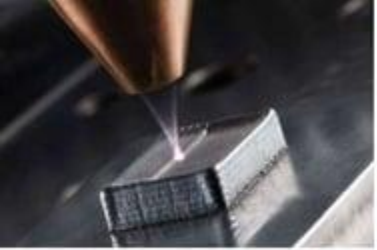
Additive Manufacturing

(CME339)

Rohini College of Engineering and Technology
Department of Mechanical Engineering



Additive Manufacturing

MODULE 1: Introduction to Additive Manufacturing

Module 1

Introduction to Additive Manufacturing: Introduction to AM, AM evolution, Distinction between AM & CNC machining, Advantages of AM.

AM process chain: Conceptualization, CAD, conversion to STL, Transfer to AM, STL file manipulation, Machine setup, build , removal and clean up, post processing.

Classification of AM processes: Liquid polymer system, Discrete particle system, Molten material systems and Solid sheet system.

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.

Module 1

Guidelines for process selection: Introduction, selection methods for a part, challenges of selection

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, defence, automobile, Bio-medical and general engineering industries

Introduction

What is Additive Manufacturing?

- The term Rapid Prototyping (or RP) is used to describe a process for rapidly creating a system or part representation before final release or commercialization.

- A recently formed Technical Committee within ASTM International agreed that new terminology should be adopted. Recently adopted ASTM consensus standards now use the term **Additive Manufacturing**.

- The basic principle of this technology is that a model, initially generated using a 3D Computer Aided Design (3D CAD) system, can be fabricated directly without the need for process planning.

Introduction

Prototype fundamentals

Definition of a Prototype

A prototype is the first or original example of something that has been or will be copied or developed; it is a model or preliminary version;

e.g.: A prototype supersonic aircraft.

or

An approximation of a product (or system) or its components in some form for a definite purpose in its implementation.

Prototype fundamentals

Types of Prototype

The general definition of the prototype contains three aspects of interests:

(1) Implementation of the prototype; from the entire product itself to its sub-assemblies and components,

(2) Form of the prototype; from a virtual prototype to a physical prototype

(3) Degree of the approximation of the prototype; from a very rough representation to an exact replication of the product.

Introduction

Additive Manufacturing – Layer Manufacturing

Often used terms:

Additive	Additive Manufacturing (AM) Additive Layer Manufacturing (ALM) Additive Digital Manufacturing (DM)
Layer	Layer Based Manufacturing Layer Oriented Manufacturing Layer Manufacturing
Rapid	Rapid Technology, Rapid Prototyping Rapid Tooling, Rapid Manufacturing
Digital	Digital Fabrication, Digital Mock-Up

- 3D Printing, 3D Modeling
- Direct Manufacturing, Direct Tooling

Introduction

Additive Manufacturing – Layer Manufacturing

"Additive Manufacturing" (AM) is a layer-based automated fabrication process for making scaled 3-dimensional physical objects directly from 3D-CAD data without using part-depending tools.

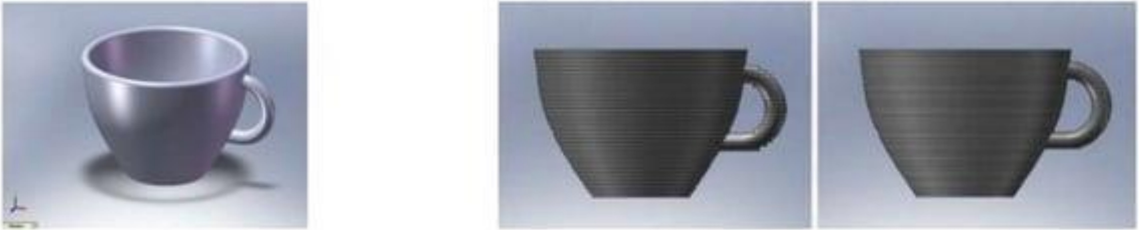
It was originally called "3D Printing".

Additive manufacturing also refers to technologies that create objects, layer by layer or sequential layering

Introduction

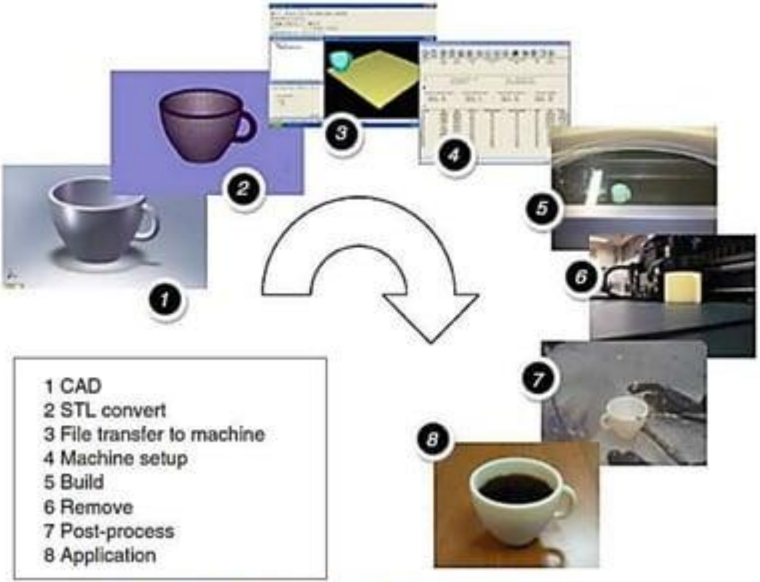
Additive Manufacturing – Layer Manufacturing

Additive manufacturing, also known as 3D printing, rapid prototyping or freeform fabrication, is 'the process of joining materials to make objects from 3D model data, usually layer upon layer, as opposed to subtractive manufacturing methodologies' such as machining.



CAD image of a teacup with further images showing the effects of building using different layer thicknesses

The Generic AM Process



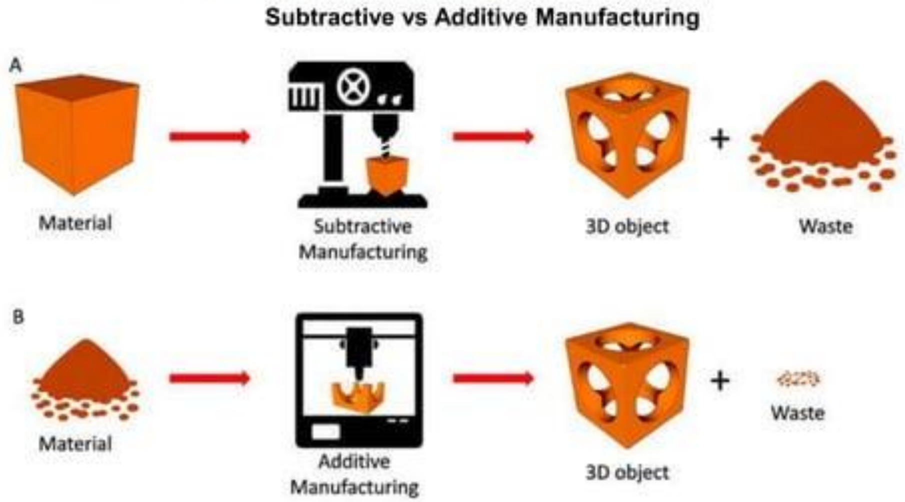
Generic process of CAD to part, showing all 8 stages

Additive Manufacturing Evolution

Year of Inception	Technology
1770	Mechanization [4]
1946	First Computer
1952	First Numerical Control (NC) Machine Tool
1960	First commercial Laser [5]
1961	First commercial Robot
1963	First Interactive Graphics System (early version of Computer-Aided Design) [6]
1988	First commercial Rapid Prototyping System

Introduction

Distinction between AM & CNC machining



Distinction between AM & CNC machining

- Materials
- Speed
- Ease of use
- Accuracy, Size limitations & Geometric Complexity
- Programming
- Cost
- Environmentally Friendly

Advantages of AM

- Elimination of design constraints
- Allow parts to be produced with complex geometry with no additional costs related to complexity
- Build speed; reduction of lead time
- Flexibility in design
- No expensive tooling requirements
- Dimensional accuracy
- Wide range of materials (polymers, metals, ceramics)
- Well suited to the manufacture of high value replacement and repair parts
- Green manufacturing, clean, minimal waste

Introduction

Limitations of AM

- Part size
- Production series: Generally suitable for unitary or small series and is not relevant for mass production. For small sized parts, series up to 25000 parts/year are already possible.

Introduction

Limitations of AM

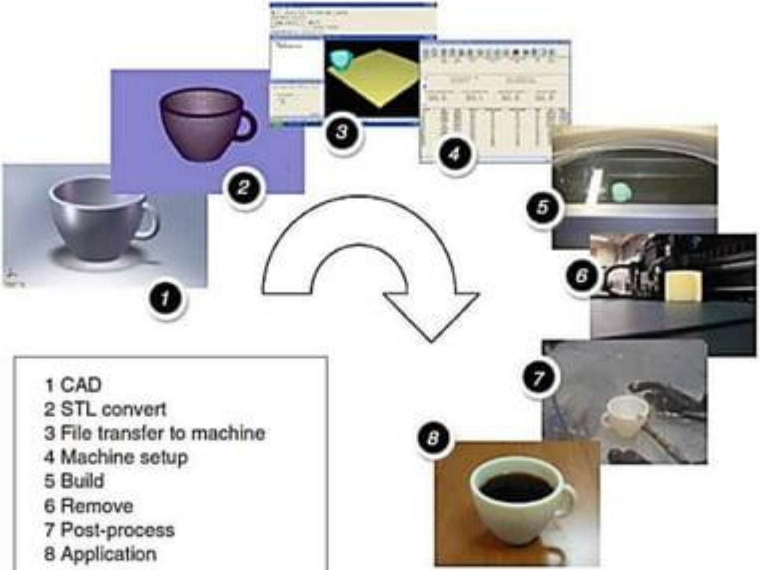
Material choice: Non weldable metals cannot be processed by additive manufacturing and difficult-to-weld alloys require specific approaches.

Material properties: Parts made by additive manufacturing tend to show anisotropy in the Z axis (construction direction).

- The densities of 99.9% can be reached, there can be some residual internal porosities.
- Mechanical properties are usually superior to cast parts but in general inferior to wrought parts.

Introduction

Additive Manufacturing Process chain



1 CAD
2 STL convert
3 File transfer to machine
4 Machine setup
5 Build
6 Remove
7 Post-process
8 Application

Introduction

Additive Manufacturing Process chain

The Eight Steps in Additive Manufacture

1. Conceptualization and CAD
2. Conversion to STL
3. Transfer and manipulation of STL file on AM machine
4. Machine setup
5. Build
6. Part removal and clean-up
7. Post-processing of part
8. Application

Introduction

Additive Manufacturing Process chain

The Eight Steps in Additive Manufacture

Step 1: Conceptualization and CAD

- The generic AM process start with 3D CAD information.
- There may be a many of ways as to how the 3D source data can be created.
- The model description could be generated by a computer.
- Most 3D CAD systems are solid modeling systems with some surface modeling components.

Additive Manufacturing Process chain

The Eight Steps in Additive Manufacture

Step 2: Conversion to STL

- The term STL was derived from STereoLithograhy.
- STL is a simple way of describing a CAD model in terms of its geometry alone.
- It works by removing any construction data, modeling history, etc., and approximating the surfaces of the model with a series of triangular facets.
- The minimum size of these triangles can be set within most CAD software and the objective is to ensure the models created do not show any obvious triangles on the surface.

Introduction

Additive Manufacturing Process chain

The Eight Steps in Additive Manufacture

Step 2: Conversion to STL

- The process of converting to STL is automatic within most CAD systems.
- STL file repair software is used when there are problems with the file generated by the CAD system that may prevent the part from being built correctly.
- With complex geometries, it may be difficult to detect such problems while inspecting the CAD or the subsequently generated STL data.
- If the errors are small then they may even go unnoticed until after the part has been built.

Introduction

Additive Manufacturing Process chain

The Eight Steps in Additive Manufacture

Step 2: Conversion to STL

- STL is essentially a surface description, the corresponding triangles in the files must be pointing in the correct direction; (in other words, the surface normal vector associated with the triangle must indicate which side of the triangle is outside vs. inside the part).
- While most errors can be detected and rectified automatically, there may also be a requirement for manual intervention.

Additive Manufacturing Process chain

The Eight Steps in Additive Manufacture

Step 3: Transfer to AM Machine and STL File Manipulation

- Once the STL file has been created, it can be sent directly to the target AM machine.
- Ideally, it should be possible to press a “print” button and the machine should build
- the part straight away.
- However there may be a number of actions required prior to building the part.
- The first task would be to verify that the part is correct.
- AM system software normally has a visualization tool that allows the user to view and manipulate the part.

Step 3: Transfer to AM Machine and STL File Manipulation

- The user may wish to reposition the part or even change the orientation to allow it to be built at a specific location within the machine.
- It is quite common to build more than one part in an AM machine at a time.
- This may be multiples of the same part (thus requiring a copy function) or completely different STL files.

Step 4: Machine Setup

- All AM machines will have at least some setup parameters that are specific to that machine or process.
- Some machines are only designed to run perhaps one or two different materials and with no variation in layer thickness or other build parameters.
- In the more complex cases to have default settings or save files from previously defined setups to help speed up the machine setup process and to prevent mistakes.
- Normally, an incorrect setup procedure will still result in a part being built.

Introduction

Additive Manufacturing Process chain

The Eight Steps in Additive Manufacture

Step 5: Build Setup

- The first few stages of the AM process are semi-automated tasks that may require considerable manual control, interaction, and decision making.
- Once these steps are completed, the process switches to the computer-controlled building phase.
- All AM machines will have a similar sequence of layer control, using a height adjustable platform, material deposition, and layer cross-section formation.
- All machines will repeat the process until either the build is complete or there is no source material remaining.

Step 6: Removal and Cleanup

- The output from the AM machine should be ready for use.
- More often the parts still require a significant amount of manual finishing before they are ready for use.
- The part must be either separated from a build platform on which the part was produced or removed from excess build material surrounding the part.
- Some AM processes use additional material other than that used to make the part itself (secondary support materials).

Introduction

Additive Manufacturing Process chain

The Eight Steps in Additive Manufacture

Step 7: Post Process

- Post-processing refers to the (usually manual) stages of finishing the parts for application purposes.
- This may involve abrasive finishing, like polishing and sandpapering, or application of coatings.

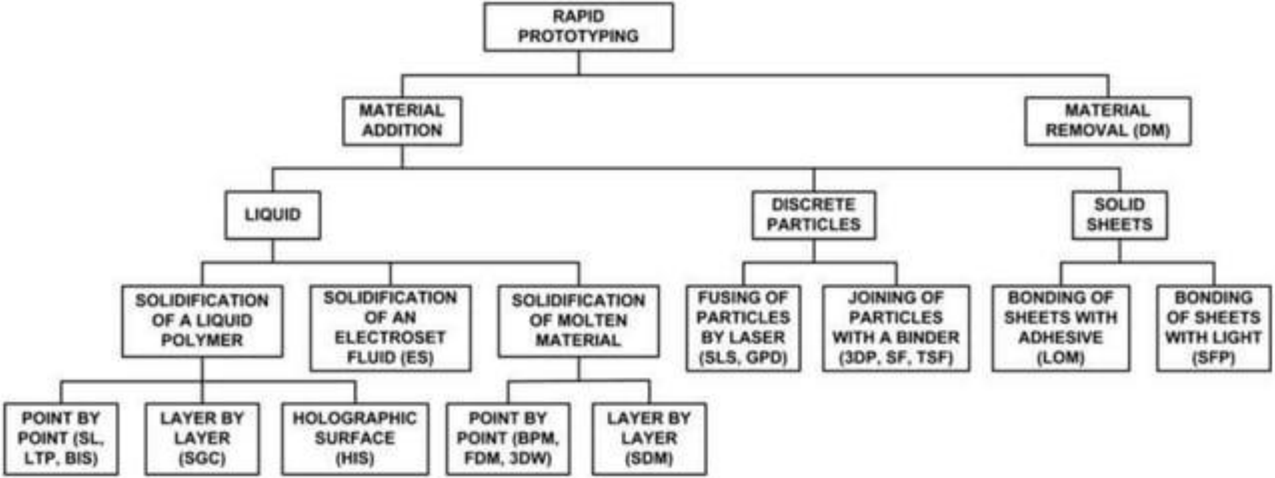
Additive Manufacturing Process chain

The Eight Steps in Additive Manufacture

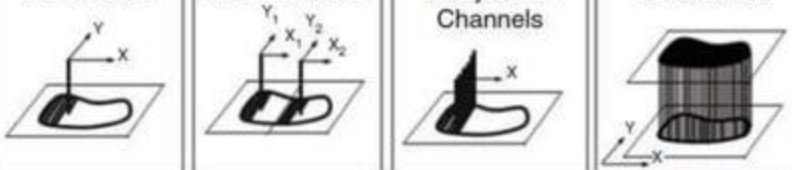
Step 8: Application

- Following post-processing, parts are ready for use.
- Although parts may be made from similar materials to those available from other manufacturing processes (like molding and casting), parts may not behave according to standard material specifications.
- Some AM processes create parts with small voids or bubbles trapped inside them, which could be the source for part failure under mechanical stress.
- Some processes may cause the material to degrade during build or for materials not to bond, link, or crystallize in an optimum way.

Classification of AM processes



Classification of AM processes



	1D Channel	2x1D Channels	Array of 1D Channels	2D Channel
Liquid Polymer	SLA (3D Sys)	Dual beam SLA (3D Sys)	Objet	Envisiontech MicroTEC
Discrete Particles	SLS (3D Sys), LST (EOS), LENS Phenix, SDM	LST (EOS)	3D Printing	DPS
Molten Mat.	FDM, Solidscape		ThermoJet	
Solid Sheets	Solido PLT (KIRA)			

Layered Manufacturing (LM) processes as classified by Pham

Classification of AM processes

- Liquid polymer system
- Discrete particle system
- Molten material systems
- Solid sheet system

Classification of AM processes

Liquid polymer system

- Liquid-based RP systems have the initial form of its material in liquid state.
- The liquid is converted into the solid state.
- The first commercial system was the 3D Systems Stereolithography process based on liquid photopolymers.

Classification of AM processes

Liquid polymer system

- The following RP systems fall into this category:

- 3D Systems' Stereolithographic Apparatus (SLA)
- Cubital's Solid Ground Curing (SGC)
- Sony's Solid Creation System (SCS)
- CMET's Solid Object Ultraviolet-Laser Printer (SOUP)
- Autostrade's E-Darts
- Teijin Seiki's Soliform System
- Meiko's Rapid Prototyping System for the Jewelery Industry
- Aaroflex
- Rapid Freeze
- Two Laser Beams
- Microfabrication
- Fockele & Schwarze's LMS
- Light Sculpting
- Denken's SLP
- Mitsui's COLAMM

Classification of AM processes

Discrete Particle Systems

- Discrete particles are normally powders that are graded into a uniform size and shape and narrow distribution.
- The finer the particles the better, but there will be problems if the dimensions get too small in terms of controlling the distribution and dispersion.
- The conventional 1D channel approach uses a laser to produce thermal energy in a controlled manner to raise the temperature sufficiently to melt the powder.
- Polymer powders must therefore exhibit thermoplastic behavior so that they can be melted and re-melted to permit bonding of one layer to another.

Classification of AM processes

Discrete Particle Systems

The two main polymer-based systems commercially available are the;

- Selective Laser Sintering (SLS) technology marketed by 3D Systems.
- The EOSint processes developed by the German company EOS.

Classification of AM processes

Discrete Particle Systems

Powder is by-and-large in the solid state. The following RP systems fall into this definition:

- 3D Systems's Selective Laser Sintering (SLS)
- EOS's EOSINT Systems
- Z Corporation's Three-Dimensional Printing (3DP)
- Optomec's Laser Engineered Net Shaping (LENS)
- Soligen's Direct Shell Production Casting (DSPC)
- Fraunhofer's Multiphase Jet Solidification (MJS)
- Acram's Electron Beam Melting (EBM)
- Aeromet Corporation's Lasform Technology
- Precision Optical Manufacturing's Direct Metal Deposition (DMDTM)
- Generis' RP Systems (GS)
- Therics Inc.'s Theriform Technology
- Extrude Hone's PrometalTM 3D Printing Process

Classification of AM processes

Molten Material Systems

- Molten material systems are characterized by a pre-heating chamber that raises the material temperature to melting point so that it can flow through a delivery system.
- The most well-known method is the Fused Deposition Modeling system (FDM) developed by the US company Stratasys.
- This approach uses an extrusion technique to deliver the material through a nozzle in a controlled manner.
- Two extrusion heads are often used so that support structures can be fabricated from a different material to facilitate part cleanup and removal.

Classification of AM processes

Molten Material Systems

- The 1D channel approach is very slow in comparison with other methods.
- The Thermojet from 3D Systems also deposits a wax material through droplet based printing heads.
- The Thermojet approach, however, is not widely used because wax materials are difficult and fragile when handled.
- Thermojet machines are no longer being made, although existing machines are commonly used for investment casting patterns.

Classification of AM processes

Solid Sheet Systems

- One of the earliest AM technologies was the Laminated Object Manufacturing (LOM) system from Helisys, USA.
- This technology used a laser to cut out profiles from sheet paper, supplied from a continuous roll, which formed the layers of the final part.
- Layers were bonded together using a heat-activated resin that was coated on one surface of the paper.
- Once all the layers were bonded together the result was very like a wooden block.
- A hatch pattern cut into the excess material allowed the user to separate away waste material and reveal the part.

Classification of AM processes

Solid Sheet Systems

Solid form can include the shape in the form of a wire, a roll, laminates and pellets.

The following RP systems fall into this definition:

- Cubic Technologies' Laminated Object Manufacturing (LOM)
- Stratasys' Fused Deposition Modeling (FDM)
- Kira Corporation's Paper Lamination Technology (PLT)
- 3D Systems' Multi-Jet Modeling System (MJM)
- Solidscape's ModelMaker and PatternMaster
- Beijing Yinhua's Slicing Solid Manufacturing (SSM), Melted
- Extrusion Modeling (MEM) and Multi-Functional RPM Systems
- (M-RPM)
- CAM-LEM's CL 100
- Ennex Corporation's Offset Fabbers

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, defence, automobile, Bio-medical and general engineering industries

AM Applications

The Use of AM to Support Medical Applications

A CT (Computerized Tomography) scanner with sliced images and a 3D image created using this technology

AM Applications

The Use of AM to Support Medical Applications

- Surgical and diagnostic aids: Human models
- Prosthetics development
- Manufacturing of medically related products
- Tissue Engineering


3DP used to make a skull with vascular tracks in a darker colour


A bone tumour highlighted using ABS


Objet Connex process showing vascularity inside a human organ

AM Applications

The Use of AM to Support Medical Applications

- Surgical and diagnostic aids: Human models
- Prosthetics development
- Manufacturing of medically related products: hearing aids
- Tissue Engineering: The ultimate in fabrication of medical implants would be the direct fabrication of replacement body parts

AM Applications

Perfume bottles with different capacity

Cast metal (left) and RP pattern for sand casting (Courtesy of Helysis Inc.)

Investment casting of fan impeller from RP pattern

SLA model of a patient's facial details

Polycarbonate investment-casting pattern (right) and the steel air inlet housing (right) for a jet turbine engine (Courtesy DTM Corporation)