ADDITIVE MANUFACTURING SYLLABI

		L	T	P	C
19MEAM01	**ADDITIVE MANUFACTURING TECHNOLOGIES AND APPLICATIONS**	**3**	**0**	**0**	**3**

Prerequisites for the course

Nil

Objectives

Students undergoing this course are expected to

1. Know the principles, methods, areas of usage, possibilities and limitations of the additive manufacturing technologies
2. Be familiar with the characteristics of various materials that are used in additive manufacturing.

UNIT I	**ADDITIVE MANUFACTURING FUNDAMENTALS**	**9**

Need for time compression in product development, Need for Additive Manufacturing (AM), Historical development, Fundamentals of Additive Manufacturing, AM Process Chain, Advantages and Limitations of AM, Classification of AM process, Comparison of AM with CNC and other technologies.

UNIT II	**LIQUID-BASED AM SYSTEMS**	**9**

Stereo lithography Apparatus (SLA): Models and specifications, Process, working principle, photopolymers, photo polymerization, Layering technology, Laser scanning, Applications, Advantages and Limitations, Case studies. Solid Ground Curing (SGC): Models and specifications, Process, working principle, Applications, Advantages and Limitations, Case studies. Polyjet: Process, working principle, Applications, Advantages and Limitations, Case studies. Introduction to microfabrication.

UNIT III	**SOLID-BASED AM SYSTEMS**	**9**

Laminated Object Manufacturing (LOM): Models and specifications, Process, working principle, Applications, Advantages and Limitations, Case studies. Fused Deposition Modelling (FDM): Models and specifications, Process, working principle, Applications, Advantages and Limitations, Case studies. Multi-Jet Modelling (MJM): Models and specifications, Process, working principle, Applications, Advantages and Limitations, Case studies. Introduction to Direct Metal Deposition (DMD), Electron Beam Based Metal Deposition and Directed Energy Deposition Processes.

UNIT IV	**POWDER-BASED AM SYSTEMS**	**9**

Selective laser sintering (SLS): Models and specifications, Process, working principle, Applications, Advantages and Limitations, Case studies. Three-dimensional Printing (3DP): Models and specifications, Process, working principle, Applications, Advantages and Limitations, Case studies. Laser Engineered Net Shaping (LENS): Models and specifications, Process, working principle, Applications, Advantages and Limitations, Case studies. Electron Beam Melting (EBM): Models and specifications, Process, working principle, Applications, Advantages and Limitations, Case studies.

UNIT V	**AM APPLICATIONS**	**9**

Applications of AM- Prototyping- Tooling- Production- Customization and Personalization- Spare Parts, Maintenance and Repair- Art, Design, and Architecture- Evaluating the Adoption of AM- Applications in Aerospace Industry, Automotive Industry, Jewellery Industryapplication. AM inMedical and

Bioengineering Applications: Planning and simulation of complex surgery, Customised Implants & Prosthesis, Design and Production of Medical Devices.

Total Periods	**45**

Suggestive Assessment Methods

Continuous Assessment Test (30 Marks)	**Formative Assessment Test (10 Marks)**	**End Semester Exams (60 Marks)**
2 Test EACH 15marks **MCQ/Descriptive Questions**	**2 test EACH 5 marks**	**Descriptive Questions**

Outcomes

Upon completion of the course, the students will be able to:

CO.1 Explain the fundamentals of various Additive Manufacturing (AM)techniques.

CO.2 Describe the working principle, capability, limitation and applications of liquid, solid and powder based additive manufacturing techniques.

CO.3 Choose a suitable AM technique for the specified application.

CO.4 Compare different AM process and materials based on application.

CO.5 Explore the range of 3D printing and Prototyping technologies and their application for industrial, design, and creative field.

CO.6 Explain current and emerging 3D printing applications for various industrial environment.

Text Books

1. Olaf Diegel, “A Practical Guide to Design for Additive Manufacturing”, Springer, 2019
2. Martin Leary, “Design for Additive Manufacturing”, Elsevier, 2019.

Reference Books

1. Ben Redwood, “The 3D Printing Handbook: Technologies, Design and Applications”,3D Hubs, 2017.
2. Rapid prototyping: Principles and Applications - Chua C.K., Leong K.F. and LIM C.S, World Scientific publications, Third Edition, 2010.
3. Rapid Manufacturing – D.T. Pham and S.S. Dimov, Springer , 2001
4. Wholers Report 2000 – Terry Wohlers, Wohlers Associates, 2000
5. Rapid Prototyping & Engineering Applications – Frank W.Liou, CRC Press, Taylor & Francis Group, 2011.
6. Ian Gibson, David W Rosen, Brent Stucker., “Additive Manufacturing Technologies: 3D Printing,Rapid Prototyping, and Direct Digital Manufacturing”, 2nd Edition, Springer, 2015

Web Recourses

Nil

CO Vs PO Mapping and CO Vs PSO Mapping

CO	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11	PO12	PSO1	PSO2	PSO3
1	3	1	1	1									2		3
2	3	1	1	2	1								2		3
3	3	2	3	2	2								2		3
4	3	2	2	2	2								2		3
5	3	2	2	2	2								2		3
6	3	3	3	2	2	2						3	2		3

19MEAM02	CAD FOR ADDITIVE MANUFACTURING	L	T	P	C
		3	0	2	4

Prerequisites for the course

Nil

Objectives

The course is aimed at giving exposure to and enhancing the knowledge and skills of fresh graduate engineers and engineers involved in the operation use of 3D Scanners and 3D printing / additive manufacturing with the aid of CAD packages and for those who want to provide training to others in this area. It gives exposure and on hand experience in the field of CAD packages, 3D Scanner and AM format.

UNIT-I	DESIGN OF SOLIDS	6

Introduction to modelling, Types of modelling, 3D modelling: Solid entities, Boolean operations, Types of solid model – Boundary representation (B-rep) technique and Construction Solid Modelling (CSG) approach, Advanced modelling methods-CAD Data exchange formats. AMF files, 3MF, XML, Meta Data, PLY, STEP for AM Application Protocols (AP).

UNIT-II	3D DATA CAPTURE AND SCANNING TECHNOLOGIES	6

Introduction to imaging, Portable CMM - Structured light, portable arm-based laser scanning - time-of-flight and phase shift (long range) scanners-X-Ray technology, -3D CT (X-Ray) scanners- Computed Tomography (CT), Basic Components of CT, Different Types of CT Scanners, Magnetic Resonance Imaging (MRI), Ultrasound imaging, 3-D laser scanners, Industrial CT Scanners.

UNIT-III	REVERSE ENGINEERING AND OBJECT DIGITIZATION	6

Reverse Engineering Methodology – Reverse Engineering Steps - The generic process-Three phases of reverse engineering-Phase I: Scanning, Phase II: Point processing, Phase III: Geometric model development, Case studies. Applications and selection of reverse engineering systems. Hardware and software involved. Point clouds, meshes (.stl), NURBS surface models and parametric CAD models.

UNIT-IV	3D RECONSTRUCTION	6

3D reconstruction, Image Reconstruction Procedure, Digital Communication Post processing the Captured Data - Handling Data Points - Curve and Surface and solid Creation. Layer-based Model Generation – Adaptive Slicing Approach for Cloud Data Modelling – Planar Polygon Curve Construction – Determination of Adaptive Layer Thickness – Application Examples.CAD Model Construction from Point Clouds, Data handling & Reduction Methods, AM Software (Magics, Mimics, 3Matic, Rhino)

UNIT-V	AM DATA FORMATS AND MESHING	6

Tessellated Models, STL Format, STL File Problems, Consequence of Building Valid and Invalid Tessellated Models, STL file Repairs: Generic Solution, Other Translators, and Newly Proposed Formats. STL File Manipulation and Repair Algorithms - Mesh Refining by Sub division Techniques.

S.No	List of Experiments	CO
1	2D sketching of product design ideas.	CO1
2	3D modelling and assembling.	CO1
3	Use of 3D digitalization scanners.	CO2
4	Use of point clouds/meshes editing software.	CO2
5	Preparation of 3D CAD models and stl file generation	CO3
6	File manipulations and repair using AMsoftware	CO5
Total Periods		**30 Theory +30 Lab**

Laboratory Requirements

Stratasys FDM Machine
3-D Scanner
Reverse Engineering Software

Suggestive Assessment Methods

Continuous Assessment Test (30Marks)	Lab Components Assessments (20 Marks)	End Semester Exams (50 Marks)
2 Test EACH 15marks MCQ/Descriptive Questions	Experiments and record of work (10) & Model practical (10)	Descriptive Questions

Outcomes

Upon completion of the course, the students will be able to:

CO1 Develop 3D solid model using B-rep and CSG techniques.
CO2 Explain the different CAD data exchange formats.
CO3 Describe the working principle of different solid component scanning techniques
CO4 Explain the different stages of reverse engineering and object digitization
C05 Construct curve, surface and solid models using AM editing software (Practical)
CO6 Convert the different AM data formats (Practical)

Text Books

1. Michael E. Mortenson, "Geometric Modeling", Wiley, NY, 1997.
2. Anupam Saxena, Birendra Sahay, "Computer Aided Engineering Design", Springer, 2005.
3. Ian Gibson, "Software Solutions for Rapid Prototyping", Professional Engineering Publishing Limited, UK, 2002.
4. Ali K. Kamrani and Emad Abouel Nasr, "Engineering Design and Rapid Prototyping", Springer, 2010.
5. Ibrahim Zeid, "CAD/CAM: Theory and Practice" TMH, 2009.

Reference Books

Nil

Web Recourses

Nil

CO Vs PO Mapping and CO Vs PSO Mapping

CO	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11	PO12	PSO1	PSO2	PSO3
1	3	2	3	1	3								2		2
2	3	1	1	1	3								2		2
3	3	1	1	1	3								2		2
4	3	2	1	1	3								2		2
5	3	3	3	3	3								2		2
6	3	3	3	3	3								2		2

		L	T	P	C
19MEAM03	**3D PRINTING AND PROTOTYPING**	**3**	**0**	**2**	**4**

Prerequisites for the course

- Additive Manufacturing Technologies and Applications
- CAD for Additive manufacturing

Objectives

Students undergoing this course are expected to

- To explain pre-processing and model preparation in AM
- To Understand and operate on tessellated/meshed model
- To import knowledge on slicing process and software
- To explain AM data process like support generation
- To explain post processing techniques of AM

UNIT-I	**PREPROCESSING IN ADDITIVE MANUFACTURING**	**6**

Preparation of 3D-CAD model, Reverse engineering and Reconstruction of 3D-CAD model, Part orientation and support generation, STL Conversion, STL error diagnostics, Slicing and Generation of codes for tool path, Surface preparation of materials. Introduction, Process, CAD Data formats, Data translation, Data loss, STL format. Pre-Processing -Preparation of 3D-CAD model, Part orientation and support generation, STL Conversion, STL error diagnostics, Slicing and Generation of codes for tool path, Surface preparation of materials - post processing.

UNIT II	**AM SOFTWARE**	**6**

Need for AM software, Build Preparation-Features of various AM software's like Magics, Mimics, Solid View, View Expert, 3 D View, Velocity 2, Rhino, STL View 3 Data Expert and 3 D doctor, SurgiGuide, 3-matic, Simplant, MeshLab.

UNIT III	**AM Data Processing**	**6**

AM Data Processing: Part Orientation and Support Structure Generation, Model Slicing and Contour Data Organization, Direct and Adaptive Slicing, Hatching Strategies and Tool Path Generation.Modelling of AM Process: Surface Roughness due to Staircase Effect, Part Build-time, Fabrication Cost, Optimal Orientation, Quantification of Building Inaccuracy and Part Stability.

UNIT IV	**POST PROCESSING OF AM PARTS**	**6**

Support Material Removal, Surface Texture Improvement- Polymer Surface Treatments - Accuracy Improvement, Aesthetic Improvement, Preparation for use as a Pattern, Property Enhancements using Non-thermal and Thermal Techniques- Gluing and Welding AM Parts – Heat Treatment and Aging. Product Quality - sanding, Acetone treatment, polishing- -Inspection and testing - Defects and their causes.

UNIT V	**PROCESS SELECTION AND MATERIAL SCIENCE**	**6**

Guidelines for Process Selection: Introduction, Selection Methods for a Part, Challenges of Selection, Example System for Preliminary Selection, Process Planning and Control.Materials science for AM - Multifunctional and graded materials in AM, Role of solidification rate, Evolution of non-equilibrium structure, microstructural studies, Structure property relationship.

S.No	List of Experiments	CO
1	Slicing of an engineering component	CO1
2	Fabrication of the component through 3D printer and dimensional analysis	CO2
3	Use of FDM, SLA, DLP and SLS machines to produce 3D physical models.	CO2
4	Simulation of additive manufacturing	CO2
Total Periods		**30 Theory +30 Lab**

Laboratory Requirements:

Suggestive Assessment Methods

Continuous Assessment Test (30Marks)	Lab Components Assessments (20 Marks)	End Semester Exams (50 Marks)
2 Test EACH 15marks MCQ/Descriptive Questions	Experiments and record of work (10) & Model practical (10)	Descriptive Questions

Outcomes

Upon completion of the course, the students will be able to:

CO1: Explain the concept of preprocessing and slicing for additive manufacturing.
CO2: Compare the different features of AM packages
CO3: Explain the data processing techniques for additive manufacturing
CO4: Discuss the different post processing methods
CO5: Select a process parameter for different AM techniques
CO6: Perform AM simulation and fabricate 3D physical product using appropriate RP machines (Practical)

Text Books

1. Gibson, I, Rosen, D W., and Stucker, B., Additive Manufacturing Methodologies: Rapid Prototyping to Direct Digital Manufacturing, Springer, 2015

Reference Books

1. Chee Kai Chua, Kah Fai Leong, 3D Printing and Additive Manufacturing: Principles and Applications: Fourth Edition of Rapid Prototyping, World Scientific Publishers, 2014.
2. Chua C.K., Leong K.F., and Lim C.S., “Rapid prototyping: Principles and applications”, Third Edition, World Scientific Publishers, 2010.

3. Gebhardt A., "Rapid prototyping", Hanser Gardener Publications, 2003.
4. Liou L.W. and Liou F.W., "Rapid Prototyping and Engineering applications: A tool box for prototype development", CRC Press, 2007.
5. Kamrani A.K. and Nasr E.A., "Rapid Prototyping: Theory and practice", Springer, 2006 6. Mahamood R.M., Laser Metal Deposition Process of Metals, Alloys, and Composite Materials, Engineering Materials and Processes, Springer International Publishing AG 2018.
6. Ehsan Toyserkani, Amir Khajepour, Stephen F. Corbin, "Laser Cladding", CRC Press, 2004.
V. Raja and K. Fernandes, Reverse Engineering: An Industrial Perspective, Springer- Verlag, 2008.

Web Recourses

Nil

CO Vs PO Mapping and CO Vs PSO Mapping

CO	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11	PO12	PSO1	PSO2	PSO3
1	3	2	2	1	3								2		2
2	3	2	2	1	3								2		2
3	3	2	3	1	3								2		2
4	3	2	3	1	3								2		2
5	3	3	3	1	3								2		2
6	3	3	3	3	3					2			2		2

19MEAM04	DESIGN FOR ADDITIVE MANUFACTURING	L	T	P	C
		3	0	0	3

Prerequisites for the course

- Additive Manufacturing Technologies and Applications
- CAD for Additive manufacturing
- 3D Printing and Prototyping

Objectives

Students undergoing this course are expected to

- To impart knowledge on
- To introduce the basics of design for additive manufacturing.
- To demonstrate comprehensive knowledge of part consolidation and tooling design
- To know the design requirements for Metal AM and Polymer AM technique.
- To illustrate the implication of part design on build time and material strength
- To realize the concept of the post processing treatments in AM

UNIT I	STRATEGIC DESIGN IN ADDITVE MANUFACTURING	9

Design for additive manufacturing (DfAM) – Value addition with AM – General Guidelines for Designing AM parts – Design to Avoid Anisotropy – Design to Minimize Print Time – Design to Minimize Post–processing – Topology Optimisation. Design Analysis for AM – Considerations for Analysis of AM Parts – role of mesh, topology and size optimization – Build process simulation - Comparing Process and Material Performance.

UNIT II	PART CONSOLIDATION AND TOOLING DESIGN	9

Part Consolidation – Design for Function – Material Considerations – Number of Fasteners - Conventional DFM/DFA principles to DfAM – Assembly Considerations – Design of Moving Parts, AM Tooling Design – Mounting Fixtures and Guides – Conformal Cooling – Coolant Flow Strategies – Coolant Channel Shape and Spacing – Steps to minimise Print Time in Tooling.

UNIT III	DESIGN CONSIDERATIONS FOR METAL AM	9

Designing for Metal Powder Bed Fusion – Metal Powder Production – Powder Morphology – Powder Size Distribution – Other Powder Considerations – Potential Defects in AM Materials – Topology Optimisation – Lattice Structures – Overhangs and Support Material Designing to Reduce Residual stress and Stress Concentrations – General Part Positioning Guidelines - Design for Laser Powder Bed Fusion, Electron Beam Melting and Metal Binder Jetting.

UNIT IV	DESIGN FOR POLYMER AM PROCESS AND OTHER AM CONSIDERATIONS	9

Design considerations due to Anisotropy, Wall Thickness, Overhangs and Support Material, Holes, Ribs, fonts and intricate details – Design guidelines for Material Extrusion, Vat Photopolymerisation and Polymer Powder Bed Fusion. Designer Machine Operator Cooperation – Health and Safety – prevention of explosion – AM Part Certification

UNIT V	**COST &VALUE OF AMAND FUTURE OF AM**	**9**
A Cost Model of Conventional Manufacturing- Modelling the Cost of AM- Assessing the Value of AM- Cost and Value Scenarios. Future of AM: Functionally Graded Materials – Bio printing - Printed Electronics - Nano Printing - Food Printers.		
	Total Periods	**45**

Suggestive Assessment Methods

Continuous Assessment Test (30 Marks)	**Formative Assessment Test (10 Marks)**	**End Semester Exams (60 Marks)**
2 Test EACH 15marks MCQ/Descriptive Questions	2 test EACH 5 marks	Descriptive Questions

Outcomes

Upon completion of the course, the students will be able to:

CO.1 Describe the design aspects for additive manufacturing.
CO.2 Convert the DFM/DFA into Design for Additive Manufacturing.
CO.3 Explain the design consideration of metal powder for AM process.
CO.4 Perform design of AM to reduce residual stresses.
CO.5 Describe the design aspects for polymer AM process.
CO.6 Compute the costing for AM products.

Text Books

1. Olaf Diegel, "A Practical Guide to Design for Additive Manufacturing", Springer, 2019.
2. Martin Leary, "Design for Additive Manufacturing", Elsevier, 2019.

Reference Books

1. Ben Redwood, "The 3D Printing Handbook: Technologies, Design and Applications", 3D Hubs, 2017.

Web Recourses

Nil

CO Vs PO Mapping and CO Vs PSO Mapping

CO	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11	PO12	PSO1	PSO2	3
1	2	1	1	1									1		3
2	3	3	3	3	1								1	2	3
3	2	2	3	2	1								1	2	3
4	3	3	3	3	1								1	2	3
5	1	1	1	1	1								1	2	3
6	2	2	2	2	2						2		1	1	

19MEAM05	PROTOTYPING PROJECT	L	T	P	C
		0	0	8	4

Prerequisites for the course

- Additive Manufacturing Technologies and Applications
- CAD for Additive manufacturing
- 3D Printing and Prototyping
- Design for additive Manufacturing

Objectives

- To prepare students to work in teams to solve open-end designing and manufacturing problems and to develop the necessary skills for using modern AM technology.
- To make the students work in small groups following the typical stages of product development - designing, prototyping and manufacturing - in one continuous project.
- To teach use of new tools and techniques required to carry out the projects.
- To give guidance on the various procedures for validation of the product and analyze the cost effectiveness.
- To provide guidelines to prepare technical report of the project.

SUGGESTED PROBLEM APPROACH

- Analyze the situation and come up with more than one possible technical solution. Choose one and justify why it is the best.
- For the selected design, produce complete technical documentation going from the hand sketches to the fully dimensioned CAD files.
- Make physical, fully functioning prototypes to verify form, fit, and function. - Analyze the prototype for design and functional flaws. Prepare the final model and report to turn in, and give a public presentation.

PROJECT ASSUMPTIONS

- Designing, prototyping and manufacturing facilities are at different locations and a system of communication has to be used to set up the working links between these locations.
- Work-in-progress should be accessible by all the participating team members. A proper file management system has to be developed and used.
- Project evaluation is based on quality and completion of listed “things to do”. Students’ statements are required to say what the involvement of each member of the group was.
- Each project should begin with work scheduling; Microsoft Project software is recommended to accomplish this. Meetings with faculty are scheduled bi-weekly (or by appointment) to analyze work-in-progress.

PROJECT ASSESSMENT

The project is structured to ensure that each team makes steady progress on the project throughout the semester, with adequate time at the end of the semester to allow for a variety of printing methods.

1	Team Project Idea Submission	5
2	First Project Part file	5

3	First Project Printed Part	10
	Final Project CAD files	15
4	Final Project Printed Parts	10
5	Final product assembly – functional test and quality	25
6	Final Printed Project & Presentation	30

The project is structured to ensure that each team makes steady progress on the project throughout the semester, with adequate time at the end of the semester to allow for a variety of printing methods,

SAMPLE PROJECT DETAILS

The team started the project with a hand sketch to show the idea of the mechanism and its location in the machinery. An Internet search of results for similar objects was required for this part of the project. Documentation - project documentation required use of a CAD package. The required documentation format was an assembly drawing as a solid model, and a detailed 3-D drawing file as the necessary technical documentation for prototyping, manufacturing, inspection, and production preparation.

Prototyping - the next step was prototyping, or making physical models. Using additive method plastic objects were built on the FDM. This machine builds precision objects layer by layer. This method is useful for shape and fit evaluation. There were two important issues in this stage of the project. AutoCAD (Mechanical Desktop) and Reverse engineering, AM software from the courses. A third file format, stereolithography (STL files), was created for use by the 3D printer. When conversions were done, the new formats were inspected for possible errors before proceeding with prototyping. Analysis at this stage of the project concentrated on two elements: design flaws: fitting parts together and possibilities of design improvements by reducing the weight and material selection, as well as developing a concept of manufacturing and adapting the design to the process requirements.

Outcomes

Upon completion of the course, the students will be able to:

CO.1 Apply tools and techniques acquired in AM courses for development of new product.
CO.2 Adapt an efficient problem-solving method in analysing industrial product needs.
CO.3 Formulate a real world problem, identify the requirement and develop the design solutions.
CO.4 Identify technical ideas, strategies and methodologies for prototyping
CO.5 Test and validate through conformance of the developed prototype and analysis the cost effectiveness.
CO.6 Prepare technical report and oral presentations.

CO Vs PO Mapping and CO Vs PSO Mapping

CO	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11	PO12	PSO1	PSO2	PSO3
1			3	3	3						2	2	3		3
2			3	3	3						2	2	3		3
3			3	3	3						2	2	3		3
4			3	3	3						2	2	3		3
5			3	3	3						2	2	3		3
6									3	3		2			