3 LIQUID BASED AND SOLID BASED ADDITIVE MANUFACTURING SYSTEMS

3.1 CLASSIFICATION

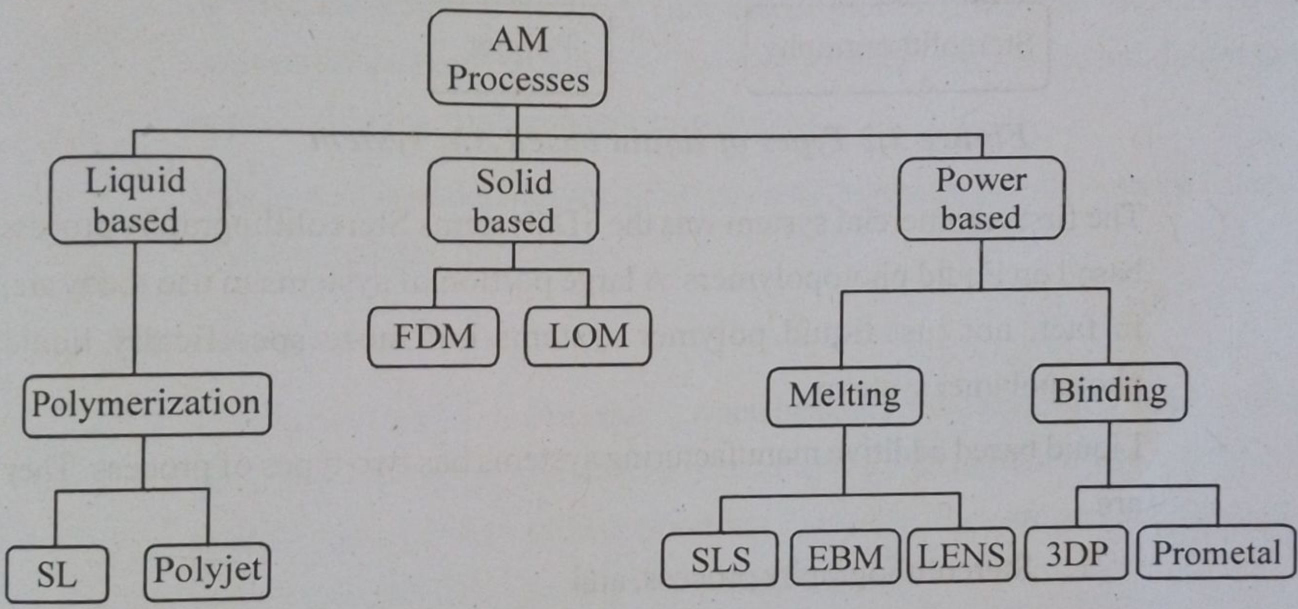

Figure 3.1 Classification of AM process

✓ Additive manufacturing can be defined as a process that can turn print 3D models into physical objects, in different raw materials using various additive manufacturing technologies. The raw materials used in the AM process are in different states, such as liquid, solid and powder states.

✓ There are numerous ways to classify AM technologies. A popular approach is to classify according to the state of material used. The classifications are:

- Liquid based additive manufacturingsystem
- Solid based additive manufacturingsystem
- Powder based additive manufacturingsystem

3.2 LIQUID BASED SYSTEM

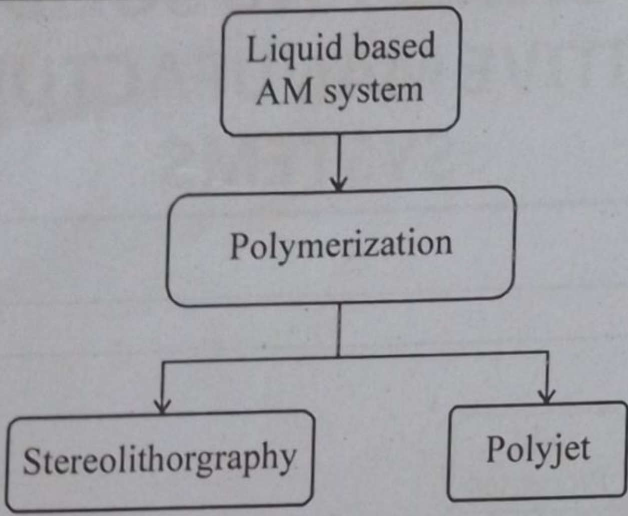

Figure 3.2 Types of liquid based AM system

- ✓ The first commercial system was the 3D Systems Stereolithography process based on liquid photopolymers. A large portion of systems in use today are, in fact, not just liquid polymer systems but more specifically liquid photopolymer systems.
- ✓ Liquid based additive manufacturing systems has two types of process. They are
    1. Stereolithography process, and
    2. Polyjet process.
- ✓ Both these process are based on polymerization technique.

3.2.1 Polymerization

- ✓ Polymerization is the process of converting a monomer or a mixture of monomers into a polymer
- ✓ **Monomer:** A monomer is the single unit or the molecule which is repeated in the polymer chain. It is the basic unit which makes up the polymer.
- ✓ **Polymer:** Polymers are any material, synthetic or organic, consisting of small simple molecules chained together to form a larger molecule.
- ✓ Polymerization is similar to constructing a large building out of the same type of Lego blocks. The blocks can be connected in various ways to create a larger, more intricately shaped structure than the original Lego block on its own.

3.2.2 Polymer Classification

- ✓ The major classification of polymers is
  1. Thermoplastic, and
  2. Thermosetting

1. Thermoplastic

- ✓ The polymers in this category are composed of monomers which are linear or have moderate branching. They can be melted repeatedly and casted into various shapes and structures. They are soluble in solvents, but do not have appreciable thermal resistance properties.
- ✓ Vinyls, cellulose derivatives, polythene and polypropylene fall into the category of thermoplastic polymers.

2. Thermosetting

- ✓ There are some polymers which, when heated, decompose, and hence, cannot be reshaped. Such polymers have a complex 3-D network (cross-linked or branched) and are called Thermosetting Polymers. They are generally insoluble in solvents and have good heat resistance quality.
- ✓ Thermosetting polymers include phenol-formaldehyde, urea-aldehyde, silicones and allyls.

3.2.3 Photopolymers

- ✓ Photopolymer is a polymer that changes from a liquid state to solid state when exposed to light of a certain wavelength.
- ✓ The word polymer is defined as any material, synthetic or organic, consisting of small simple molecules chained together to form a larger molecule.
- ✓ The term photo in photopolymer denotes its sensitivity to light.

Typical ingredients of photopolymers

- ✓ Monomers: small molecules, lower viscosity.

- ✓ Oligomers: relatively high molecular weight, acrylates, epoxies, etc.
- ✓ Photoinitiators: generate reactive species (free radicals, irons) under light exposure to initiate the polymerization.
- ✓ Additives: binders, surfactants, stabilizers, etc.

3.2.4 How Photopolymers Works

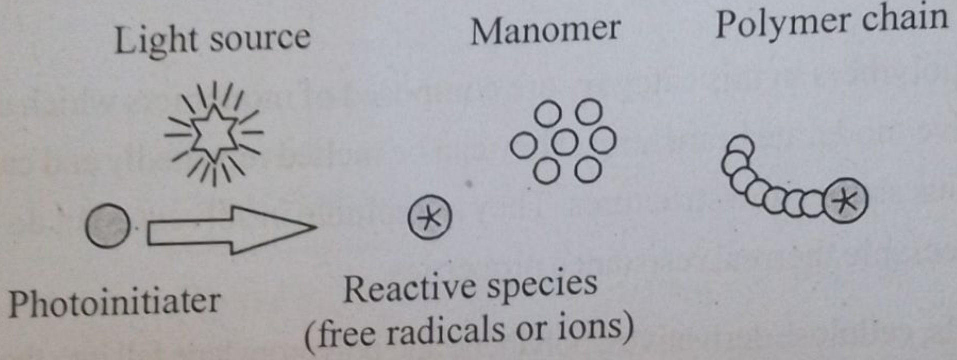

Figure 3.3 Photopolymers work

- Free Radical Polymerization
  - ✓ Initiation: Free radicals are generated through the initiator when exposed to light
  - ✓ Propagation: Free radicals react with monomer molecules to generate new reactive center, monomers react with reactive center repetitively to grow into a long chain
  - ✓ Termination: Chain termination occurs when two reactive centers come close and react with each other to yield complete macromolecules

3.3 STEREOLITHOGRAPHY APPARATUS (SLA)

- ✓ SLA is the first "additive manufacturing" technology and it is the most widely used process among the AM technology.
- ✓ The Stereolithography process was first developed in 1986, by Charles Chuck Hull founder of 3D Systems of Valencia, California, USA.
- ✓ It is a liquid based additive manufacturing process which builds parts directly from CAD software. This process uses 3D CAD data and a SLA machine to create 3D objects from liquid based AM materials.
- ✓ Stereolithography gives a fast and easy way to turn CAD drawings into real objects.

- ✓ In brief, this process can be explained as follows: SLA builds parts in a pool of UV-curable photopolymer resin using a computer controlled laser. The laser traces out and cures a cross-section of the part design on the surface of the liquid resin. The solidified layer is then lowered just below the surface of the liquid resin and the process is repeated until the part is completely built. Each newly cured layer adheres to the layer below it.
- ✓ The quality of the object fabricated by stereolithography process depends on the quality of the SLA machine used to print it.
- ✓ The amount of time it takes to create an object with stereolithography also depends on the size of the machine used to print it. Small objects are usually produced with smaller machines and typically take between six to twelve hours to print. Larger objects, which can be several meters in three dimensions, take days.

3.3.1 Principle

- ✓ The basic principle of this process is the photopolymerization, which is the process where a liquid monomer or a polymer converts into a solidified polymer by applying ultraviolet light which acts as a catalyst for the reactions.
- ✓ Photopolymer is a material which changes from a liquid state to solid state when exposed with light of a certain wavelength.
- ✓ SLA works by curing and solidifying successive layers of liquid photopolymer resin using an ultraviolet laser.
- ✓ Thin layers formed in this process are built from the bottom up.

3.3.2 Basic Elements of SLA

SLA has the following main parts:

1. A vat of liquid photopolymer resin.
2. A perforated platform that is lowered into the tank.
3. An elevator to provide up and down movement for platform.
4. An ultraviolet (UV) laser unit and
5. A computer controlling the platform and the laser.

3.3.3 Process

The SLA process is simple, comprising of three stages:

1. Pre-processing
2. Processing
3. Post-processing

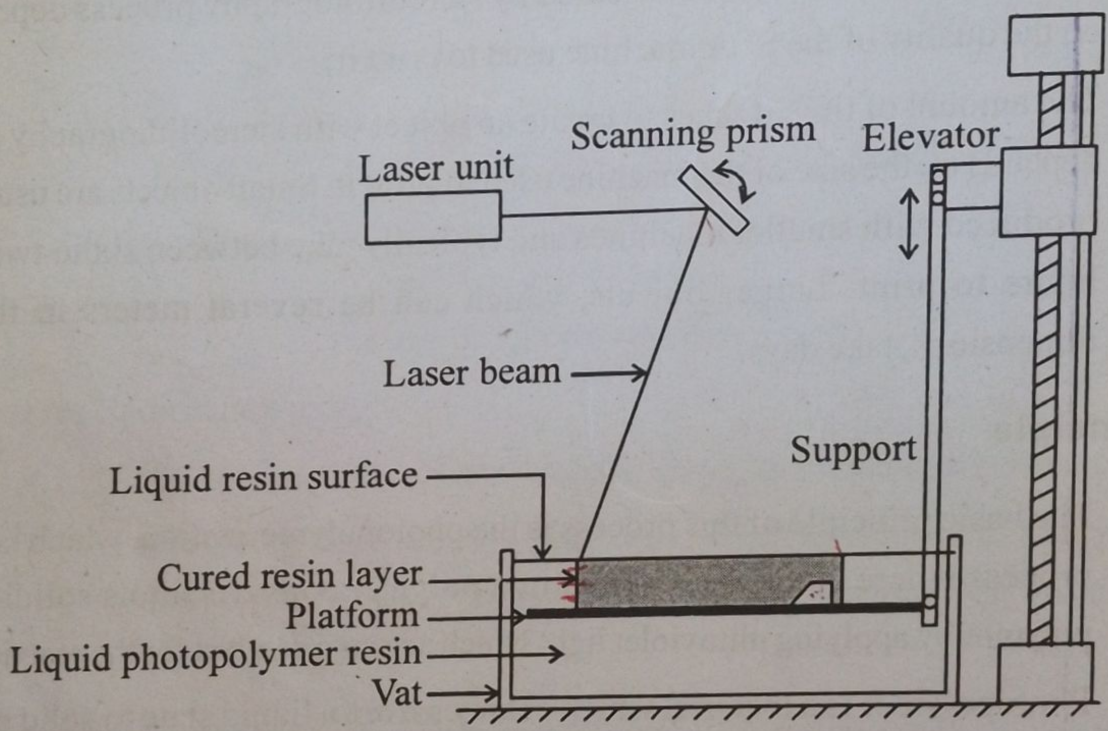

Figure 3.4 Stereolithography process

1. **Pre-processing**

✓ The Stereolithography process begins with a 3D CAD file of the part.

✓ The 3D CAD file is first converted into STL file.

✓ The data is then "sliced" horizontally into thin layers of cross sections in z-axis, with a thickness between 0.002" and 0.006" (0.05 mm to 0.15 mm) and formatted into SL build data.

✓ The Stereolithography machine uses the data to build the part layer by layer with an ultraviolet laser.

2. **Processing**

- ✓ The SLA machine starts to build the model upon a perforated platform which is kept inside a vat of liquid photopolymer resin.
- ✓ The platform is positioned on an elevator structure, which provides up and down movement for platform.
- ✓ In the initial step, the elevator keeps the platform immersed in a vat of liquid photopolymer resin, with only a thin liquid film above it.
- ✓ A low-power highly focused UV laser traces out the first layer, solidifying the model's cross section while leaving excess areas liquid.
- ✓ Once the initial layer of the object has solidified, the elevator incrementally lowers the platform 0.05 mm to 0.15 mm (equal to the thickness of the layers to be build) into the liquid polymer, exposing a new surface layer of liquid polymer.
- ✓ This layer thickness can vary based on laser strength, material, or tolerance desired.
- ✓ The laser again traces the second layer, solidifying the model's cross section, which instantly bonds atop the first.
- ✓ This process is repeated again and again until the entire object has been formed and is fully submerged in the tank.
- ✓ Some objects have overhangs or undercuts which must be supported during the fabrication process by support structures. The support structures are either manually or automatically designed, and it is fabricated right along with the object.
- ✓ The completed parts are not built fully cured in order to drain out excess resin, and hence it needs post-curing.
- ✓ Figure 3.4 is an illustration of the SLA process.

3. **Post-processing**

- ✓ Upon completion of the production process, the platform is raised to expose the completed object.

- ✓ The solid part is removed from the platform and rinsed with a liquid solvent to free it of excess resin.
- ✓ After it is rinsed with a liquid solvent, supports are broken off and the part is placed in an ultraviolet oven for complete curing. Curing involves subjecting the part to intense light in an oven-like machine.
- ✓ After the part is completely cured, further finishing can be done depending on the desired application.

3.3.4 Materials

- ✓ The materials used in Stereolithography process are photopolymers.
- ✓ Principally photo curing polymers which simulate polypropylene, ABS, PBT, rubber are used.
- ✓ Stereolithography materials are available in rigid clear, grey and white opaque.
- ✓ This class of materials quickly solidifies wherever the laser beam strikes the surface of the liquid.
- ✓ These materials have self-adhesive property that makes the layers to bond to one another.

3.3.5 Errors Induced in Stereolithography

There are some errors induced to the final piece from the process of stereolithography. They are:

1. Overcuring
2. Scanned line shape, and
3. Man-made error

1. Overcuring

- ✓ Overcuring is the error, which occurs to overhang parts because there is no fusing with a bottom layer.

2. Scanned line shape

- ✓ Another error is the scanned line shape, which is introduced by the scanning process. Because the resin is a high-viscosity liquid the layer thickness is variable and this introduces an error in the border position control.

3. **Man-made error**

✓ Another error caused could be if the part needed to have a surface finished process that is normally done by hand.

All these errors are minimized in equipments of high quality.

3.3.6 Advantages

✓ Provides the greatest accuracy of any AM technology.

✓ Provides excellent surface finish as compared to other AM technology.

✓ Easy manufacture of undercuts, complex structures, internal holes.

✓ Finely detailed features like thin vertical walls, sharp corners & tall columns can be fabricated with ease.

✓ No need for support material

✓ Photosensitive polymers have acceptable mechanical properties

✓ High speed

✓ Good resolution

3.3.7 Disadvantages

✓ It requires post curing.

✓ Material suite limited to only polymers that may be photopolymerized.

✓ The liquid polymers can be very toxic.

✓ Careful handling of raw materials required.

✓ Working with liquid materials can be messy.

✓ High cost of photo curable resin.

3.3.8 Applications

✓ Prototypes for demonstrational purposes

✓ Master patterns for molding and casting processes.

✓ Quick Cast patterns for investment casting

✓ Injection Mould Tools.

- ✓ Wind Tunnel Modeling.
- ✓ Automotive design components
- ✓ Consumer electronics (cell phones etc.)
- ✓ Medical instruments, devices and labware
- ✓ Lighting components (lenses etc.)
- ✓ Transparent assemblies
- ✓ Clear display models
- ✓ Concept and marketing models

3.3.9 Micro-Stereolithography

- ✓ Microstereolithography, derived from conventional stereolithography, was introduced by Ikuta in 1993.
- ✓ Whereas in conventional stereolithography the laser spot size and layer thickness are both in the 100-μm range, in microstereolithography a UV laser beam is focused to a 1–2-μm spot size to solidify material in a thin layer of 1–10 μm.
- ✓ The monomers used in conventional stereolithography and micro-stereolithography are both UV-curable systems, but the viscosity in the latter case is much lower (e.g., 6cP vs. 2000 cP), because high surface tension hinders both efficient crevice filling and flat surface formation at the microscale.
- ✓ In microstereolithography the solidified polymer is light enough so that it does not require a support as is required for the heavier pieces made in stereolithography.

3.4 POLYJET PROCESS

- ✓ Polyjet was developed by Israeli company, Objet Ltd in 1999. Polyjet is a great alternative to SLA because similar materials are used, but with greater accuracy.
- ✓ Polyjet is an additive manufacturing technology that jets layers of liquid photopolymer to build models and prototypes with extremely complex geometries, fine details, and smooth surfaces.

- ✓ In polyjet process, multiple materials can be combined in one print to create over-molded parts and models with multiple durometers.
- ✓ The Polyjet process uses high-resolution inkjet technology to produce parts quickly and economically, making it an excellent option for presentation models, detailed prototypes, and master patterns.
- ✓ In brief, this process can be explained as follows: The polyjet machine jets tiny droplets of liquid photopolymer and instantly cures the droplets of liquid photopolymer by UV lights. Fine layers accumulate on the build platform to create precise 3D models or parts. Where overhangs or complex shapes require support, the polyjet machine jets a removable support material.

3.4.1 Principle

- ✓ Polyjet is based on material jetting and photopolymerization technique.
- ✓ Material jetting is a process in which droplets of build material are selectively deposited onto a build bed to develop a three-dimensional object.
- ✓ Photopolymerization is a process where a liquid polymer converts into a solidified polymer by applying ultraviolet light which acts as a catalyst for the reactions.
- ✓ Polyjet works similarly to inkjet printing, but instead of jetting drops of ink onto paper, Polyjet 3D Printers jet layers of curable liquid photopolymer onto a build tray.
- ✓ Polyjet works by jetting, curing and solidifying successive layers of liquid photopolymer resin using an ultraviolet flood lamp mounted on the print head.
- ✓ Thin layers formed in this process are built from the bottom up.

3.4.2 Basic Elements of Polyjet

Polyjet has the following main parts:

1. A resins tank
2. A build platform
3. A print head
4. An UV flood lamp mounted on the print head and
5. A computer controlling the platform and the print head.

3.4.3 Process

The Polyjet process is simple, comprising of three stages:

1. Pre-processing
2. Processing
3. Post-processing

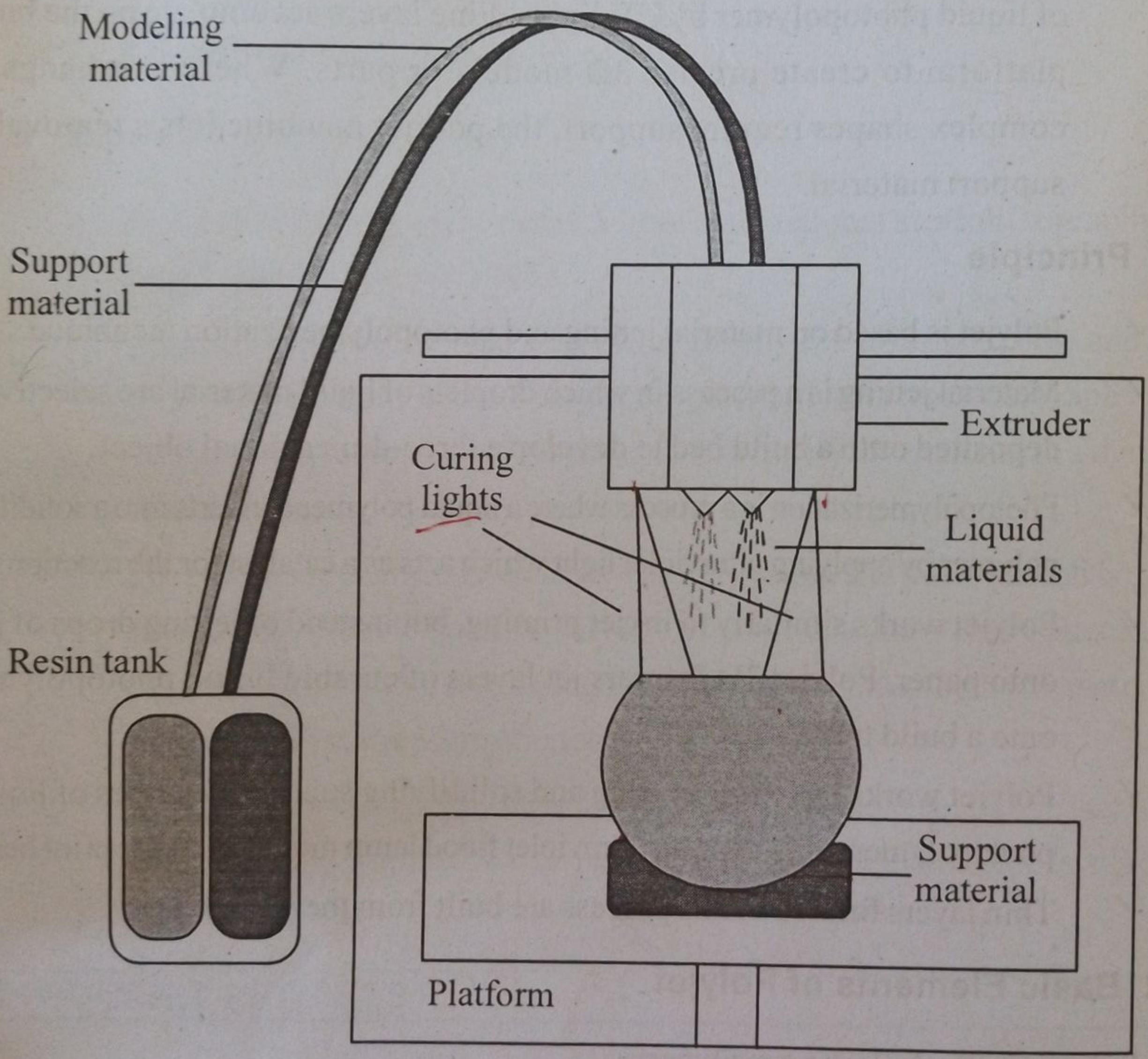

Figure 3.5 Polyjet process

1. Pre-processing

✓ The Polyjet process begins with a 3D CAD file of the part.

✓ The 3D CAD file is first converted into STL file.

- ✓ The data is then "sliced" horizontally into thin layers of cross sections in z-axis, with a thickness of 16 microns (0.0006") and formatted into Polyjet build data.
- ✓ The Polyjet machine uses the data to build the part layer by layer with the print head.

2. Processing

- ✓ The Polyjet machine builds the model upon a build platform.
- ✓ The process uses a wide area inkjet head to layer wise deposit both build and support materials.
- ✓ The polyjet machine starts jetting photopolymer materials in ultra-thin layers (16 microns) onto a build platform layer by layer.
- ✓ Subsequently each layer is completely cured after it is deposited, with an UV flood lamp mounted on the print head.
- ✓ Layers are built one at a time to create the prototype.
- ✓ These layers accumulate on the build platform until the part is complete.
- ✓ In addition to the model materials, the print head jets a removable gel-like support material for complex geometries with overhangs.
- ✓ In this process, the completed parts are built fully cured, and hence it does not need post-curing.
- ✓ Figure 3.5 is an illustration of the Polyjet process.

3. Post-processing

- ✓ There is less post processing cleanup on parts.
- ✓ The gel-like support material, which is specially designed to support complicated geometries, is easily removable.
- ✓ The support materialis removed by hand with water or in a solution bath, or by washing it away with pressurized water.
- ✓ Models and parts are ready to handle and use right out of the polyjet machine, with no post-curing needed.

3.4.4 Materials

- ✓ The materials used in Polyjet process are liquid acrylate-based photopolymer resin.
- ✓ The materials are available with a variety of characteristics.
- ✓ Some are rigid and opaque and come in blue, black, white, and gray colors.
- ✓ Some are rigid and transparent.
- ✓ The materials properties vary, ranging from rigid to rubber-like.
- ✓ Polyjet materials are best suited for applications where accuracy, surface finish, and detail are essential components of the printed part.

3.4.5 Advantages

- ✓ Create complex shapes
- ✓ Smooth surface finish
- ✓ Faster build times
- ✓ High accuracy
- ✓ Good tensile strength.
- ✓ Simulate final-product aesthetics
- ✓ Minimum layer thickness of 16μm.
- ✓ Produce accurate molds, jigs, fixtures and other manufacturing tools.
- ✓ Polyjet machine jets multiple materials and colors into a single print.
- ✓ Multi-material technology allows mixed trays, mixed material parts, and digital material printing
- ✓ No need for post-curing.
- ✓ The advantage of polyjet systems over SLA systems is that the resins come in cartridge form (no vat of liquid photopolymer)
- ✓ The machines are clean, quiet and office friendly.

3.4.6 Disadvantages

- ✓ Typically Polyjet is not considered suitable for production applications because the materials are photocurable resins that do not remain stable with exposure to UV light.
- ✓ Requires manual support removal
- ✓ Water jet is recommended means of removing support (requires plumbing)
- ✓ Where support material is needed, gloss finish is not achieved until post processing
- ✓ The print heads are relatively expensive and need to be replaced regularly.

3.4.7 Applications

- ✓ Form and Fit Testing
- ✓ Plastic part rapid tooling patterns
- ✓ Focus group and Presentation models
- ✓ Electronic components and connectors, and electronic packaging
- ✓ Medical devices, and
- ✓ Urethane castings.

3.4.8 Comparison of Stereolithography and PolyJet

Table 3.1 Comparison of SLA and PolyJet

S.No	SLA	PolyJet
1	Every component of the 3D printed part is made from the same material.	Multiple materials are used for production.
2	Stereolithography uses UV lasers directed onto a bed of liquid photopolymer resin to cure patterns, layer by layer.	Polyjet uses multiple print heads to deposit liquid photopolymer resin onto a clean build platform layer by layer. The material is cured as it is deposited.
3	Ultra Violet (UV) laser cured process.	UV lamp cured process.
4	Minimum layer thickness is 50μm	Minimum layer thickness is 16μm.

5	Size doesn't make a difference to Stereolithography build time.	Polyjet is the fastest 3D printing technology for parts within a 5" cube, but outside of 5", Polyjet becomes slower.
6	Parts are not built fully cured in order to drain out excess resin.	Parts are built fully cured.
7	Post-curing is needed. Parts to be cured in a UV oven.	Post-curing is not needed.
8	Limited color capability	Multiple color capability
9	High-resolution parts with very fine features and a smooth surface finish (as long as support structures are not touching part surface)	High-resolution parts with detailed features that simulate final-product aesthetics
10	Part blemishes due to removal of support structures	Part's gloss finish will get affected by support removal. But gloss finish can be achieved after post processing.
11	Supports are created out of the same material as the final part.	Supports are created out of separate material.
12	Support Removal is done with hand sanding and light bead blasting	Support Removal is done with water blasting and some residue removal by hand labor.

3.5 SOLID BASED SYSTEM

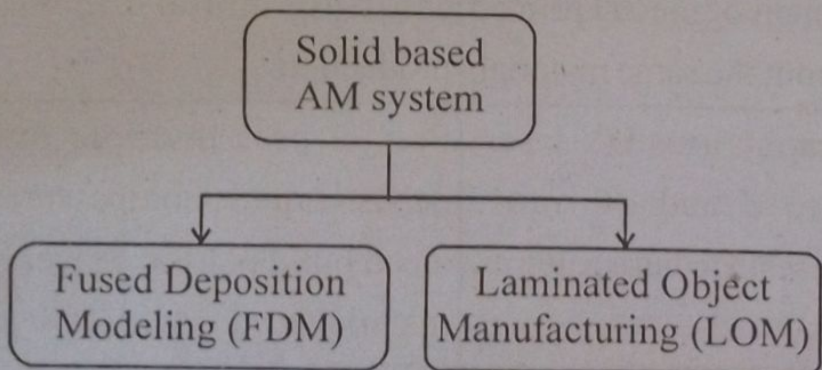

Figure 3.6 Types of liquid based AM system

- ✓ Solid based additive manufacturing systems has two types of process. They are
  1. Fused Deposition Modeling (FDM) process, and
  2. Laminated Object Manufacturing (LOM) process.
- ✓ The Fused Deposition Modeling (FDM) process is based on extrusion technique.
- ✓ Laminated Object Manufacturing (LOM) process is based on lamination technique.

3.6 FUSED DEPOSITION MODELING

- ✓ The fused deposition modeling (FDM) technology was developed by S. Scott Crump in 1988. Stratasys of Eden Prairie, Minnesota makes Fused Deposition Modeling (FDM) machines for commercialization.
- ✓ FDM is the second most widely used AM technology after the SLA process.
- ✓ Fused Deposition Modeling (FDM) is a solid based additive manufacturing process which builds parts directly from CAD software.
- ✓ This process uses 3D CAD data and a FDM machine to create 3D objects from solid based AM materials.
- ✓ In brief, this process can be explained as follows: Initially, filaments of heated thermoplastic are extruded from a nozzle tip that moves in the x-y plane. The controlled extrusion head deposits very thin beads of material onto the build platform to form the first layer. After the platform lowers, the extrusion head deposits a second layer upon the first, and the process continues till the part is completely formed.
- ✓ There are multiple types of and names for extrusion techniques, including: FDM (fused deposition modeling), FFF (fused filament fabrication) and occasionally PJP (plastic jet printing).

3.6.1 Principle

- ✓ FDM is a material extrusion process used to make thermoplastic parts through heated extrusion and deposition of materials layer by layer.

✓ Material extrusion is a process in which material is selectively dispensed through a nozzle or orifice.

✓ The thermoplastic materials are heated above its melting point temperature for extrusion.

✓ Thin layers formed in this process are built from the bottom up.

3.6.2 Basic Elements of FDM

FDM has the following main parts:

1. Part material supply spool
2. Support material supply spool
3. Nozzle
4. Build platform

3.6.3 Process

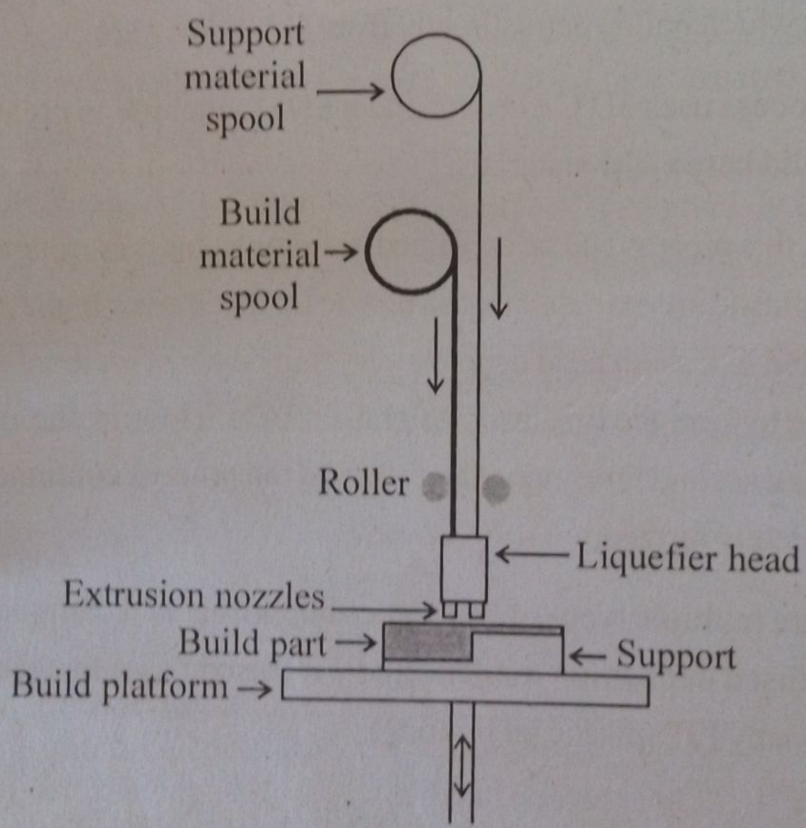

Figure 3.7 Schematic system of FDM process

The Fused Deposition Modeling (FDM) process is simple, comprising of three stages:

1. Pre-processing
2. Processing
3. Post-processing

1. Pre-processing

✓ The Fused Deposition Modeling (FDM) process begins with a 3D CAD file of the part.

✓ The 3D CAD file is first converted into STL file, which is a format that a FDM machine could understood.

✓ The data is then "sliced" horizontally into thin layers of cross sections in z-axis and formatted into FDM build data.

✓ The FDM machine uses the data to build the part layer by layer with an extrusion nozzle.

2. Processing

✓ The FDM machine starts to build the parts from the bottom up through the use of a computer controlled print head.

✓ A spool of thermoplastic wire is unwound from the coil and is continuously supplied to an extrusion nozzle.

✓ The 'nozzle heater block' heats up the filament and keeps the plastic slightly(0.5°C) above its melting point.

✓ A computer controls the nozzle movement along the x- and y-axes.

✓ As per the command from the computer, the nozzle is moved over the table in the required geometry, depositing a thin bead of extruded plastic onto the build platform. The deposited plastic hardens immediately after being squirted from the nozzle to form the first layer.

✓ After the first layer is built, the platform is lowered by about the typical thickness of one layer, and the extrusion nozzle deposits a second layer upon the first. Thedeposited plastic hardens immediately and bonds to the layer below.

✓ The process continues until the part is completely formed.

✓ There is a second extrusion nozzle for the support material. The second nozzle carries a support wax to build the support structure. Some objects have overhangs or undercuts which must be supported during the fabrication process by support structures. These are fabricated right along with the object.

✓ The entire system is contained within a chamber which is held at a temperature just below the melting point of the plastic.

✓ Figure 3.7 is an illustration of the FDM process.

3. **Post-processing**

✓ The support structure can easily be removed.

✓ The sacrificial support material is dissolved in a heated sodium hydroxide (NaOH) solution with the assistance of ultrasonic agitation.

3.6.4 Extrusion Nozzle Construction

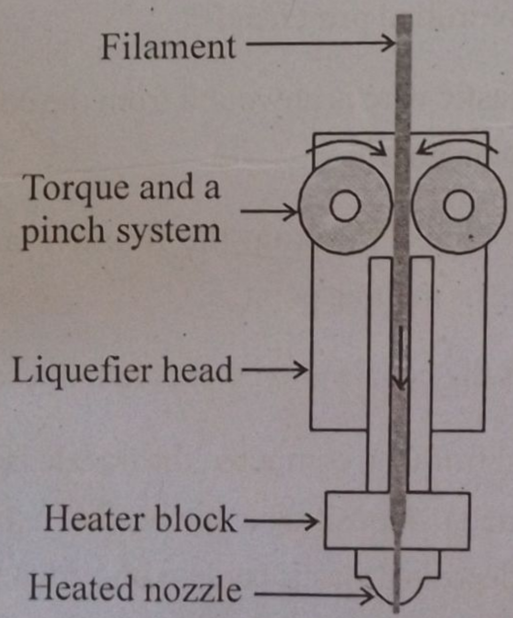

Figure 3.8 FDM nozzle construction

- ✓ The extrusion nozzle is mounted to a mechanical stage which can be moved in both horizontal and vertical directions.
- ✓ The nozzle has a liquefier head in which the filament is led into from the filament spool.
- ✓ The liquefier head has a torque and a pinch system to feed and retract the filament in precise amounts.
- ✓ The nozzle contains a heater blockwhich melts the plastic filament to the usable temperature.
- ✓ The nozzle has a mechanism which allows the flow of the melted plastic material to be turned on and off.
- ✓ The heated filament is forced out of the heated nozzle at a smaller diameter.
- ✓ The second nozzle carries a support wax to build the support structure.
- ✓ Nozzle moves on multiple axes to form the shape of the desired object.
- ✓ A computer controls the nozzle movement along the x, y-axes and the nozzle moves over the table in the required geometry.
- ✓ Figure 3.8 is an illustration of the FDM nozzle construction.

3.6.5 Materials

- ✓ The materials used in FDM process are:
  - ABS plastic
  - Medical grade ABS (MABS)
  - Elastomer,
  - Polycarbonate (PC),
  - Polyphenylsulfone (PPS), and
  - Investment casting wax.
  - Polyamide
  - Polyethylene
  - Polypropylene

- ✓ The Materials used in FDM process are in the form of filaments of extruded resin.
- ✓ ABS offers good strength, while Polycarbonate (PC) and polyphenylsulfone (PPS) materials offer more strength and a higher temperature range.
- ✓ PVA are used for support structure. These are Water-soluble materialswhich can simply be washed away.
- ✓ Most FDM printers can use standard filament rolls that are available in two standardized sizes (diameter: 1.75 or 2.85mm) from various sources.

3.6.6 Advantages

- ✓ Can make parts with complex geometries.
- ✓ Parts made have a high stability.
- ✓ The method is office-friendly and quiet.
- ✓ FDM is fairly fast for small parts on the order of a few cubic inches, or those that have tall, thin form-factors.
- ✓ Caters to home and industrial markets (one of the most common technologies for home 3D printing).
- ✓ Low price point machinery.
- ✓ Economical (inexpensive materials).
- ✓ Enables multiple colors.
- ✓ A wide range of materials possible by loading the polymer.

3.6.7 Disadvantages

- ✓ It is a slower process from the standpoint of build time.
- ✓ Parts are sometimes porous.
- ✓ Poor surface finish (have a pronounced stair-stepping or rippling texture on the outside finish especially at layer junctions).
- ✓ Meso-layers of build visible.
- ✓ Some post processing (solvent dipping) requires for getting a smooth finish.
- ✓ It may be difficult to achieve tight tolerances with the process.
- ✓ Materials suite currently limited to thermoplastics.

3.6.8 Applications

- ✓ Conceptual Models
- ✓ Engineering Models
- ✓ Rapid prototyping
- ✓ Functional Testing Prototypes

3.6.9 Comparison of Fused Deposition Modeling and PolyJet

Table 3.2 Comparison of FDM and PolyJet

S.No	FDM	PolyJet
1	FDM process uses thermoplastic materials	The PolyJet process uses photopolymers.
2	Printing is done by melting and extruding the thermoplastic material from a nozzle.	Printing is done by jetting photopolymers onto the work space and curing it by UV light.
3	A nozzle is used for melting and extruding the thermoplastic filament.	A carriage is used for jetting photopolymers.
4	FDM has the ability to produce durable parts that are ready for end-use applications.	PolyJet has the ability to create parts with great intricacy.
5	The surface finish of the parts produced by FDM process is not as good as PolyJet process.	The parts produced by PolyJet process have good surface finish and aesthetics.
6	FDM parts can be built up to 36×24×36 in.from a single system.	PolyJet parts can be built up to 39.3×31.4×19.6 in.from a single system.
7	FDM process is most preferable, if durability and end-use function in extreme conditions is important.	PolyJet process is most preferable, for high-resolution, ultra-fine parts.

3.6.10 Comparison of Fused Deposition Modeling and Stereoli-Thography

Table 3.3 Comparison of FDM and SLA

S.No	FDM	SLA
1.	Typically use PLA or ABS filament materials. Some can even handle nylon and a variety of PLA blends (mixed with wood, ceramics, metals, carbon fibre, etc.).	SLA printers have only a limited material choice as the resins are proprietary and cannot be exchanged between printers from different makers.
2.	Filaments are available in various colors	The choice of colors is definitely limited. Black, white, grey and clear resins.
3.	The precision and smoothness of the printed models is influenced by nozzle size, precision of the extruder movements (X/Y axis), and bonding force between the layers.	The precision and surface finish of SLA is much smoother. The resolution is primarily determined by the optical spot size either of the laser or the projector – and that is really small. Moreover, during printing less force is applied to the model.
4.	Printed objects can be easily removed. If the object sticks to the print bed, a palette knife will be used to do removal job.	Difficult to remove the printed model from the print platform and often there is a lot of resin left on the platform that has to be removed using a palette knife. This takes more effort than on a FDM printer.
5.	FDM printer is preferable, if cost does play a role.	SLA printer is preferable, if high precision and smooth finish is the top priority and if cost is of no or of minor importance for a print job.

3.7 LAMINATED OBJECT MANUFACTURING

✓ Laminated Object Manufacturing (LOM) was developed by Helisys of Torrance, California, USA in the 1990s.

✓ Laminated Object Manufacturing (LOM) is a solid based additive manufacturing process which builds parts directly from CAD software.

✓ In this technique, layers of adhesive coated sheet material are bonded together to form a prototype. The original materials are laminated with heat-activated glue and rolled up on spools.

✓ This process uses 3D CAD data and a LOM machine to create 3D objects from solid based AM materials.

✓ In brief, this process can be explained as follows: In the LOM technology, the layered material is rolled on the building platform. A heated roller is then passed over the material and melts its adhesive and pressing it onto the platform. The layer is then glued to the previous one. A laser is used to draw the geometry of the object to build and draw crosses on the rest of the surface to facilitate the extraction of the final objects.

✓ The LOM is very useful in manufacturing large parts quickly.

3.7.1 Principle

✓ In LOM process, parts are produced by stacking, bonding, and cutting layers of adhesive-coated sheet material on top of the previous one.

✓ This method cuts the cross-section of heat activated adhesive coated paper with a laser. Layers are bonded together to form a finished part.

✓ Thin layers formed in this process are built from the bottom up.

3.7.2 Basic Elements of LOM

1. A laser unit
2. A heated roller
3. A build platform
4. A feed mechanism
5. Material feeder/collector mechanism
6. A computer controlling the process

3.7.3 Process

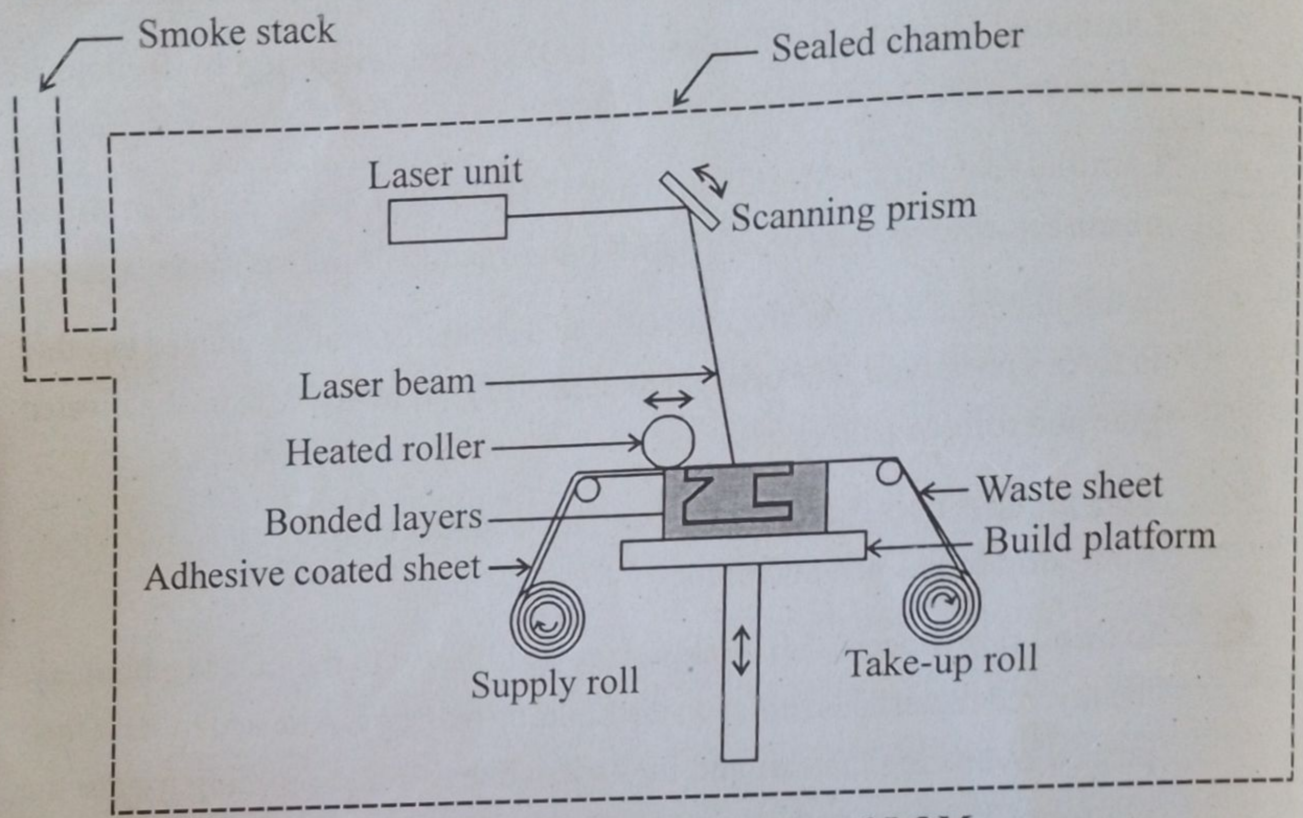

Figure 3.9 Schematic system of LOM

The Laminated Object Manufacturing (LOM) process is simple, comprising of three stages:

1. Pre-processing
2. Processing
3. Post-processing

1. Pre-processing

✓ The Laminated Object Manufacturing (LOM) process begins with a 3D CAD file of the part.

✓ The 3D CAD file is first converted into STL file, which is a format that a LOM machine can understand.

✓ The data is then "sliced" horizontally into thin layers (typically 0.002-0.020 in thickness) of cross sections and formatted into LOM build data.

✓ The LOMmachine uses the data to build the part layer by layer with an ultraviolet laser.

2. Processing

✓ LOM apparatus uses a continuous sheet of material such as plastic, paper or (less commonly) metal, which are rolled up on spools. Plastic and paper build materials are laminated with heat-activated glue.

✓ Initially the sheet is unwound from the spool and advances over the build platform by a feeder/collector mechanism.

✓ A heated roller is then passed over the sheet of material on the build platform, melting its adhesive and pressing it onto the platform to bond the sheet to the base.

✓ A computer controlled laser then cuts the outline of the first layer into the sheet.

✓ Once the border has been cut, the laser then proceeds to create hatch marks, or cubes that surround the pattern within the border. The cubes behave as supports for the part to ensure that no shifting or movement takes place during the entire build.

✓ After the first layer of the object is formed, the build platform is lowered by about the typical thickness of one layer.

✓ New material is then pulled across the platform.

✓ The heated roller again passes over the material, binding the second layer to the first, and the laser cuts the second layer.

✓ This process is repeated until the entire object has been formed.

✓ The process generates considerable smoke and a localized flame. Either a chimney or a charcoal filtration system is required and the build chamber must be sealed.

3. Post-processing

✓ Once an object is built completely, it is removed from the build platform. The completed product comes out as a rectangular block of laminated material containing the model and the scrap cubes.

- ✓ The next step involves decubing. or removing the supports from the model part.
- ✓ Often times the supports can be removed from simple shaking the part; other times it is necessary to use a chisel to pry the cubes away from the part.
- ✓ Objects printed in paper material usually absorb moisture, which tends to expand and compromise the dimensional stability. Therefore, these models are sealed with paint or varnish to block moisture ingress.
- ✓ Also objects printed in paper material take on wood-like properties, and can be sanded or finished accordingly.
- ✓ Figure 3.9 is an illustration of the LOM process.

3.7.4 Materials

- ✓ The materials used in LOM process are:
  - Paper (most common)
  - Plastic sheets
  - PVC
  - Metal powder tapes
  - Ceramic powder tapes
  - Composites
- ✓ The powder tapes produce a"green" part that must be sintered for maximumstrength.

3.7.5 Advantages

- ✓ Relatively high-speed process
- ✓ Ability to produce larger-scaled models
- ✓ No need for post-curing
- ✓ Parts can be used immediately after the process
- ✓ No additional support structure is required

- ✓ The removable excess area itself acts as support structure
- ✓ Low cost (readily available materials)
- ✓ Fast and accurate
- ✓ Good handling strength
- ✓ No chemical reactions
- ✓ Environmentally friendly
- ✓ Not health threatening
- ✓ Precision claimed to be ±0.005 in.

3.7.6 Disadvantages

- ✓ Removal of the scrap material is laborious
- ✓ The 'z' resolution is not as high as for other technologies
- ✓ Limited material set
- ✓ Emission of smoke or fumes
- ✓ Can be a fire hazard
- ✓ Need for sealing step to keep moisture out
- ✓ Finishing, accuracy and stability of paper objects not as good as materials used with other AM methods

3.7.7 Application

Key application areas:

- ✓ Investment casting patterns
- ✓ Rapid tooling patterns
- ✓ Masters for silicone-rubber injection tools
- ✓ Form/fit testing
- ✓ Concept verification
- ✓ Decorative Objects

PART – B

1. Explain the working principle of SLA.
2. What are the part building and post building process involved in SLA?
3. Explain the recoating issues in SLA?
4. Explain the working principle of SGC.
5. Brief about strength, Weakness and applications of SGC?
6. Explain the working principle of FDM.
7. Explain the process variables of FDM.
8. Explain the working principle of LOM.
9. What are the steps in pre build and post-build process for LOM?
10. Compare the liquid based and solid based AM systems.