation, Marcell Dekker,1996.
4. Taha H.A, Operations Research: An Introduction, Prentice Hall,1997.
5. Rolfe, J M ; Staples, K.J.Flight , Simulation(Cambridge Aerospace Series), Cambridge. Univ. Press 1986.
6. Nicola Bellomo and Luigi Preziosi, Modelling Mathematical Methods and Scientific Computations, 1995, , CRC Press.
7. I.J. Nagarath and M. Gopal, Systems Modelling and Analysis, , Tata McGraw Hill, New Delhi.