LIQUID BASED SYSTEM

STEREOLITHOGRAPHY APPARATUS (SLA)

Models and Specifications

There are several models available, including those in the series of SLA 250/30A, SLA 250/50, SLA-250/50HR, SLA 3500, SLA 5000, SLA 7000 and Viper si2. The SLA 250/30A is an economical and versatile SLA starter system that uses a Helium Cadmium (He–Cd) laser. The SLA 250/50 is a supercharged system with a higher powered laser, interchangeable vats and Zephyr recoater system, whereas the SLA 250/50HR adds a special feature of a small spot laser for high-resolution application. All SLA 250 type systems have a maximum build envelope of 250 × 250 × 250 mm and use a He–Cd laser. For bigger build envelopes, the SLA 3500, SLA 5000 and SLA 7000 are available. These three machines use a different laser from the SLA 250 (solid-state Nd:YVO4). The SLA 7000 is the top of the series. It can build parts up to four times faster than the SLA 5000 with the capacity of building thinner layers (minimum layer thickness 0.025 mm) for finer surface finish.

Process

stereolithography process creates three-dimensional plastic objects directly from CAD data. The process begins with the vat filled with the photo-curable liquid resin and the elevator table set just below the surface of the liquid resin (see Figure 3.2). The operator loads a three-dimensional CAD solid model file into the system. Supports are designed to stabilize the part during building. The translator converts the CAD data into a STL file. The control unit slices the model and support into a series of cross sections from 0.025 to 0.5 mm (0.001 to 0.020 in) thick. The computer-controlled optical scanning system then directs and focuses the laser beam so that it solidifies a two dimensional cross-section corresponding to the slice on the surface of the photo-curable liquid resin to a depth greater than one layer thickness. The elevator table then drops enough to cover the solid polymer with another layer of the liquid resin. A leveling wiper or vacuum blade moves across the surfaces to recoat the next layer of resin on the surface. The laser then draws the next layer. This process continues building the part from bottom up, until the system completes the part. The part is then raised out of the vat and cleaned of excess polymer.

The main components of the SLA system are a control computer, a control panel, a laser, an optical system and a process chamber.

Working Principle

The SLA process is based fundamentally on the following principles

(1) Parts are built from a photo-curable liquid resin that cures when exposed to a laser beam (basically, undergoing the photopolymerization process) which scans across the surface of the resin.

(2) The building is done layer by layer, each layer being scanned by the optical scanning system and controlled by an elevation mechanism which lowers at the completion of each layer.

Photopolymers

There are many types of liquid photopolymers that can be solidified by exposure to electro-magnetic radiation, including wavelengths in the gamma rays, X-rays, UV and visible range, or electron-beam (EB). The vast majority of photopolymers used in the commercial RP systems, including 3D Systems' SLA machines are curable in the UV range. UV-curable photopolymers are resins which are formulated from photoinitiators and reactive liquid monomers. There are a large variety of them and some may contain fillers and other chemical modifiers to meet specified chemical and mechanical requirements. The process through which photopolymers are cured is referred to as the photopolymerization process.

Photopolymerization

Loosely defined, polymerization is the process of linking small molecules (known as monomers) into chain-like larger molecules (known as polymers). When the chain-like polymers are linked further to one another, a cross-linked polymer is said to be formed.

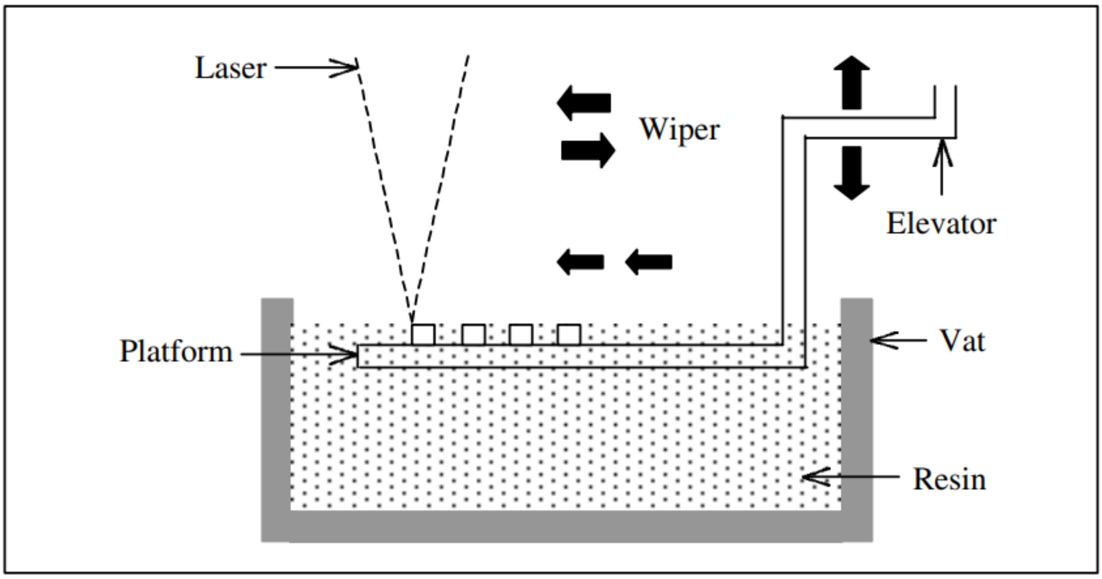


Figure 3.2: Schematic of SLA process

Advantages of SLA

The main advantages of using SLA are:

1. **Round the clock operation**. The SLA can be used continuously and unattended round the clock.
2. **Good user suppor**t. The computerized process serves as a good user support.
3. **Build volumes**. The different SLA machines have build volumes ranging from small to large to suit the needs of different users.
4. **Good accuracy.** The SLA has good accuracy and can thus be used for many application areas.

5. **Good Surface finish**. The SLA can obtain one of the best surface finishes amongst RP technologies.

Disadvantages of SLA:

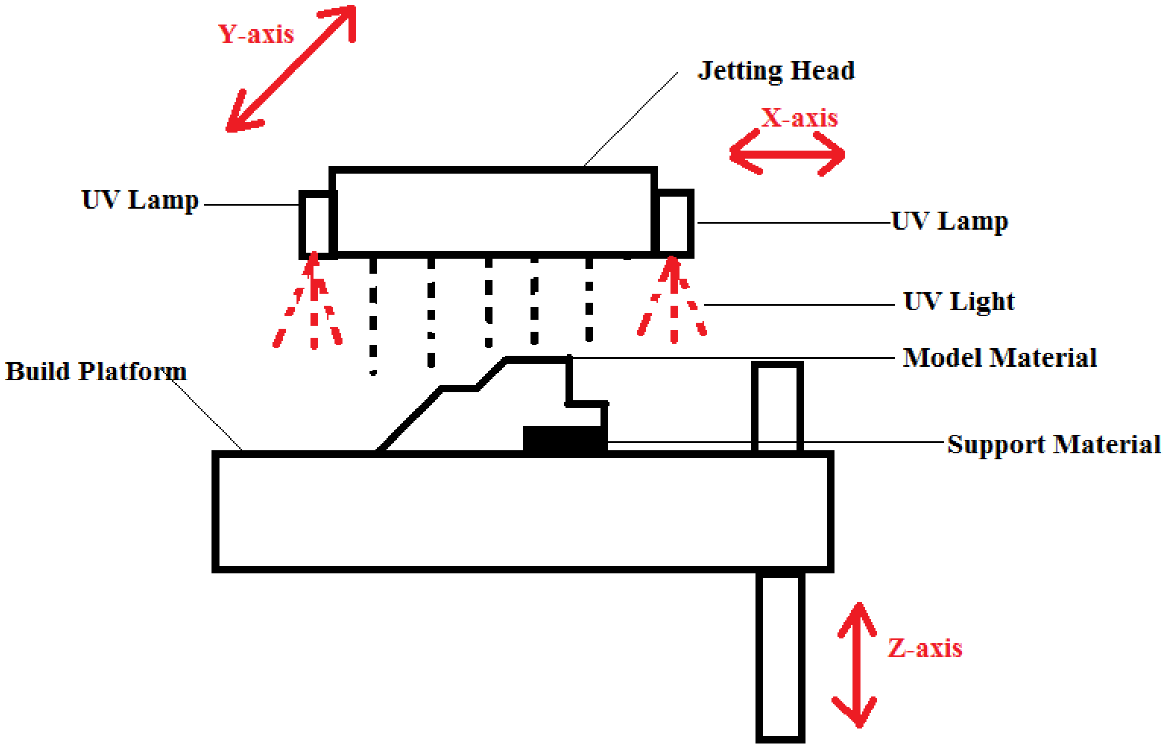
1. **Requires support structures.** Structures that have overhangs and undercuts must have supports that are designed and fabricated together with the main structure.
2. **Requires post-processing.** Post-processing includes removal of supports and other unwanted materials, which is tedious, time consuming and can damage the model.
3. **Requires post-curing**. Post-curing may be needed to cure the object completely and ensure the integrity of the structure.

Applications

1. Prototypes for design, analysis, verification and functional testing.
2. Parts for prototype tooling and low volume production tooling.
3. Patterns for investment casting, sand casting and molding.
4. Tools for fixture and tooling design, and production tooling.

LIQUID BASED SYSTEM

Material Jetting (PolyJet) 3D Printing:



- It's very similar to standard inkjet printing, just with each printed layer stacking up to make a 3D part. It's also one of the only technologies that allows for full color 3D printing, and can also print multiple materials at the same time.

- Both PolyJet and Material Jetting are the same technology. PolyJet is the name patented by Objet Geometries back in the late 1990s, whereas Material Jetting is the technical name for the process.

- As with all technologies, you need a 3D printer file. Usually an STL file, you will then need to send this file to 3D slicer program such as Cura. These programs will then work out how to print your part based on the layer sizes and print settings.

- PolyJet is one of the most accurate 3D printing technologies, with accuracy of up to 16 microns as well as the ability to create extremely smooth finishes. Two aspects of Material Jetting heavily influence part quality: jet droplet size (similar to laser spot size in SLA); and layer height.

· Material Jetting is compatible with a great variety of materials and colors. With PolyJet, you can create multi-colored or even full color 3D printer parts using Material Jetting, and even have print parts with multiple different materials in different areas of the part! PolyJet printers can print a near infinite range of colors since they're compatible with Pantone color ranges, much like a high quality 2D inkjet printer.

· PolyJet uses the same liquid polymer resins as Stereolithography, which are jetted and then cured by being exposed to a UV light. This is somewhat similar to 2D inkjet printing, just with printing layers on top of each other to create a solid part rather than printing on paper.

· Since PolyJet uses photopolymers like SLA, so it could be said that the two processes are similar.

· The process is similar to inkjet printing, just instead of jetting drops of ink onto paper, PolyJet uses small nozzles to deposit droplets of liquid photopolymers onto the build tray. As it is being jetted, the material is simultaneously cured by a UV light. The polymers are heated to between 30-60°C to control their viscosity as they are jetted and printed.

· Parts created using this process require supports to protect the part from deforming or warping, and are printed concurrently with the part. Supports are usually made from a different material which is designed to separate from the part when dissolved in water.

· Since no extreme heating is used there is very little warping or shrinkage of parts during the printing process. This helps reinforce PolyJet as one of the accurate and best surface finishes of all the 3D printing technologies.

· Though PolyJet offers the best surface finishes of all additive manufacturing technologies, there are still a number of post-processing techniques available. These include sanding the part if the part is to be coated afterwards. Also, parts can be dyed and painted to change color. However, with the ability to print in full color anyway, this isn't always necessary.

· There are a huge range of materials available to be used with PolyJet, literally thousands. These range in color and chemical properties, from rigid, to flexible, to castable. To be considered a suitable material for printing, the material needs to have low viscosity and be able to be jetted in droplet form.

PolyJet / Material Jetting Advantages

- **Accurate:** the most dimensionally accurate 3D printing technology, up to 16 microns.
- **Smooth surface finish:** comparable to injection molding, hence Material Jetting has applications in injection molding prototypes.
- **Fast and scalable:** PolyJet can print multiple parts simultaneously without loss of speed unlike FDM or SLS 3D printers.

- **Full color:** not many technologies can produce full color prints — just Binder Jetting, PolyJet and some Multi Jet Fusion printers. Add in the fact that multiple materials can be printed in the same part, and Material Jetting really stands out. Moreover, the fact that nearly infinite shades of color can be used make this extremely versatile for color printing.

PolyJet / Material Jetting Disadvantages

- **Poor mechanical properties:** parts often have worse mechanical properties than parts creating with technologies such as FDM or SLS. Like SLA 3D printed parts they are vulnerable to heat and sunlight, and can lose strength over time.
- **Very expensive:** they are industrial 3D printers and materials can cost $300-$1,000/kg, with industrial Material Jetting printers sometimes costing $100,000+.

PolyJet / Material Jetting Applications

1. **Realistic models for education:** another common use of Material Jetting 3D printing is to create realistic models, such as accurate anatomical models of human organs. These models can then be used to help teach students how to perform medical procedures so they have more experience before performing real surgeries. This shortening of the learning curve is key in reducing fatality rates during surgeries
2. **Full color prototypes:** since full-color and smooth surfaces can be achieved, PolyJet is the perfect method for detailed visual prototypes. This enables designers and engineers to see how their product looks up close, and assess the details and functionality.
3. **creating patterns:** It’s often used in creating patterns for molds to be used in other processes such as injection molding. The original prototype is created using PolyJet, and is then used to create many more injection molded products.

CASE STUDIES

Ford Uses Stereolithography to Cast Prototype Tooling

With a single project triumph, Ford has begun a new era of “rapid manufacturing” — applying QuickCast technology to the development of both prototype and, ultimately, production tooling. Such innovation demonstrates the potential to save manufacturing industries millions in tooling costs.

Ingenuity was Ford’s most critical ingredient. When production units of a rear wiper motor cover for the 1994 Explorer were needed for testing, several tooling alternatives were explored. Traditional methods would have provided the tool in three months. Ford used QuickCast in its first application of rapid tooling by investment casting stereolithography mold halves to create the hard tool.

They first built a SL model of the cover, fit it over the wiper motor to verify design integrity, and found a clearance problem. The plastic part was modified by hand, the fit was re-verified, and the CAD model was adjusted.

The SLA 250-generated QuickCast patterns resulted in a core and cavity pair investment cast in A2 steel. Knowledge of the cast metal’s characteristics facilitated changes in a second set of production tooling, e.g., inclusion of ejector holes and addition of cooling lines. The turnaround time for the second set of tooling was only four weeks, and the cost for “QuickCast Tooling” was only \$5000 per tool set, compared to the \$33 000 quoted for machining a single tool. Ford was able to start durability and water flow testing 18 months ahead of schedule, with costs reduced by 45% and time savings of more than 40% achieved.

Black & Decker Saves a Year by Using Stereolithography to Prototype their Improved Shearer/Shrub Trimmer Power Tool

Designers at Black & Decker had only 100 days to transform an idea for an improved shearer/shrub trimmer power tool into an attractive functioning prototype that could be introduced at an important trade show. The new power tool, which would expand the company’s VersaPak outdoor power tool product line, had to undergo design, proofing, building, assembly and testing of at least 30 copies of the product in that time frame. Failing to deliver functioning prototypes would put Black & Decker back one year in introducing the product to the market place. The new concept would offer a more ergonomically designed shearer/shrub trimmer. This model would also be more streamlined in appearance. The new design was also to incorporate, in the single body of the trimmer, an easy-access battery pop-out.

Bose Saves Five Weeks Using Stereolithography Over Traditional Hard Tooling

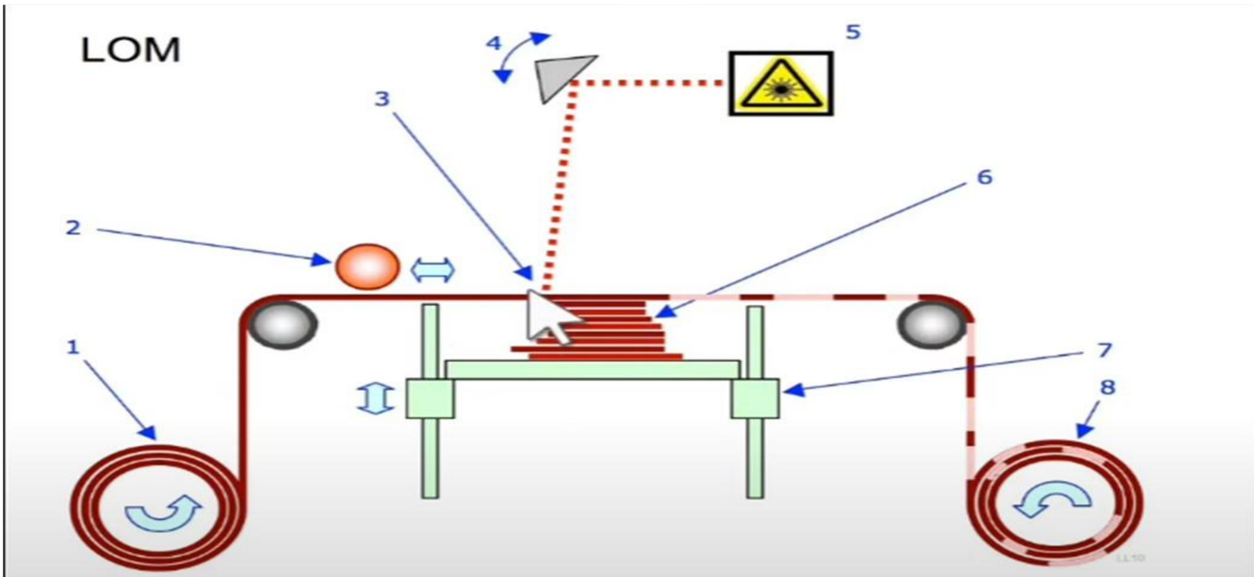
Bose Corporation, world leader in audio components and systems located in Framingham, Massachusetts, needed appearance parts for two different car speaker grills, one being 101 mm (4 in) in diameter and the other 76 mm (3 in) in diameter, for actual road testing on an Oldsmobile Aurora. Needing more than an SL prototype, Bose approached Drew Santin, owner of Santin Engineering, and requested a short run of production parts in end-use material which included uniform texture and multiple colors to match the car interior color options. The catch? Parts needed to be delivered in exactly four weeks. Santin determined that traditional hard tooling would take nine weeks to complete due to each part's contoured design, compound curvature parting line, and complex detail. Because of its ability to produce a textured surface finish, its greater temperature control of the tool, and its durability to guarantee a run of at least 500 parts, Santin turned to the Shaw process of rapid tooling for successful delivery of these timesensitive parts.

SOLID BASED SYSTEM

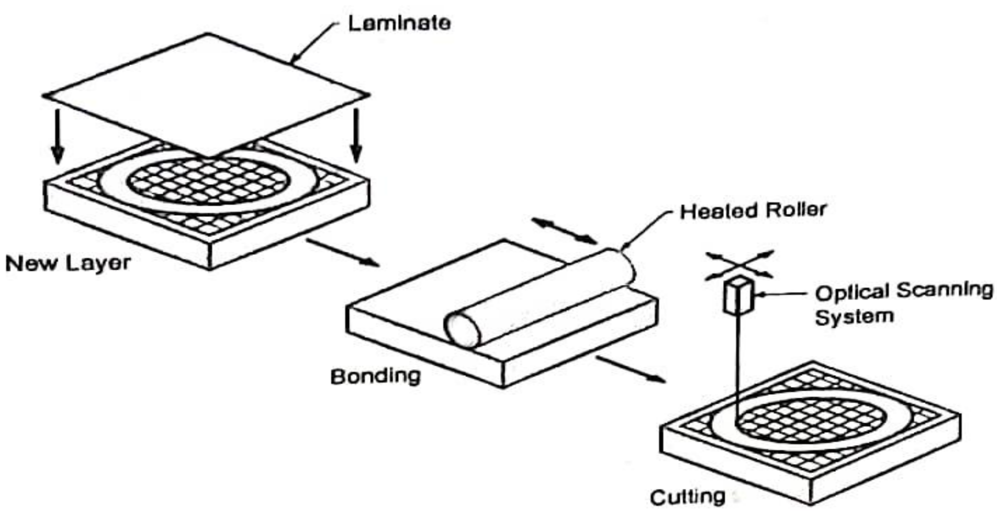
Laminated Object Manufacturing (LOM) :

- Laminated object manufacturing (LOM) is the solid-based rapid prototyping system.
- In this process, a thin sheet or laminate (plastic, metal or ceramic) coated with adhesive on one side is used as a material.

  Components of Laminated Object Manufacturing (LOM) System :
- Laser ,Optical,Scanning System,Control Unit.Tile (Cross Hatch),Heated-Press Roller, Sheet Material,Layer Contour, Block. Build Platform,Supply Roll,Take-up Roll,Servo Motor etc.



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.



Working of Laminated Object Manufacturing (LOM) Process :

- The first step in the process is creation of 3D-model.
- The second step is pre-processing which includes:
  (i)STL file generation, (ii) Part orientation iii)Checking of STL files,
  (iv) Transmission of STL files, and (v) Slicing of STL model.
- The real part building process starts with transfer of slice file format data to rapid prototyping machine by system computer.
- A LOM process typically consists of three steps:
  (i) Placing the thin sheet or laminate
  (ii) Bonding the sheet or laminate to previous layer
  (iii) Cutting the laminate as per slice layer data
- In LOM process, the material consists of continuous and long thin sheet or laminate, made of plastic, metal or ceramic, which is coated with heat activated adhesive form lower side.
- The material is rolled up on supply roll. It passes over the build platform and finally goes to the take up roll. The sheet is unwound from a supply roll on to the build platform.
- The heating press roller passes across the sheet after placing it on the build platform. Due to heat activated adhesive, the layer is bonded to previous layer.
- The CO_2 laser beam cuts the cross-sectional outline of the layer as per the slice data of 2D cross-section, to a depth of exactly one layer thickness. The optical scanning system controls the X-Y motion of the laser beam.
- The software then demarkets the outer perimeter. The unused material between the outer perimeter and the part boundary is hatched by laser beam using a cross- hatch platform into small rectangular pieces called tiles. This cross hatched part acts as support during building of the part and it can be easily removed later once the build process is complete..

- After cutting of the one layer is complete, the build platform is lowered by a depth equal to one layer thickness. The remaining portion of sheet in wound on a take up roll and sheet for next layer is supplied by the supply roll.
- The process is repeated until the part is completely built.
- The last step is post-processing which includes separating the part from its support material and finishing it.

Advantages of Laminated Object Manufacturing (LOM) Process:

(i) **Low material cost :** The material used in LOM process is relatively of low cost.

(ii)**Vide variety of materials** : Any material in sheet form can be used in LOM process. Some of the materials that can be used in LOM process are : paper, plastics, metals, composites, ceramics, etc.

(iii) **Faster process :** In LOM process, the laser beam does not scan the entire surface area of each layer, but it only cuts the outline. Therefore, the process is fast.

(iv) **High accuracy :** In LOM process, there is no possibility of distortion or shrinkage, and hence, the accuracy of parts produced is high.

(v) **No additional part supports :** In LOM process, the part is supported by its own material which is outside the periphery to built part. Hence, additional supports are not required.

(vi) **No post curing :** The parts produced by LOM process does not require post curing.

Limitations of Laminated Object Manufacturing (LOM) Process :

- (i) Requirement of precise laser control : In LOM process, the laser beam has to be precisely controlled so that it cuts only current layer of laminate and dose not of penetrate the pervious layer.
- Inability to built hollow and thin walled parts : The LOM process is not suitable for building hollow parts like bottles as well as thin walled parts. This is due to the fact that such walls are not rigid enough to withstand the forces applied to remove the hatched portion, during the post processing.
- Limited strength of parts : The strength of parts made by LOM process is limited by bonding strength of the glued layers. Therefore, such parts cannot with stand high tensile or shear stresses.
- Tedious process of removal of supports : The process of removal of hatched portion is tedious, time-consuming, and hence, labour intensive.

Applications of Laminated Object Manufacturing (LOM) Process :

(i) Prototype for marketing purpose : The prototype produced by LOM process are highly accurate. Therefore, such prototypes can be painted and finished to exactly look like actual product and can be used by marketing department for visual demonstration of product.

(ii) Functional models in low stress environment : The LOM process is used for making parts that can be successfully used for functional testing under low stress condition.

(iii)Patterns for casting and moulding: The LOM process can be used for making percise

patterns for sand casting, investment casting and rubber moulding.
(iv) Medical applications : The LOM process can be used for making the models of human organs like bones, skull, etc. for study purpose before patient goes for surgery.

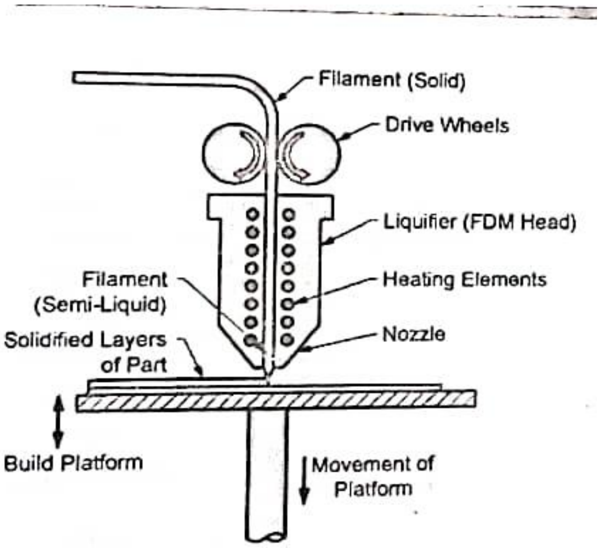
SOLID BASED SYSTEM

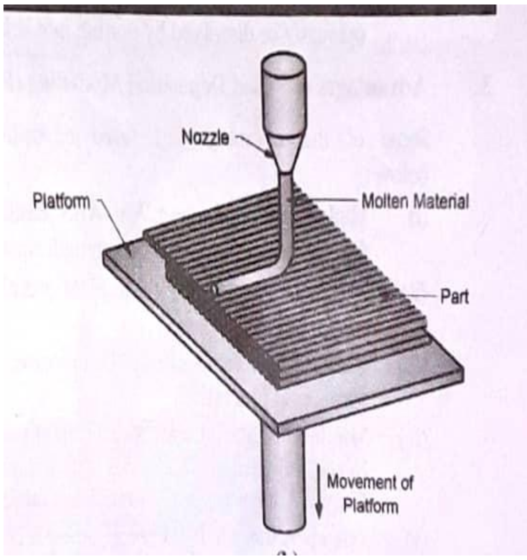
Fused Deposition Modeling

Fused deposition modeling (**FDM**) is an additive manufacturing (**AM**) technology commonly used for modeling, prototyping, and production applications. It is one of the techniques used for 3D printing.

Fused deposition modeling (FDM) was developed by S. Scott Crump in the late 1980s and was commercialized in 1990 by Stratasys.

FDM works on an "additive" principle by laying down material in layers; a plastic filament or metal wire is unwound from a coil and supplies material to produce a part. Thus, FDM is also known as a solid-based AM technology.





Process

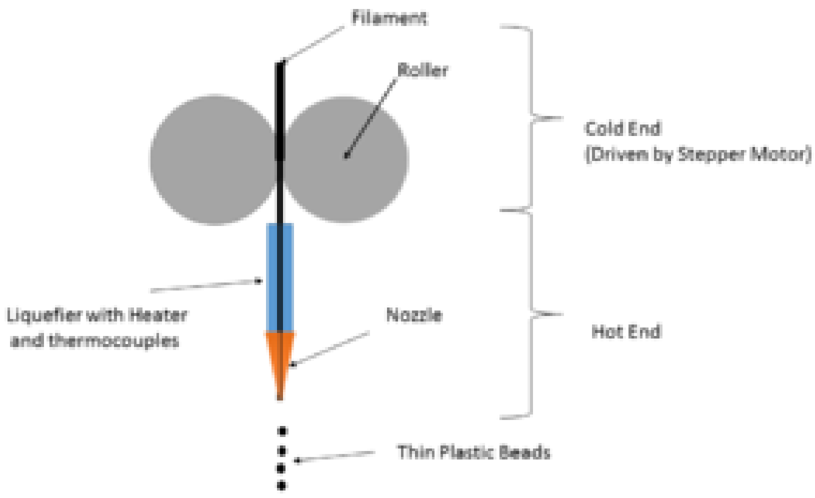
FDM begins with a software process which processes an STL file (Stereolithography file format), mathematically slicing and orienting the model for the build process. If required, support structures may be generated.
The model or part is produced by extruding small flattened strings of molten material to form layers as the material hardens immediately after extrusion from the nozzle.

A plastic filament is unwound from a coil and supplies material to an extrusion nozzle which can turn the flow on and off. There is typically an accurately controlled drive that pushes the filament into the nozzle.

The nozzle is heated to melt the material. The thermoplastics are heated well and then deposited by an extrusion head.

The nozzle can be moved in both horizontal and vertical directions by a numerically controlled mechanism. The nozzle follows a tool-path controlled by a computer-aided manufacturing (CAM) software package, and the part is built from the bottom up, one layer at a time. Stepper motors or servo motors are typically employed to move the extrusion head.

A wide variety of materials are extruded, including thermoplastics such as *acrylonitrile butadiene styrene* (ABS), *polylactic acid* (PLA), *high-impact polystyrene* (HIPS), *thermoplastic polyurethane* (TPU), *aliphatic polyamides* (nylon), polyphenylsulfone (PPSF), polycarbonate (PC) etc..



3-D Printer Extruder

During FDM, the hot molten polymer is exposed to air. Operating the FDM process within an inert gas atmosphere such as nitrogen or argon can significantly increase the layer adhesion and leads to improved mechanical properties of the 3D printed objects. An inert gas is routinely used to prevent oxidation.

Extrusion

Extrusion in 3-D printing using material extrusion involves a cold end and a hot end.
The **cold end** is part of an extruder system that pulls and feed the material from the spool, and pushes it towards the hot end. The cold end is mostly gear- or roller-based supplying torque to the material and controlling the feed rate by means of a stepper motor. By this means the process rate is controlled.

The **hot end** is the active part which also hosts the liquefier of the 3D printer that melts the filament. It allows the molten plastic to exit from the small nozzle to form a thin and tacky bead of plastic that will adhere to the material. The hot end consists of a heating chamber and a nozzle. The hole in the tip (nozzle) has a diameter of between 0.3 mm to 1.0 mm. Different types of nozzles and heating methods are used depending upon the material to be printed.

Physics

During extrusion the thermoplastic filament is introduced by mechanical pressure from rollers, into the liquefier, where it melts and is then extruded. The rollers are the only drive mechanism in the material delivery system; therefore filament is under tensile stress upstream to the roller and under compression at the downstream side acting as a plunger. Therefore, compressive stress is the driving force behind the extrusion process.

The force required to extrude the melt must be sufficient to overcome the pressure drop across the system, which strictly depends on the viscous properties of the melted material and the flow geometry of the liquefier and nozzle. The melted material is subjected to shear deformation during the flow. Shear thinning behavior is observed in most of the materials used in this type of 3-D printing. This is modeled using power law for generalized Newtonian fluids.

The temperature is regulated by heat input from electrical coil heaters. The system continuously adjusts the power supplied to the coils according to the temperature difference between the desired value and the value detected by the thermocouple, forming a Negative Feedback loop. This is similar to Heat Flow rate in Cylindrical Pipe.

Commercial applications

FDM, a prominent form of rapid prototyping, is used for prototyping and rapid manufacturing.

FDM is also used in prototyping scaffolds for medical tissue engineering applications.

ADVANTAGES

- FDM is clean, simple to use.
- Thermoplastic parts can endure exposure to heat, chemical, humid or dry environments, mechanical stress.
- Soluble support materials make it possible to produce complex geometric and cavities that would be difficult to build with traditional manufacturing methods.
- Economical (inexpensive materials)
- Enables multiple colors
- Easy to build DIY kits (one of the most common technologies for home 3D printing)
- A wide range of materials possible by loading the polymer

DISADVANTAGES

- Materials suite currently limited to thermoplastics.
- The extrusion head must continue moving or else material bumps up.
- Supports are required.
- Part strength is weak perpendicular to the build axis.
- As layer increases, the build up increases.
- Temperature fluctuation during production could lead to delamination.

KEY APPLICATION AREAS

- Conceptual Models
- Engineering Models
- Functional Testing Prototypes
- Aerospace-human supporting rovers
- Automotive – automobile parts
- Commercial – mobile covers
- Medical – drug injection system.