

MODULE-1

INTRODUCTION TO ADDITIVE MANUFACTURING

15ME82

DEFINITION:

- *Additive Manufacturing (AM) refers to a process by which digital 3D design data is used to build up a component in layers by depositing material.*

Introduction

Manufacturing is a process in which raw materials are transformed into finished goods.

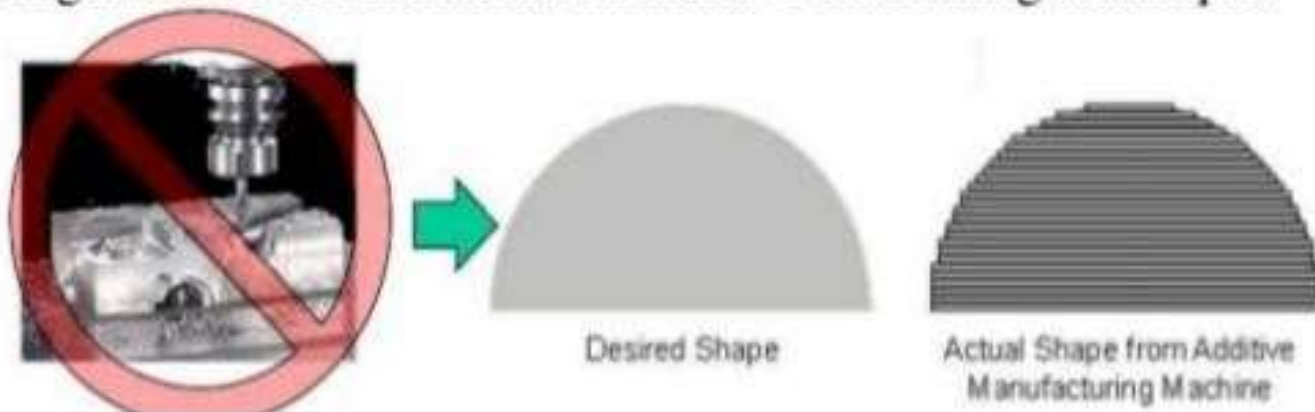
Additive Manufacturing

- Technology that can make anything.
- Eliminates many constraints imposed by conventional manufacturing
- Leads to more market opportunities.
- Increased applications such as 3D faxing sender scans a 3D object in cross sections and sends out the digital image in layers, and then the recipient receives the layered image and uses an AM machine to fabricate the 3D object.

- **Additive Manufacturing (AM)** is an appropriate name to describe the technologies that build 3D objects by *adding* layer-upon-layer of material, whether the material is plastic, metal, concrete or one day.....human tissue.
- Common to AM technologies is the use of a computer, 3D modeling software (Computer Aided Design or CAD), machine equipment and layering material.
- Once a CAD sketch is produced, the AM equipment reads in data from the CAD file and lays down or adds successive layers of liquid, powder, sheet material or other, in a layer-upon-layer fashion to fabricate a 3D object.
- The term **AM** encompasses many technologies including subsets like 3D Printing, Rapid Prototyping (RP), Direct Digital Manufacturing (DDM), layered manufacturing and additive fabrication.

What is Additive Manufacturing?

- *The process of joining materials to make objects from three-dimensional (3D) model data, usually **layer by layer***
- Commonly known as “**3D printing**”
- Manufacturing components with virtually no geometric limitations or tools.
- AM uses an *additive process*
- *Design for manufacturing to manufacturing for design*
- Distinguished from traditional subtractive machining techniques





Additive vs Subtractive Manufacturing

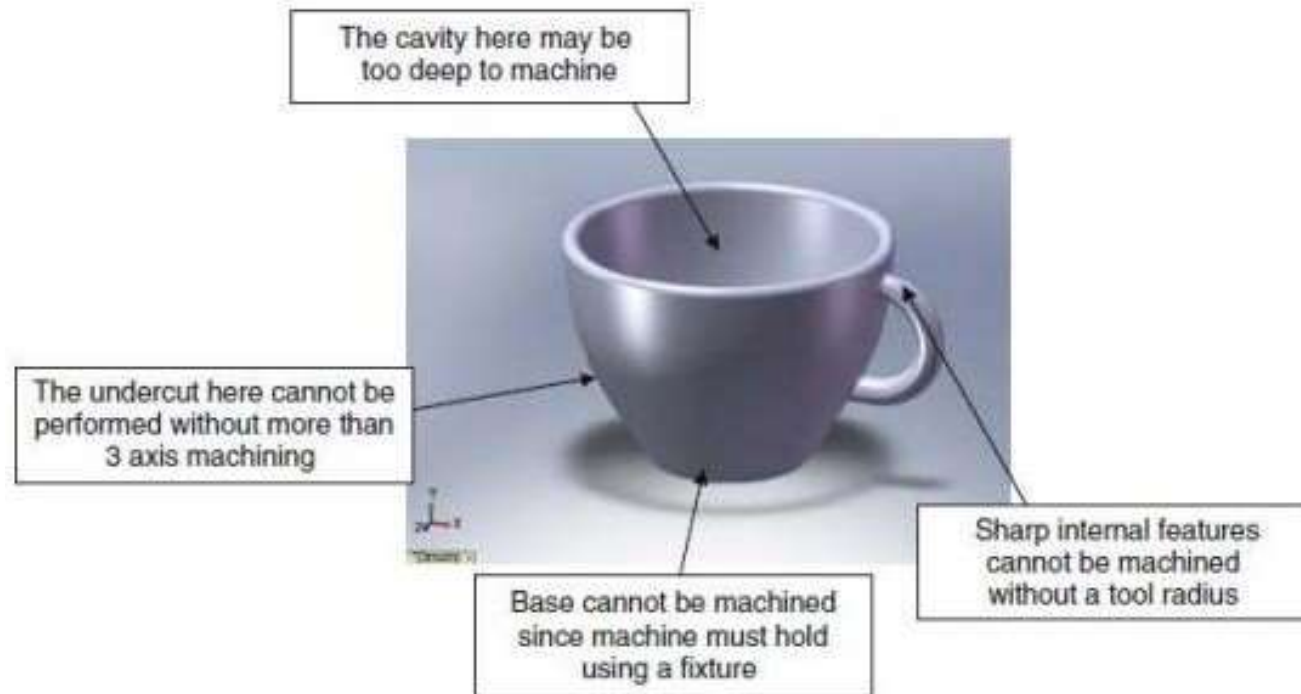


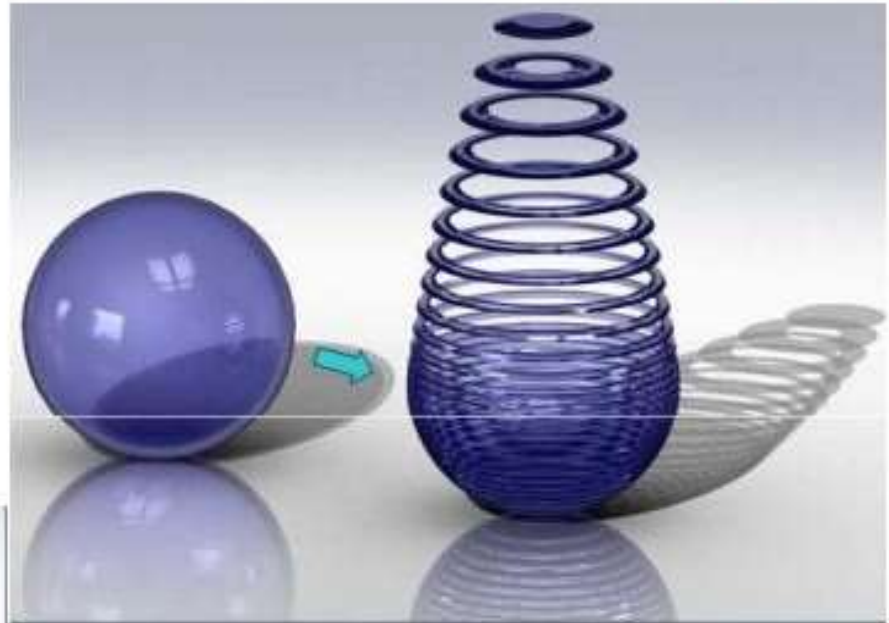
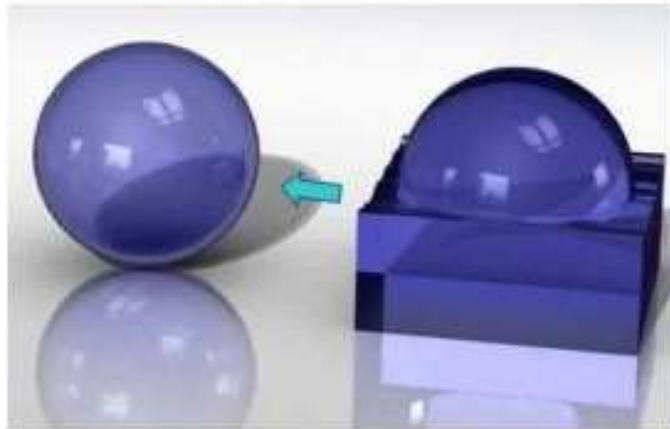
Figure: Features that represent problems using CNC machining.

Source: Gibson, Additive Manufacturing



Additive vs Subtractive Manufacturing

- Part Complexity;
- Material;
- Speed;
- Part Quantity;
- Cost.



A



Material



Subtractive
Manufacturing



3D object

+



Waste

B



Material



Additive
Manufacturing



3D object

+



Waste

Evolution

AM applications timeline

This timeline lays out past, present and potential future AM developments and applications.

(courtesy of Graham Tromans)

1988-1994	rapid prototyping
1994	rapid casting
1995	rapid tooling
2001	AM for automotive
2004	aerospace (polymers)
2005	medical (polymer jigs and guides)
2009	medical implants (metals)
2011	aerospace (metals)
2013-2016	nano-manufacturing
2013-2017	architecture
2013-2018	biomedical implants
2013-2022	in situ bio-manufacturing
2013-2032	full body organs

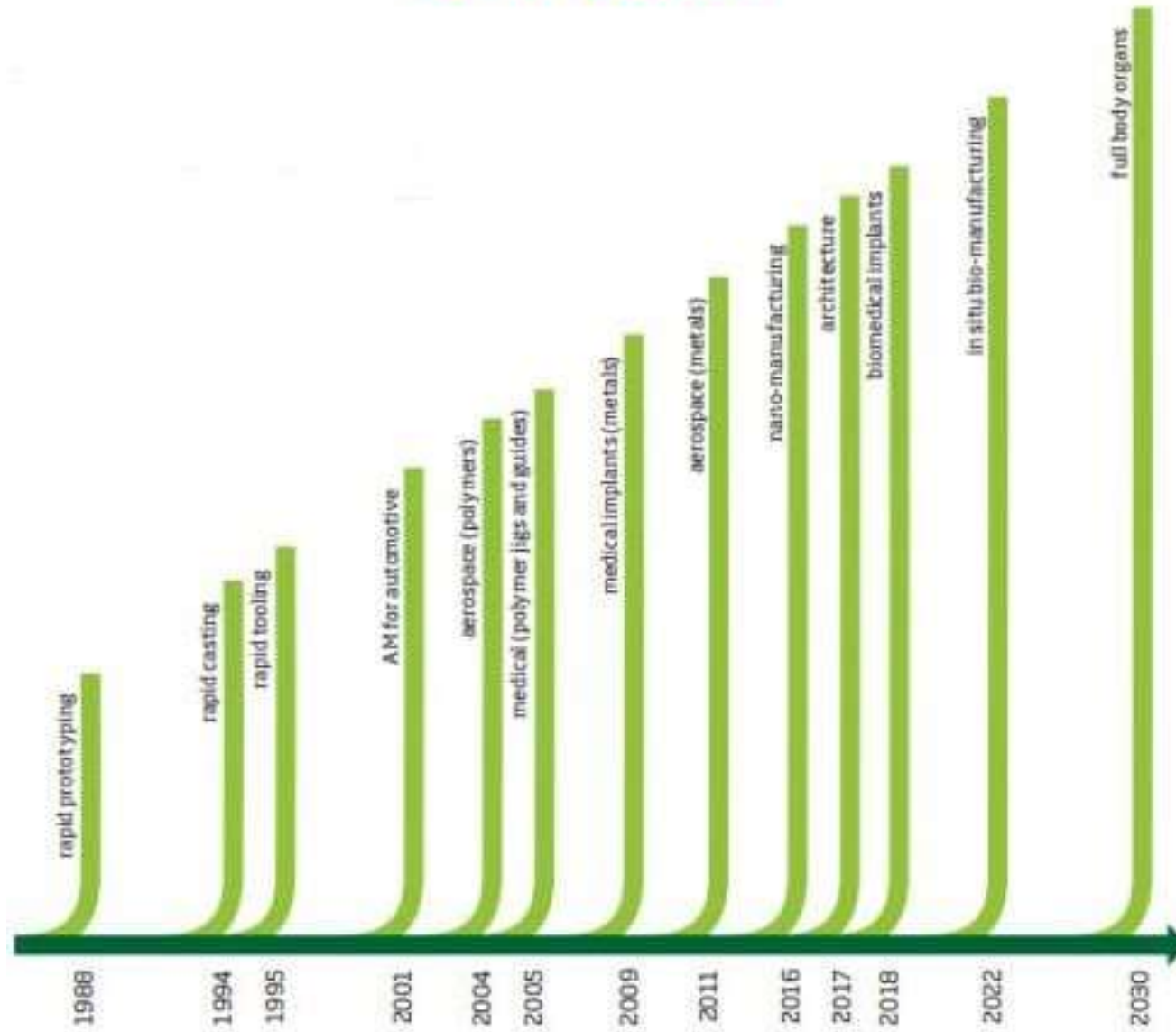
CASE STUDY

GE AND MORRIS TECHNOLOGY Graham Tromans

The automotive and aerospace industries are two of the main beneficiaries of AM. In 2012, GE Aviation bought AM Morris Technologies, one of the biggest metal additive manufacturers in the world. GE is ramping up AM manufacturing of aero engine fuel nozzles. The conventional method of making fuel nozzles requires making 20 separate parts and welding them together, "which is extremely labour-intensive and has a high scrap rate," said Graham Tromans, Principal and President of AM consultancy GP Tromans Associates. AM allows the creation of pre-assembled nozzles. GE predicts that, by late 2015/16, it will make 10-20 fuel nozzles for each engine using AM, or 25,000 a year. The company also envisages that 50% of a jet engine will be additive manufactured within current lifetimes.

Source: Royal Academy of Engineering

Evolution



Source: Royal Academy of Engineering

Source
Google Images



Current and Potential industries for Additive Manufacturing

Pros and Cons

Pros	Cons
Freedom to design and innovate without penalties	Unexpected pre- and post-processing requirements
Rapid iteration through design permutations	High process cost
Excellent for mass customization	Lack of industry standards
Elimination of tooling	Low speed, not suitable for mass production
Green manufacturing	Inconsistent Materials
Minimal material waste	Limited number of materials
Energy efficient	High equipment cost for high-end manufacturing
Enables personalized manufacturing	

Benefits

AM benefits: Weight reduction

TRADITIONAL DESIGN

Source: SAVING project



- > A conventional steel buckle weights 155 g¹⁾
- > Weight should be reduced on a like-for-like basis within the SAVING project
- > Project partners are Plunkett Associates, Crucible Industrial Design, EOS, 3T PRD, Simpleware, Delcam, University of Exeter

AM OPTIMIZED DESIGN

Source: SAVING project



- > Titanium buckle designed with AM weighs 70 g – reduction of 55%
- > For an Airbus 380 with all economy seating (853 seats), this would mean a reduction of 72.5 kg
- > Over the airplane's lifetime, 3.3 million liters of fuel or approx. EUR 2 m could be saved, assuming a saving of 45,000 liters per kg and airplane lifetime

1) 120 g when made of aluminum

Source: SAVING project/Crucible Industrial Design Ltd.; Roland Berger

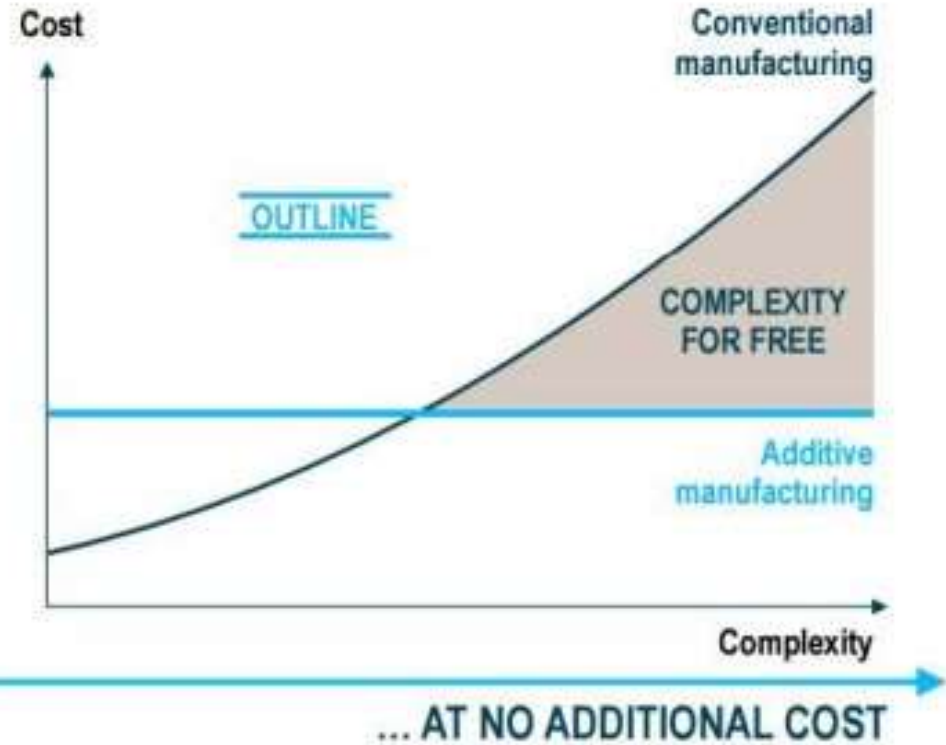
AM benefits: Complexity for free

AM ENABLES NEW GEOMETRIC SHAPES ...

Source: PEP



- > AM enables the manufacturing of new geometric shapes that are not possible with conventional methods
- > Example: AM makes it possible to design advanced cooling channels that cool tools/ components better and therefore reduce cycle time



Source: Roland Berger

AM for customized medical products

DENTAL CROWNS/BRIDGES

Source: EOS



- > **AM holds a large share of the dental crowns and bridges market** – Geometry is scanned and processed via CAD/CAM. More than 30 million crowns, copings and bridges have already been made on AM machines over the last 6 years
- > **Increasing market share** – Experts estimate that more than 10,000 copings are produced every day using AM
- > **Faster production** – One AM machine produces up to 450 crowns per day, while a dental technician can make around 40

IMPLANTS

Source: EOS



- > **AM offers advantages with regard to manufacturing time, geometric fit and materials** – Example of a skull implant with modified surface structure
- > **Improved fit via AM** – Based on 3D scans of the skull, the resulting implant fits perfectly into the skull cap, leads to faster recovery and reduces operation time

Additive manufacturing will replace conventional manufacturing methods for customized products

Source: Roland Berger

Future: Home Manufacturing



3D Printing Vs CNC Machining

- The key difference between 3D printing and CNC machining is that 3D printing is a form of additive manufacturing, while the CNC machining is subtractive.
- This means CNC machining starts with a block of material (called a blank), and cuts away material to create the finished part. To do this, cutters and spinning tools are used to shape the piece.
- Some advantages of CNC machining include great dimensional accuracy as well as many compatible materials, including wood, metals and, plastic

3D Printing Vs CNC Machining: Materials

- Both 3D printing and CNC machining are compatible with a wide variety of materials, including both plastics and metals.
- 3D printing however is more focused on plastics overall, though this is changing rapidly as better and more affordable ways of 3D printing metal are being developed by manufacturers such as 3D Systems, Arcam, Desktop Metal and Markforged.

3D Printing Vs CNC Machining: Materials

- The most commonly used plastics used in CNC include ABS([Acrylonitrile butadiene styrene](#)), Nylon (PA66), Polycarbonate (PC), Acrylic (PMMA), Polypropylene (PP).
- A very commonly used metal in CNC machining is aluminium, used by [prototyping companies](#) to create high-quality prototypes in a variety of industries.
- Aluminium is recyclable, has good protective qualities, and can create effective prototypes for machining. Other commonly used metals include stainless steel, magnesium alloy, zinc alloy titanium, and brass.

3D Printing Vs CNC Machining: Materials

- In 3D printing, commonly used thermoplastics include ABS([Acrylonitrile butadiene styrene](#)), PLA (Polylactic acid), [Nylon](#), ULTEM, but also photo-polymers such as wax, calcinable or biocompatible resins.
- Some niche 3D printers also allow for the printing of parts in sand, ceramics, and even living materials.
- The most common metals used in 3D printing include aluminium, stainless steel, titanium, and inconel.
- It is also worth noting that to 3D print metal, expensive (\$100,000+) industrial machines are required. Some materials such as super alloys or TPU (flexible material) cannot be created with CNC, so must be used with 3D printing or rapid tooling technology.

PLA



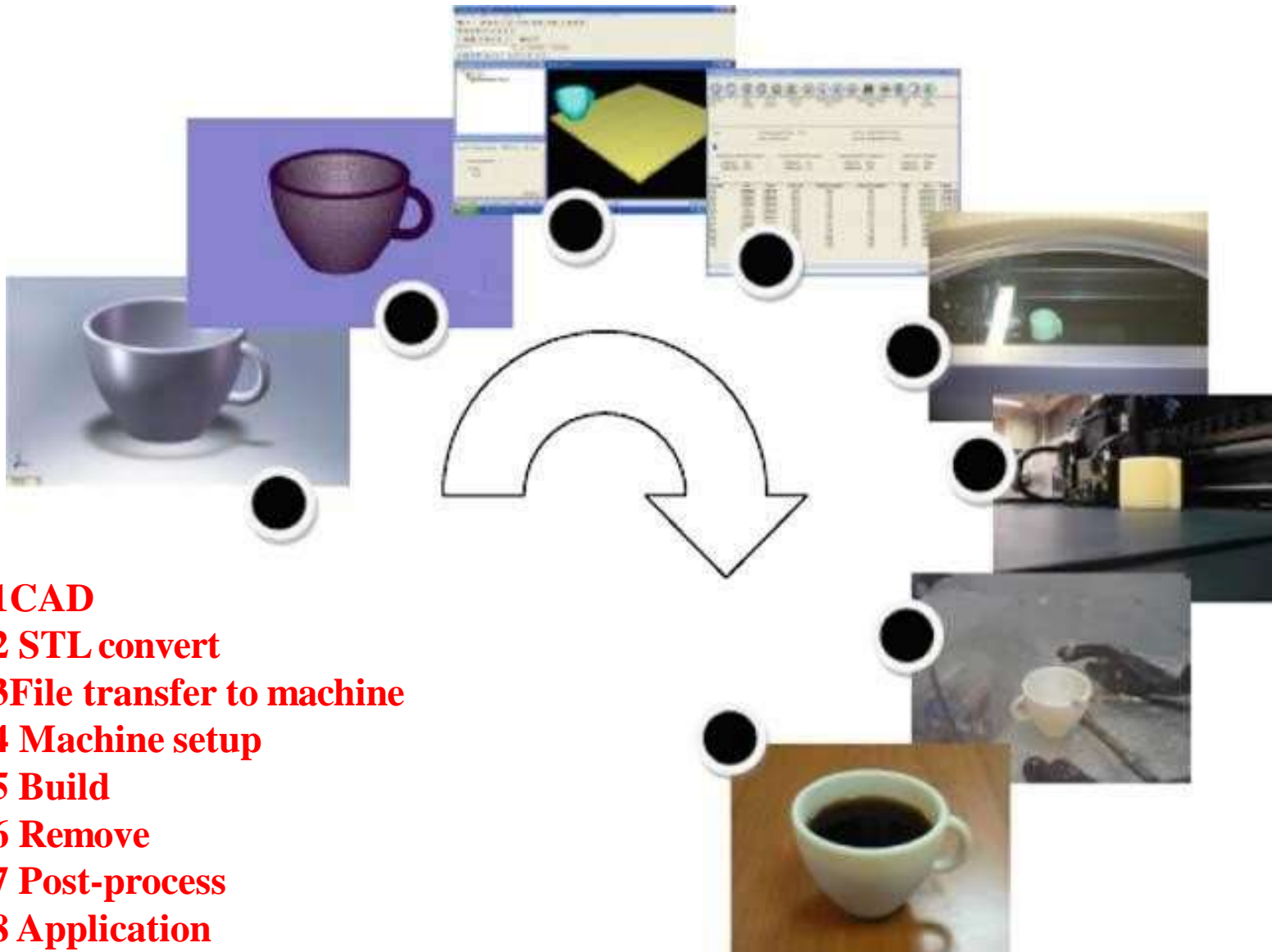
ABS



NYLON



Stages in



Step 1: CAD

- All AM parts must start from a software model that fully describes the external geometry. This can involve the use of almost any professional CAD solid modeling software, but the output must be a 3D solid or surface representation.
- Reverse engineering equipment (e.g., laser scanning) can also be used to create this representation.

Step 2: Conversion to STL

- Nearly every AM machine accepts the STL file format, which has become a de facto standard, and nearly every CAD system can output such a file format.
- This file describes the external closed surfaces of the original CAD model and forms the basis for calculation of the slices.

Step 3: Transfer to AM Machine and STL File Manipulation

- The STL file describing the part must be transferred to the AM machine.
- Here, there may be some general manipulation of the file so that it is the correct size, position, and orientation for building.

Step 4: Machine Setup

- The AM machine must be properly set up prior to the build process.
- Such settings would relate to the build parameters like the material constraints, energy source, layer thickness, timings, etc.

Step 5: Build

- Building the part is mainly an automated process and the machine can largely carry on without supervision.
- Only superficial monitoring of the machine needs to take place at this time to ensure no errors have taken place like running out of material, power or software glitches, etc.

Step 6: Removal

- Once the AM machine has completed the build, the parts must be removed.
- This may require interaction with the machine, which may have safety interlocks to ensure for example that the operating temperatures are sufficiently low or that there are no actively moving parts.

Step 7: Post processing

- Once removed from the machine, parts may require an amount of additional cleaning up before they are ready for use. Parts may be weak at this stage or they may have supporting features that must be removed. This therefore often requires time and careful, experienced manual manipulation.

Step 8: Application

- Parts may now be ready to be used. However, they may also require additional treatment before they are acceptable for use.
- For example, they may require priming and painting to give an acceptable surface texture and finish. Treatments may be laborious and lengthy if the finishing requirements are very demanding.

Advantages of AM

- Freedom of design
- Complexity for free
- Potential elimination of tooling
- Lightweight design
- Elimination of production steps

Applications of AM

AM has been used across a diverse array of

- industries, including;
- Automotive
- Aerospace
- Biomedical
- Consumer goods and many others

Classification of Additive Manufacturing Systems

The Better way is to classify AM systems broadly by the initial form of its material, categorised all AM Systems can be easily into

1) Liquid Based

2) Solid Based

3) Powder Based

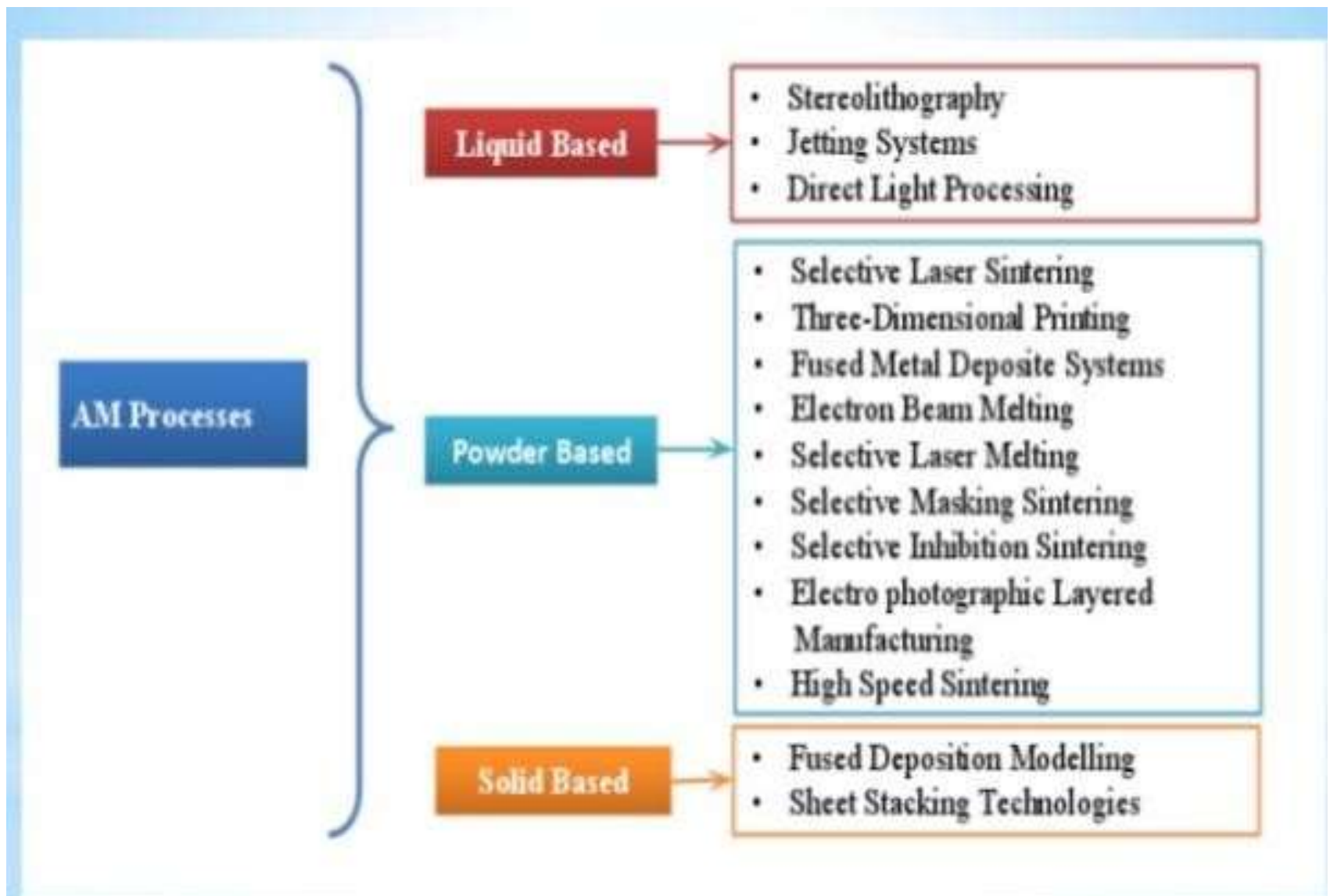


Photo Polymerization (Stereolithography)

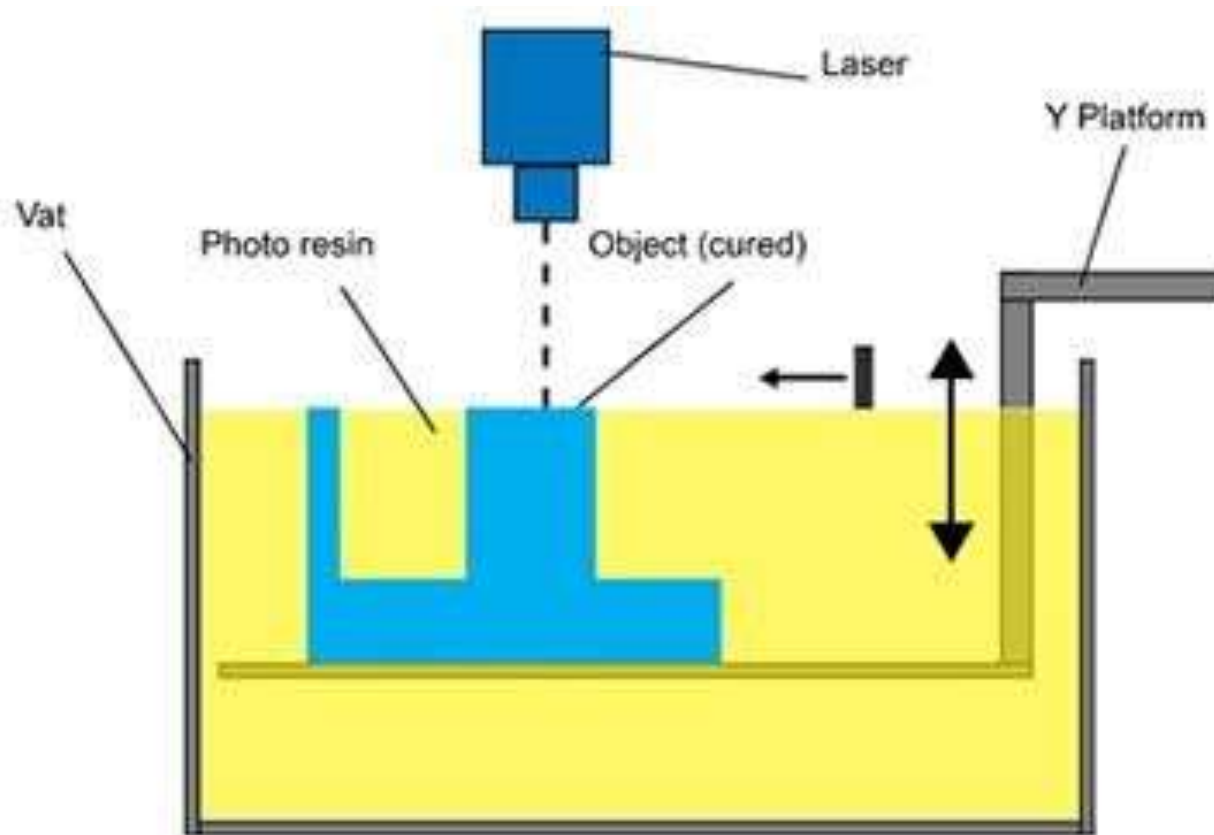


Photo Polymerization

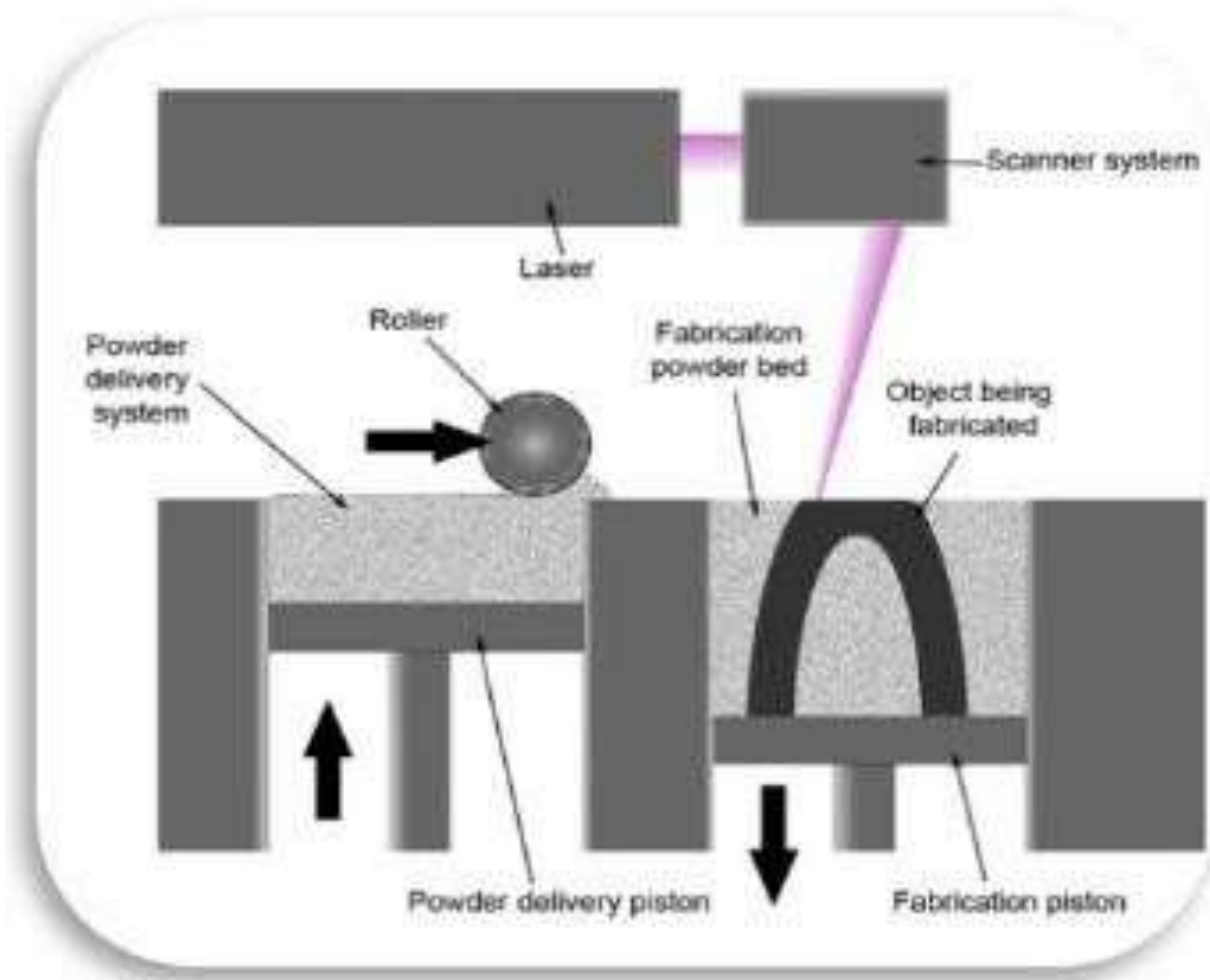
- Stereolithography Apparatus (SLA) is a liquid-based process which builds parts directly from CAD software.
- SLA uses a low-power laser to harden photo-sensitive resin and achieve polymerization.
- The process begins with a 3D CAD file. The file is digitally sliced into a series of parallel horizontal cross-sections which are then provided to a Stereolithography Apparatus (SLA) one at a time.
- A laser traces the cross-section onto a bath of photopolymer resin which solidifies the cross-section. The part is lowered a layer thickness into the bath and additional resin is swept onto the surface.
- The laser then solidifies the next cross-section. This process is repeated until the part is complete. Most parts are completed in a matter of hours, thereby defined as a "Rapid Prototype".

Discrete Particle Systems

- Discrete particles are normally powders that are generally graded into a relatively uniform particle size and shape and narrow size 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.

Powder Bed Fusion Processes

Selective Laser Sintering(SLS)



Powder Bed Fusion Processes

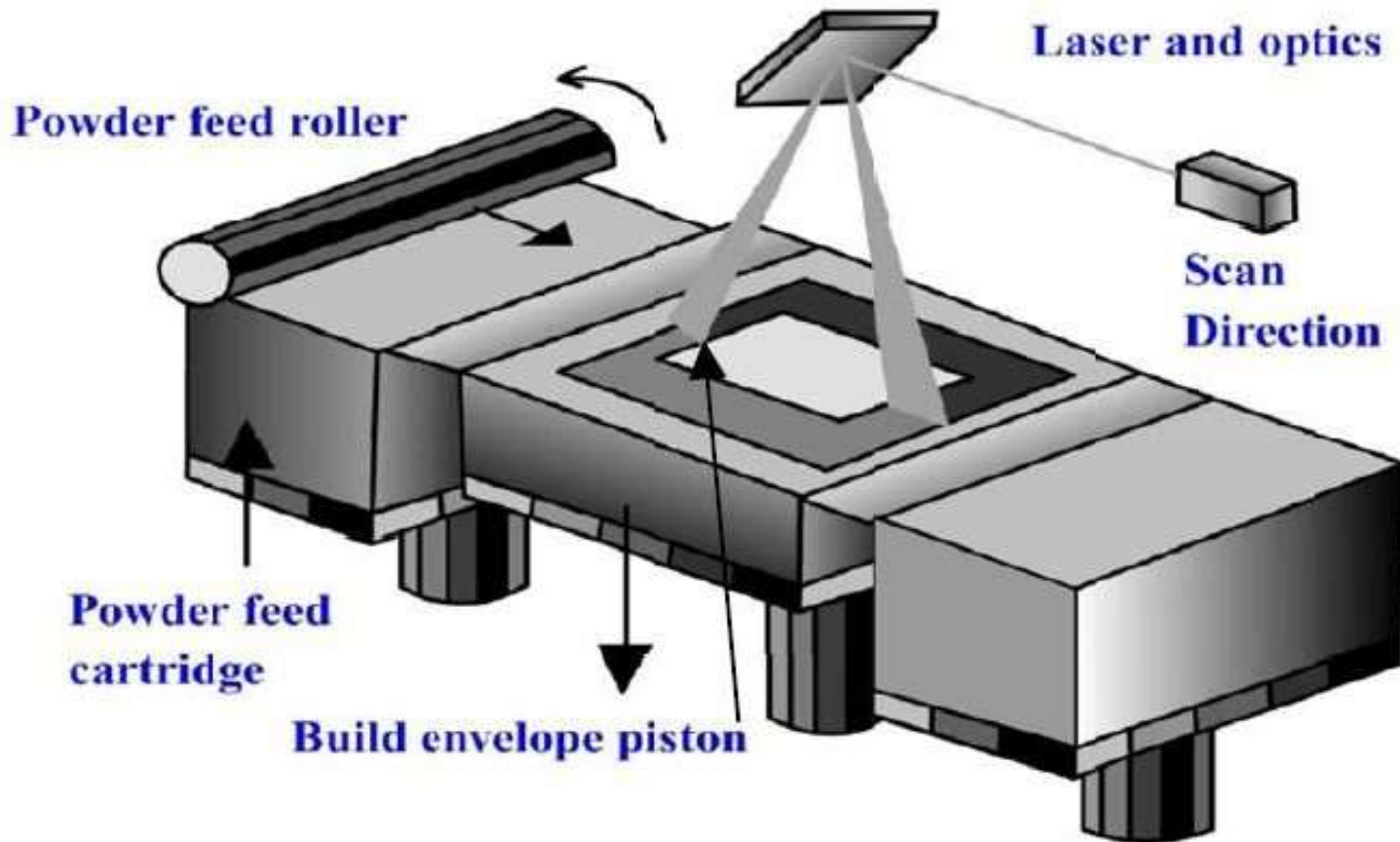


Fig. 5.2.4 Schematic of the Selective Laser Sintering process

Powder Bed Fusion Processes

- Selective Laser Sintering (SLS), the most prominent of the powder bed fusion processes, was originally developed at the University of Texas at Austin.
- In SLS a layer of powdered material is spread out and levelled over the top surface of the growing structure.
- A laser then selectively scans the layer to fuse those areas defined by the geometry of the cross-section; the laser energy also fuses layers together.
- The unfused material remains in place as the support structure. After each layer is deposited, an elevator platform lowers the part by the thickness of the layer, and the next layer of powder is deposited.
- When the shape is completely built up, the part is separated from the loose supporting powder.

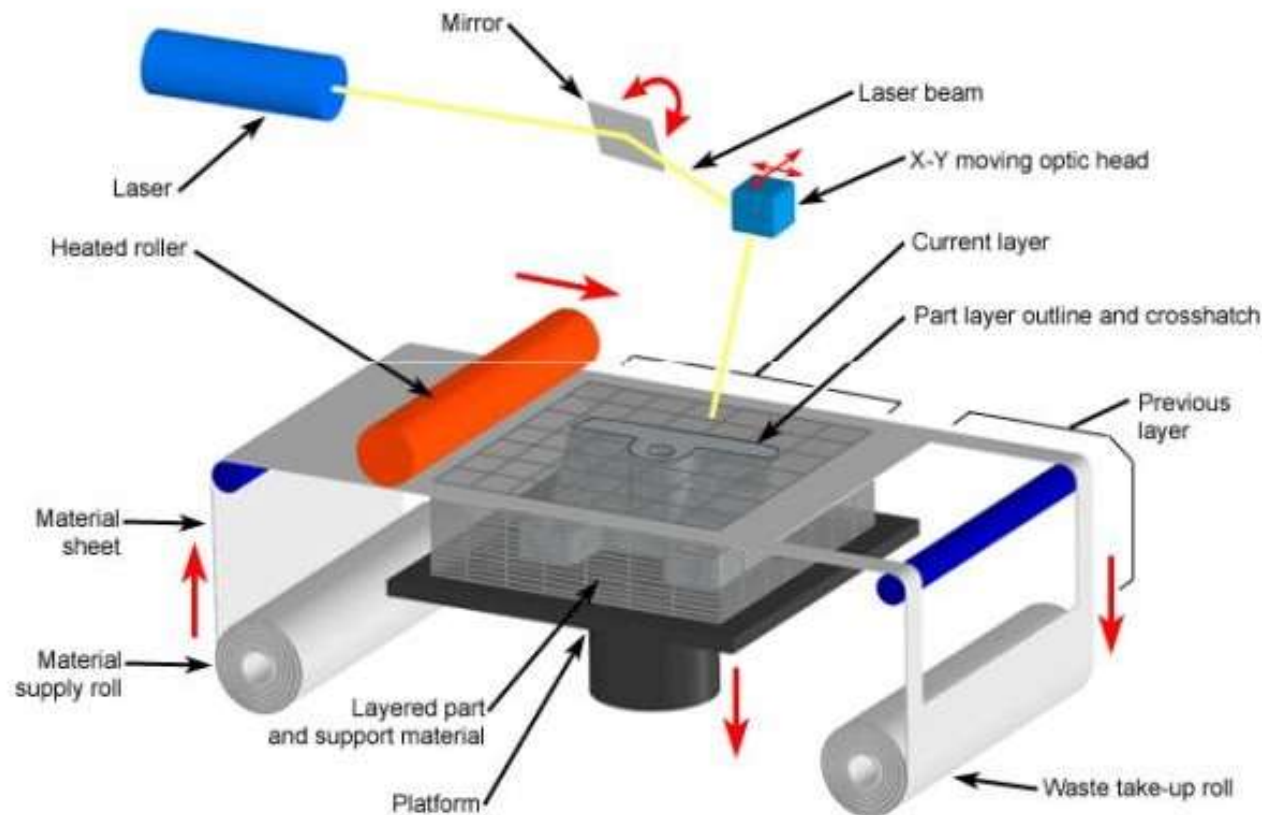
Solid Sheet Systems

- 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 much like a wooden block.

Laminated Object Manufacturing

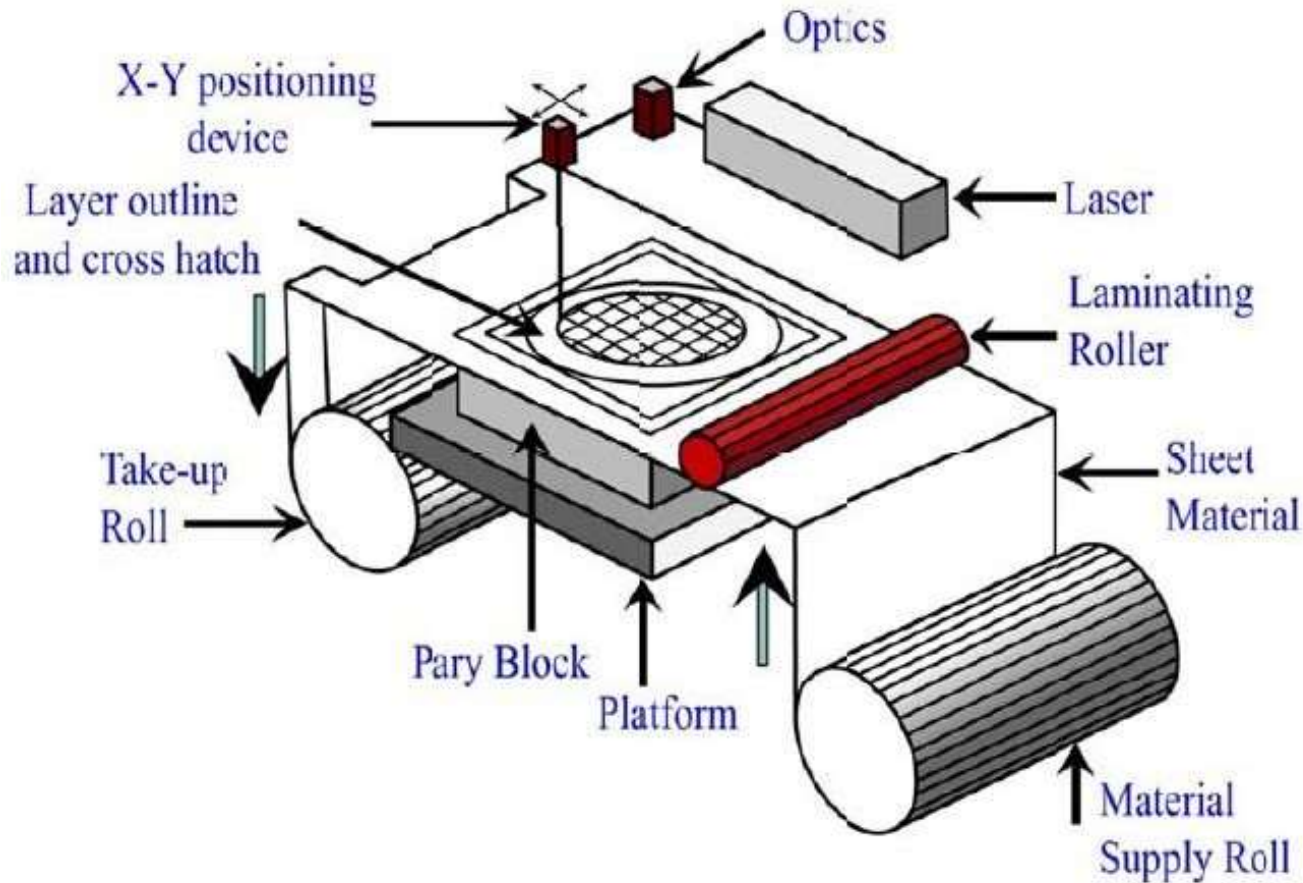
- Laminated Object Manufacturing (LOM) is a process that combines additive and subtractive techniques to build a part layer by layer.
- In this process the materials come in sheet form. The layers are bonded together by pressure and heat application and using a thermal adhesive coating.
- A carbon dioxide laser cuts the material to the shape of each layer given the information of the 3D model from the CAD and STL file.
- **The advantages** of this process are the low cost , no post processing and supporting structures required, no deformation or phase change during the process, and the possibility of building large parts.
- **The disadvantages** are that the fabrication material is subtracted thus wasting it, low surface definition, the material is directional dependent for machinability and mechanical properties, and complex internal cavities are very difficult to be built.
- This process can be used for models with papers, composites, and metals

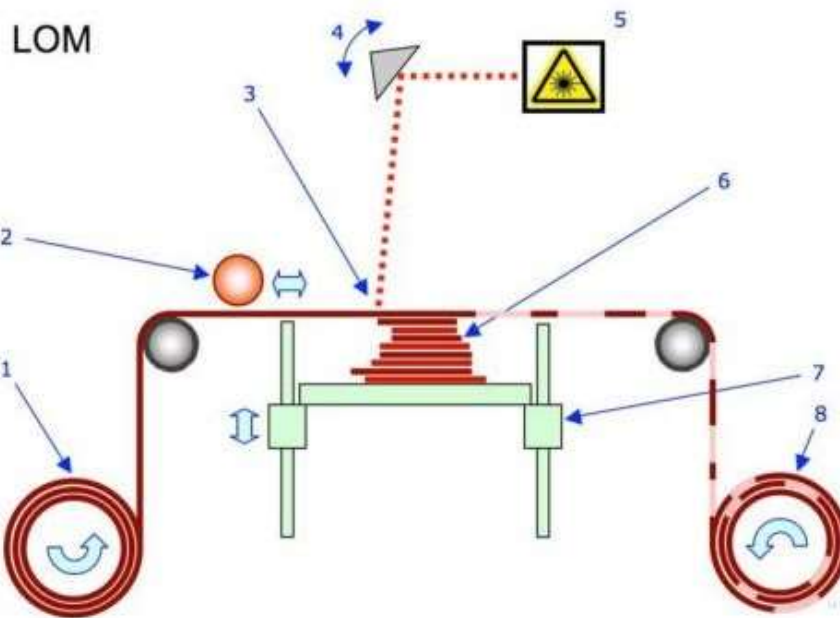
Laminated Object Manufacturing



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Laminated Object Manufacturing





1 Foil supply. 2 Heated roller. 3 Laser beam. 4. Scanning prism. 5 Laser unit. 6 Layers. 7 Moving platform. 8 Waste.

- Sheet is adhered to a substrate with a heated roller
- Laser traces desired dimensions of prototype
- Laser cross hatches non-part area to facilitate waste removal
- Platform with completed layer moves down out of the way
- Fresh sheet of material is rolled into position
- Platform moves up into position to receive next layer

Advantages

- Ability to produce larger-scaled models.
- Uses very inexpensive paper
- Fast and accurate
- Good handling strength
- Environmentally friendly
- Not health threatening.

Disadvantages

- Need for decubing, which requires a lot of labor
- Can be a fire hazard
- Finish, accuracy and stability of paper objects not as good as materials used with other RP methods

Typical Uses

- Investment casting patterns
- Concept verification
- Masters for silicone-rubber injection tools
- Fit-check
- Direct use

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 for doing this is the Fused Deposition Modeling (FDM) material extrusion technology developed by the US company Stratasys.

Fused Deposition Modeling

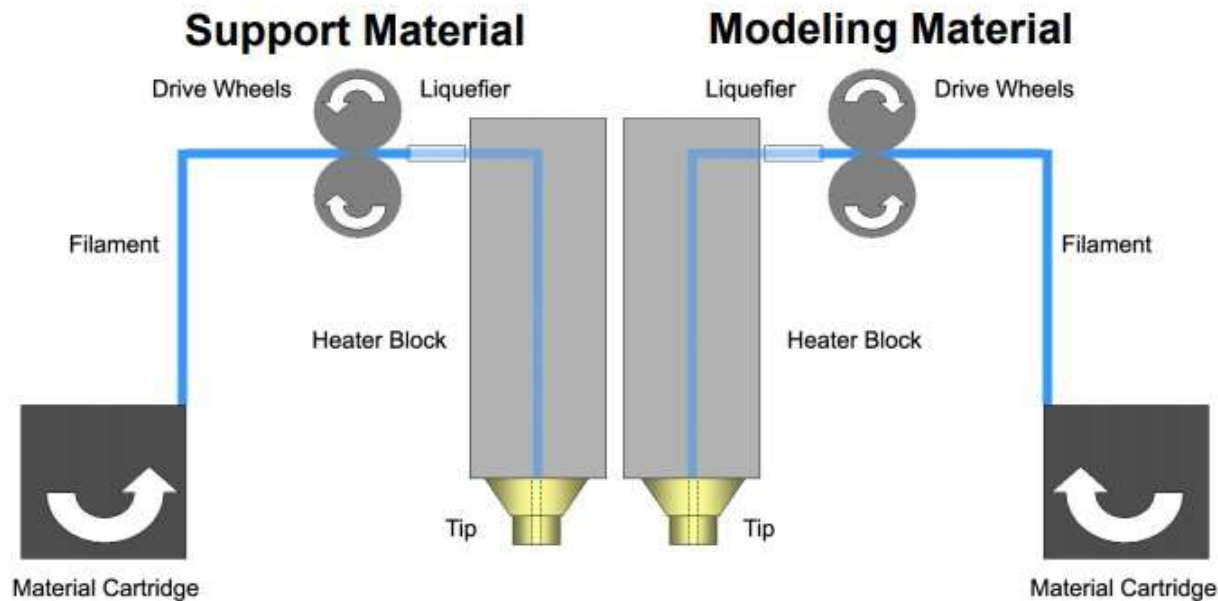
- FDM is a filament-based technology where a temperature-controlled head extrudes a thermoplastic material layer by layer onto a build platform.
- A support structure is created where needed and built in a water-soluble material.



- Filament is made of thermoplastic materials
 - Acrylonitrile butadiene styrene (ABS)
 - Polylactide (PLA) - biodegradable!
 - Many new materials



- Dual extruder machines exist
 - Temporary support structures can be made from water-soluble material
 - Two colors

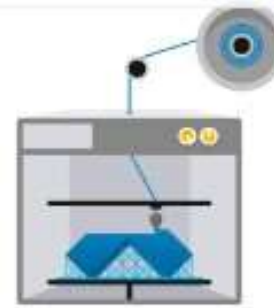




The 3D model



The thermoplastic modeling filament is heated to a semi-liquid state



The extrusion head 'draws' the part and its support one layer at a time

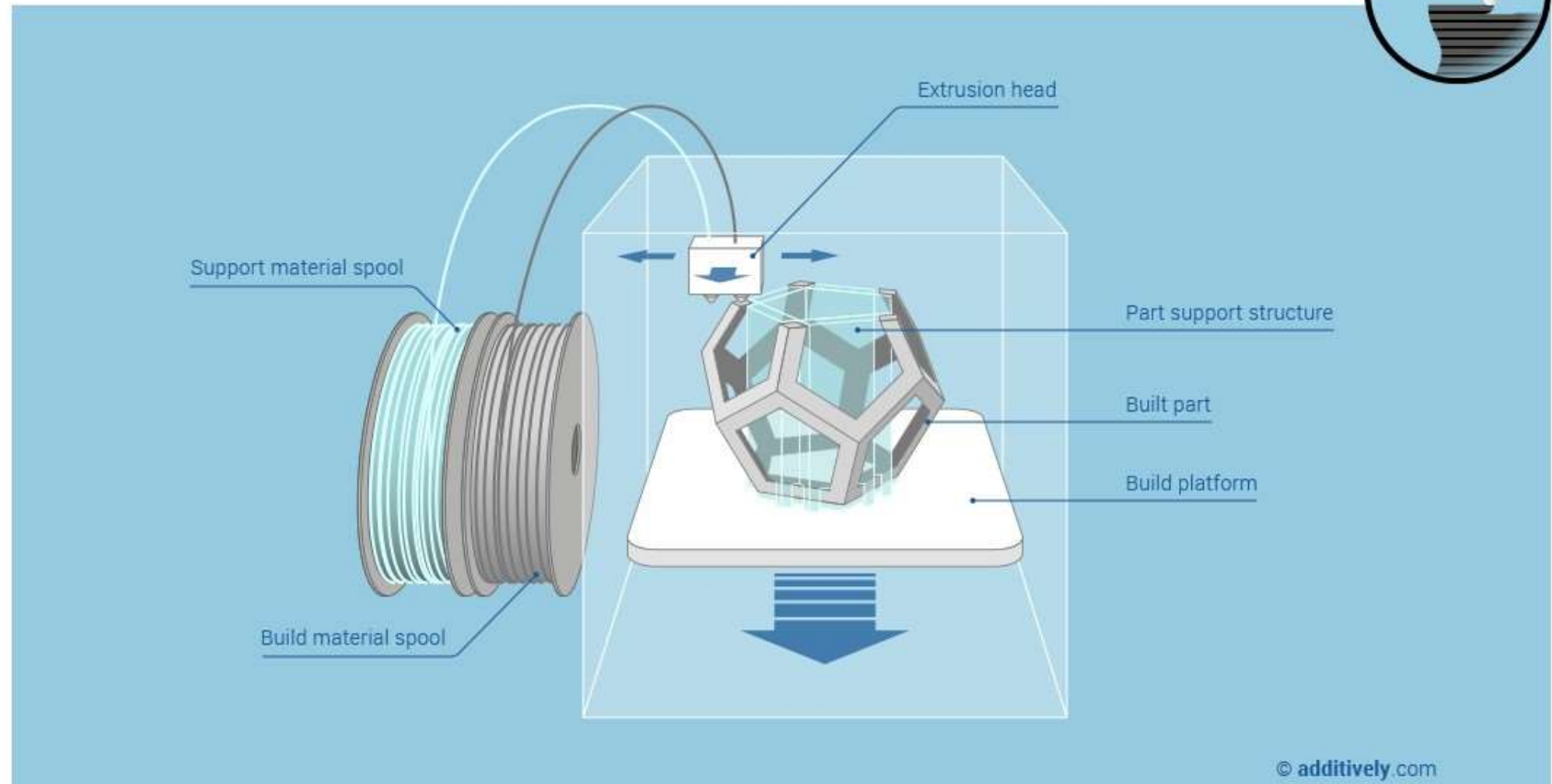


The support is removed



The part is finished

Fused Deposition Modeling (FDM)



Application areas

Prototypes are produced for form / fit and functional testing in standard materials by FDM

Support parts (jigs, fixtures, helps) can be produced directly

Small series parts down to one of a kind are built in standard materials by fused deposition modeling

Post processing of AM parts

- Post-processing is an essential stage of additive manufacturing. It's the last step in the manufacturing process, where parts receive finishing touches such as smoothing and painting.
- **Why is post-processing important?**
- Post-processing improves the quality of parts and ensures that they meet their design specifications.
- The finishing process can enhance a part's surface characteristics, geometric accuracy, aesthetics, mechanical properties, and more. For samples and prototypes, this can mean the difference between a sale or a loss.
- For production parts, finishing creates a part that is ready to use.

- **A metal additive manufacturing (AM)** part is essentially “welded” to the build plate, and you will not be able to pull it off without some assistance. Even then, the AM part will need postprocessing before it is ready to use.
- Here are some costs associated with postprocessing AM parts

Powder Removal:

- AM parts build “down” in a powder-bed fusion system as new layers are added to the top, which means that parts are buried in powder when they are done .
- After the build has finished and the parts/build plate have cooled, the machine operator has to remove all of the powder
- from the build volume and sieve/filter/recycle it for later use, assuming you want to reuse it.
- This is not an expensive step, but it does take time.

Stress Relief:

- The heating and cooling of the metal as the part builds layer-by-layer leads to internal stresses that must be relieved before the part is removed from the build plate. Otherwise, the part may warp or even crack.
- Stress-relieving the part requires an oven or furnace (preferably with environmental controls) that is big enough to fit the entire build plate.
- Many recommend using an oven with an inert environment to minimize oxidation on the part surface.

Part Removal:

- Most companies use wire EDM to remove parts from the build plate, however many machine shops are starting to use a bandsaw because it is faster and the bottoms of the parts must be finished anyway.
- Keep in mind that materials such as Inconel strain-harden as they are worked, making it difficult to remove them from the build plate with just a bandsaw.
- A bandsaw can complete the task in minutes.

Heat Treatment:

- Heat treatment (aging, solution annealing and so on) improves the microstructure and mechanical properties of the parts and is necessary for nearly all AM parts.
- In many cases, this step also requires an environmentally controlled furnace with the ability to regulate the temperature and cool-down schedule.
- Heat treatment may affect the dimensions of the parts, so most people prefer to heat-treat parts before they machine/finish them.
- The American Society for Testing and Materials (ASTM) just released a standard for thermal postprocessing of metal AM parts.

Machining:

- Machining of mating interfaces, surfaces, threads, support structures and more likely will be required to ensure dimensional accuracy of the finished part.
- Few AM parts meet specifications “as built,” and if nothing else, the surface of the part that was connected to the build plate will need to be finished.
- Most manufacturing companies already have machining systems on hand, but registering parts and establishing datums for machining can be tricky, especially for complex, organically shaped parts made with AM.
- Accessing internal channels or cooling passages that need to be machined can also increase costs. The cost here is highly dependent on the material and the job as well as the fixturing needed to hold the part.

Surface Treatments:

- Surface finishing also might be required to improve surface finish/quality, reduce surface roughness, clean internal channels or remove partially melted particles on a part.
- When outsourced, these costs can easily run in the hundreds if not thousands of dollars.

Inspection and Testing:

- Metrology, inspection and nondestructive testing using white/blue -light scanning, dye-penetrant testing, ultrasonic testing, computed tomography (CT) scanning and more will be needed after post processing and possibly at multiple points during post processing.
- Destructive testing of sample parts and analysis of witness coupons (for example, tensile bars), powder chemistry, material microstructure and more also may be needed to gather data to help with process qualification and ultimately part certification.
- Most companies will have a range of metrology and non-destructive testing methods on hand, but AM parts with internal channels, lattice structures and other internal enhancements may require CT scanning to ensure clear passageways, evaluation of internal geometries and more.

Guidelines for process selection

- A variety of AM technologies have been developed. According to ASTM Standard F2792 (ASTM F2792-12a 2012), these technologies can be catalogued into seven groups: binder jetting, directed energy deposition, material extrusion, material jetting, powder bed fusion, sheet lamination and vat photo- polymerization.
- More than 350 industrial AM machines and 450 materials have been identified in the market (Senvol LLC 2015). The debate about which machine or technology fares better than others has little value as each of them has its targeted applications.
- AM technologies are no longer limited to prototyping usage, but are increasingly also being used for making end products .
- Therefore, „Design for Additive Manufacture“ (DfAM) becomes increasingly significant for avoiding potential manufacturing pitfalls and maximizing utilization of AM capability.

The commonly used decision process can be described by a six-stage sequential decision-making model as proposed

- Identification of the problem
- Obtaining necessary information
- Production of possible solutions
- Evaluation of such solutions
- Selection of a strategy for performance
- Implementation and subsequent learning and reformulation

AM Applications

1. Rapid Prototyping

- Models and parts for research purposes can be easily manufacture whenever required. Easy to make changes in the models as per the research proceedings.

2. Food

- Cornell Creative Machines Lab is making food items such as chocolates, candy, pasta, pizza using 3D printing technique since 2012.

3. Apparel

- Products such as customize shoes, clothes and eye wears are being manufactured. •Nike is using 3D printing to manufacture the “Vapor Laser Talon” football shoe for players of American football

4. Vehicle

- In 2010 Urbee became the first car whose whole body was 3D printed (by US engineering group Kor Ecologic and the company Stratasys).
- In early 2014, Swedish supercar manufacturer, Koenigsegg ,manufactured a supercar having many 3D printed mechanical parts in it.

5. Firearms

Defense arms such as guns, rifles and safety equipment has also been manufacture by AM.

In 2012 US based group “Defense Distributed”, designed a working plastic gun that could be downloaded and reproduced by anybody with a 3D printer.

In 2013, „Solid Concepts“,based in Austin, Texas, US Asucceeded in manufacturing first working metal gun.

6. Medical

- •Nowadays medical devices, specific implants, hearing aids, dental products and pills are being manufacture by AM. •During October 2014, a five year old girl born without fully formed fingers on her left hand
- became the first child in the UK to have a prosthetic hand made with 3D printing . Till now more than 400 hands have been transplanted by E-NABLE.
- •In august 2015, US FDA (Food and Drug administration) approved 3D printed pills which allows very porous pills to be produced, which enables high drug doses in a single pill which dissolves quickly and can be ingested easily.
- Currently, active research is pursued by different groups to use cells and biomaterials by different print-heads to produce organs on demand. This might answer the organ shortage scenario in regenerative medicine application.”

DENTAL



7. Bioprinting

- Bioprinting refers to manufacturing artificial biological organs and body parts capable of working like original ones.
- In this process, layers of living cells are deposited onto a gel medium or sugar matrix and slowly built up to form three dimensional structures including vascular systems.
- The first production system for 3D tissue printing was delivered in 2009, based on NovoGen bio -printing technology. •In 2013, Chinese scientists began printing ears, livers and kidneys,with living tissue. •In 2014, researchers at the University of Hasselt, in Belgium had successfully printed a new jawbone for an 83 year old woman.

8. Space

- In September 2014, “SpaceX” delivered the first zero gravity 3D printer to the International Space Station (ISS).
- In December 2014, NASA emailed CAD drawings for a socket wrench to astronauts aboard the ISS, who then printed the tool using its 3D printer.
 - The European Space Agency plans to deliver its new advance Portable On Board 3D Printer to the International Space Station by the end of 2015

Assignment questions

- Define additive manufacturing(AM)?
- Distinguish between AM and CNC.
- List applications and advantages of CNC.
- List and explain stages of AM.
- Classify AM Process, explain any one in each processes.
- Explain post-processing of AM part.
- Explain guideline for process selection.
- Explain applications of AM in different areas.

Thank you...!!!