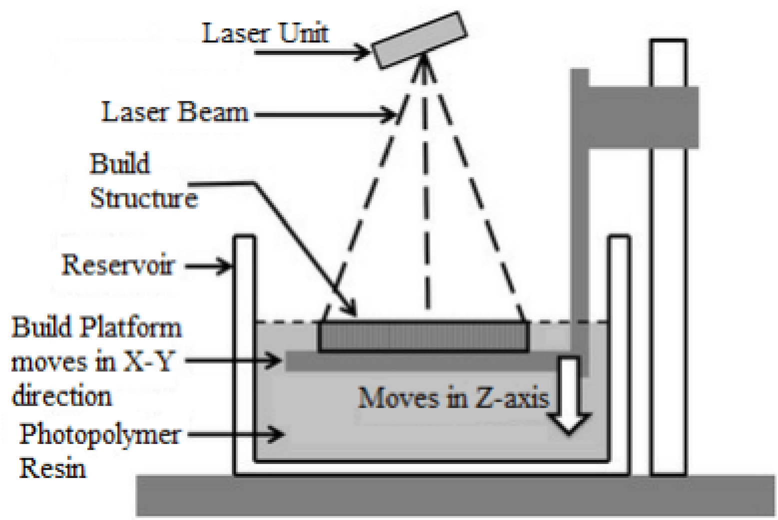
Chapter 3 - Additive Manufacturing Techniques

Define VAT photopolymerization

Vat photopolymerization is a category of additive manufacturing (AM) processes that create 3D objects by selectively curing liquid resin through targeted light-activated polymerization. Stereolithography, the first AM process to be patented and commercialized, is a vat photopolymerization technique.

Laser-Stereolithography (SL)

- Laser stereolithography delivers parts with very good surfaces and fine details.
- The parts are created by local polymerization of the initially liquid monomers. Initiated by a UV-laser beam, the polymerization turns the liquid into a solid, leaving a scaled solid layer.
- The laser beam is directed by a galvo-type scanning device that is controlled according to the contour of each layer.



Schematic representation of Stereolithography (SLA) process

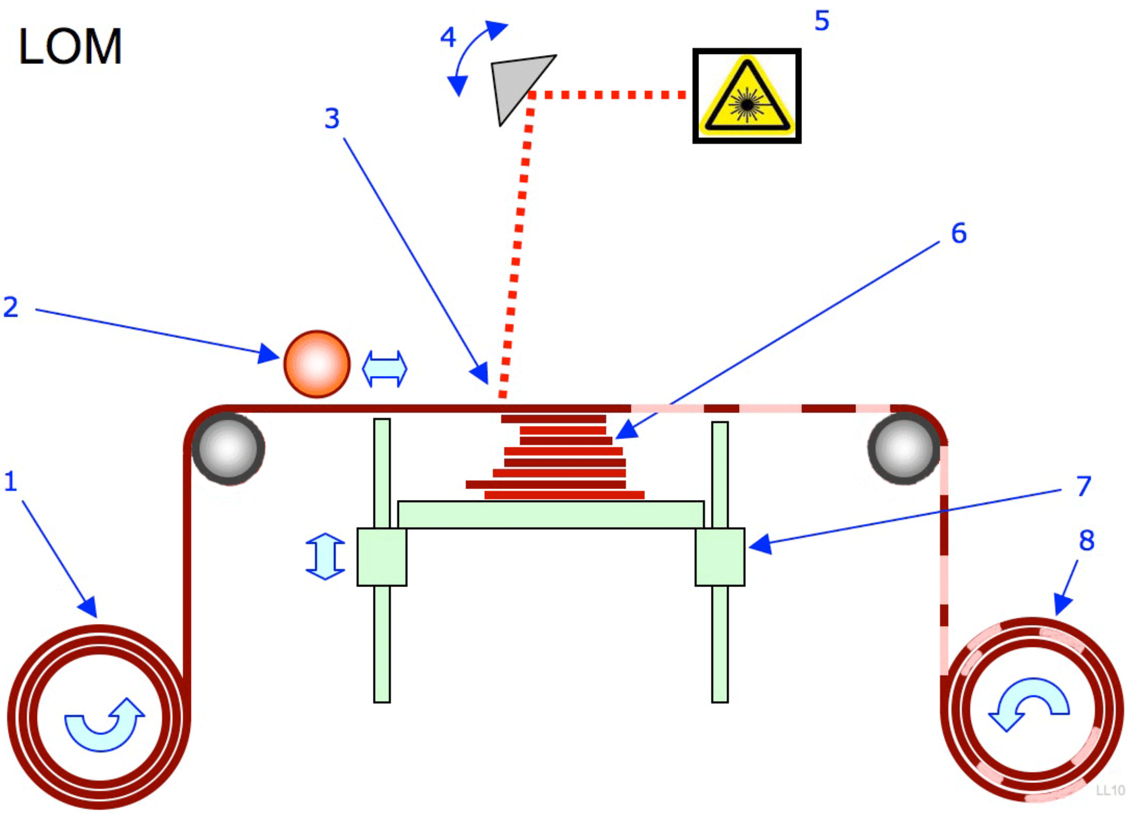
- A laser stereolithography machine consists of a build chamber filled with the liquid build material and a laser scanner unit mounted on top of it which generates the x-y contour.

- The build chamber is equipped with a build platform fixed on an elevator-like device that can be moved in the build (z^-) direction
- The laser beam simultaneously does the contouring and the solidification of each layer as well as the bonding to the preceding layer. The motion of the beam is controlled by the slice data of each layer and directed by the scanner.
- As the beam penetrates the surface of the resin, an instantaneous solidification takes place.
- Depending on the reactivity and transparency of the resin, the layer thickness can be adjusted by the laser power and by its traveling speed. After solidification of one layer, the build platform, including the partially finished part, is lowered by the amount of one layer thickness.
- A new layer of resin is applied. This is called recoating. Because of the low resin viscosity, the recoating procedure needs to be supported by vipers and vacuum depositing devices. The new layer is then solidified according to its contour. The process continues from the bottom to the top until the part is finished.
- The process requires supports, which limits the possible orientation of the part in the build chamber, because after removal the supports leave tiny spots on the surface.
- For this reason the orientation should be chosen carefully. Because of the supports the parts cannot be nested to increase the packing density and the productivity accordingly.
- After the build, the part is cleaned and finally fully post-cured in a UV chamber (post curing oven).
- This process step is an integral part of the AM process and called “post processing”. The parts can be sanded, polished, and varnished if necessary.
- These process steps are called “finishing”. Finishing is a process independent step and not a part of the AM process. It depends only on the user requirements for the parts and possible restrictions regarding its application.
- The available materials are unfilled and filled epoxy and acrylic resins. Unfilled materials show a comparably poor stability and heat deflection temperature.

- This can be improved by adding micro spheres or rice-grain shaped geometric objects made from glass, carbon, or aluminum. Today, these filled materials contain nano-particles made from carbon or ceramics.

Layer Laminate Manufacturing, Laminated Object Manufacturing (LOM)

- The machine consists of a build table that can be moved in z-direction and a mechanism to uncoil the paper, position it on the build table, and wind up the remaining paper on the opposite side. A laser does the cutting of the contour.



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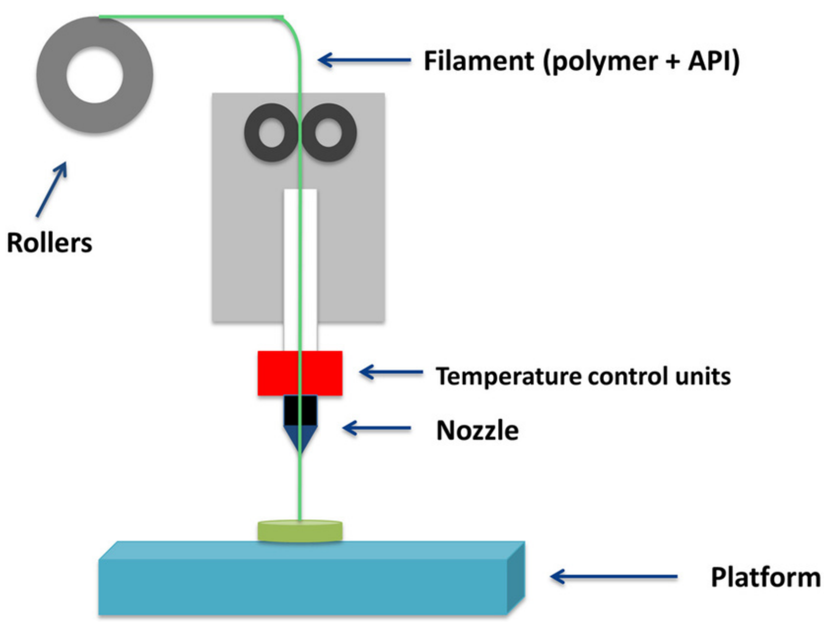
- To build a part, the paper is positioned on the build table and fixed by a heated roller that activates the glue. The contour is cut by a plotter type laser device that allows adjusting the cutting depth according to the paper thickness.

- Another frame-like laser cut defines the boundaries of the part. It leaves two paper stripes on each side of the part that enables the exceeding paper to be lifted and wound up by the second coil
- The material that fills the space between the contour and the frame remains within the part and supports it. It is cut into squares for easy removal of the waste material.
- After the build process is finished, the block of paper, including the part and the support material is removed from the build platform.
- The frame and the squares that result in small blocks are removed and finally the part is obtained.
- The parts need varnishing to prevent de-lamination of the layers

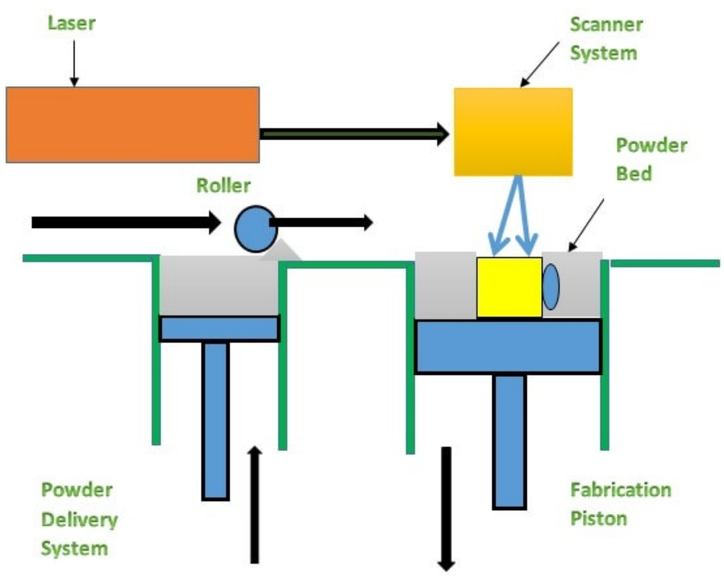
Fused Deposition Modelling (FDM)



- A FDM machine consists of a heated (app. 80 °C for ABS plastic processing) build chamber equipped with an extrusion head and a build a platform.
- The extrusion head provides the material deposition in the x-y area according to the contour of the actual layer.

- The build material is a prefabricated filament that is wound up and stored in a cartridge from which it is continuously fed to the extrusion head. The cartridge has a build-in sensor that communicates with the material management system of the machine.
- In the head, the material it is partly molten by an electric heating system and extruded through a nozzle that defines the string diameter that nearly equals the layer thickness.
- The process needs supports. They are made by a second nozzle that extrudes another plastic support material simultaneously with the build material.
- The simultaneous processing of two materials indicates that the FLM process is basically capable of handling multi-material print heads. Therefore, the manufacture of multi material parts can be expected in the future.
- After deposition, the pasty string (of the build material as well as of the support material) solidifies by heat transfer into the preceding layer and forms a solid layer.
- Then the platform is lowered by the amount of one-layer thickness and the next layer is deposited. The process repeats until the part is completed.
- Post processing requires the removal of the supports, which can be done manually, or using a special washing device. Finishing requires manual skills and time; but together with artisan capabilities leads to perfect surface qualities and astonishing results.

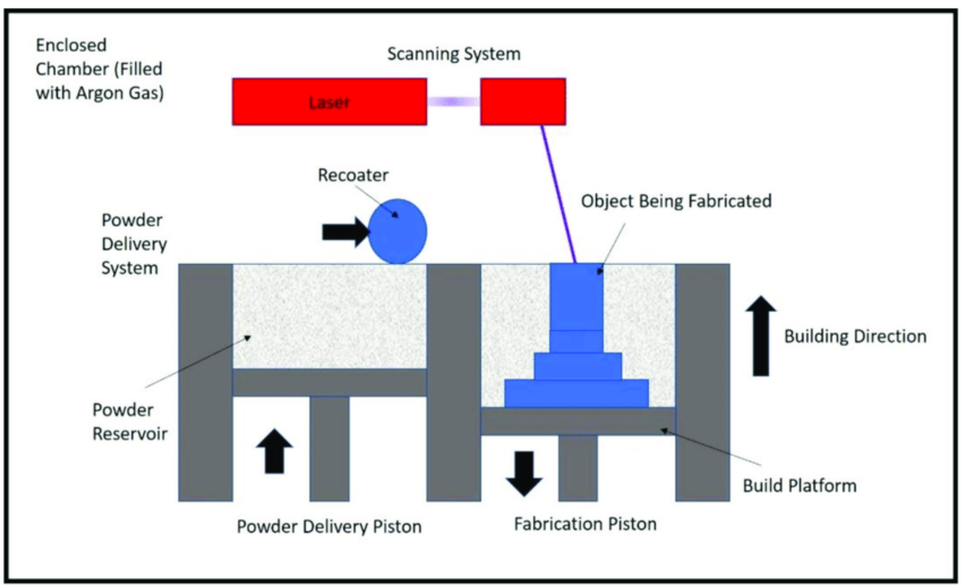
Selective Laser Sintering – (SLS)



- It consist of a build chamber to be filled with powder with a grain size of up to 50 µm and a laser scanner unit on top that generates the x-y contour.
- The bottom of the build chamber is designed as a movable piston that can be adjusted at any z-level.
- The top of the powder bed defines the build area in which the actual layer is built.
- The whole build chamber is preheated to minimize laser power and completely flooded by shielding gas to prevent oxidation.
- The laser beam contours each layer. The contour data are obtained from the slice data of each layer and directed by the scanner. Where the beam touches the surface, the powder particles are locally molten.
- The geometry of the melting spot is defined by the laser beam diameter and the traveling speed.
- While the beam travels further, the molten material solidifies by thermal conductivity into the surrounding powder. Finally, a solid layer is achieved.
- After solidification of one layer, the piston at the bottom is lowered by the amount of one layer thickness, thus lowering the whole powder cake including the semi-finished part.
- The emerging space on the top of the powder is filled with new powder taken from the adjacent powder feed chamber using a roller.
- The roller rotates counter-clock wise to its linear movement in order to spread the powder uniformly. This procedure is called recoating.

- After recoating, the build process starts again and processes the next layer. The whole process continues layer by layer until the part is completed. In most cases, the top layer is made using a different scan strategy in order to improve its solidity.
- After the build is finished and the top layer is processed, the whole part, including the surrounding powder, is covered by some layers of powder. This so-called powder cake has to be cooled down before the part can be taken off by removing the part from the surrounding powder.
- The cool-down can be done in the machine; however cooling down in a separate chamber allows immediate beginning of a new build job.
- Sintering allows the processing of all classes of materials: plastics, metals, and ceramics.

Laser Melting – Selective Laser Melting (SLM)



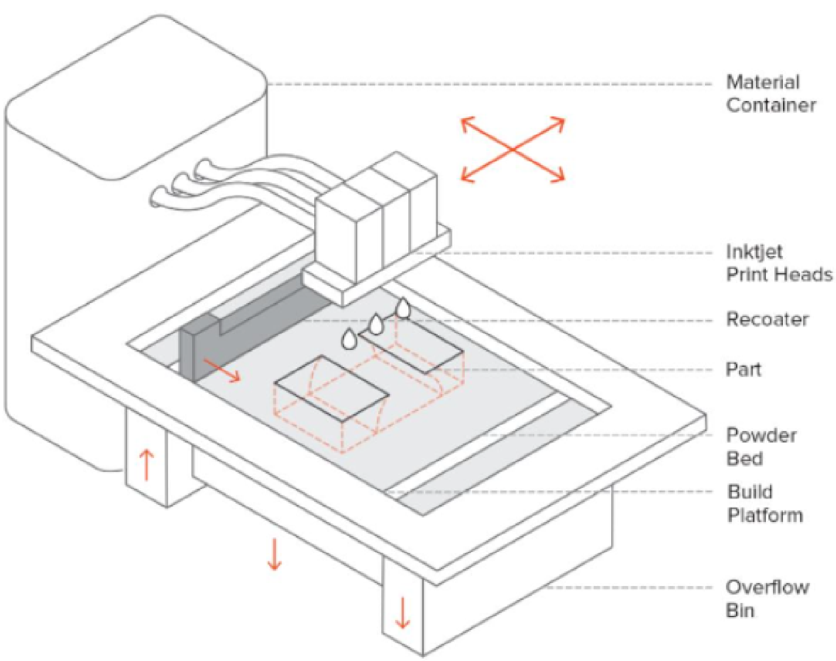
- Laser melting basically is a laser sintering process as described earlier. It was developed in particular to process metal parts that need to be very (> 99%) dense.
- The laser melts the material completely. Therefore, it produces a local (selective) melt pool that results in a fully dense part after re-solidification. The process is generally called selective laser melting, SLM.

- There are some proprietary names as well such as "CUSING", which is an acronym of "cladding" and "fusing". •Today, most of the machines come from Germany: EOS-GmbH of Munich, RealizerGmbH of Borchen, Concept Laser GmbH of Lichtenfels, and SLM-Solutions of Lübeck.
- In addition, 3D Systems, Rock Hill, SC, USA offers a re-branded system based on MTTmachines, the predecessor of SLM Solutions. MTT, UK, now separated from its German branch, continues to design its own machine.
- For almost all metal machines a wide variety of metals, including carbon steel, stainless steel, CoCr, titanium, aluminum, gold and proprietary alloys are available. •Typically, metal parts are final parts and used as (direct manufactured) products or components of such products.

Binder Jetting Technology

- Binder Jetting is a family of additive manufacturing processes.
- In Binder Jetting, a binder is selectively deposited onto the powder bed, bonding these areas together to form a solid part one layer at a time.
- The materials commonly used in Binder Jetting are metals, sand, and ceramics that come in a granular form.

Binder Jetting Process



- First, a recoating blade spreads a thin layer of powder over the build platform.
- Then, a carriage with inkjet nozzles (which are similar to the nozzles used in desktop 2D printers) passes over the bed, selectively depositing droplets of a binding agent (glue) that bond the powder particles together.
- In full-color Binder Jetting, the colored ink is also deposited during this step. The size of each drop is approximately 80 μm in diameter, so good resolution can be achieved.
- When the layer is complete, the build platform moves downwards and the blade re-coats the surface. The process then repeats until the whole part is complete.
- After printing, the part is encapsulated in the powder and is left to cure and gain strength. Then the part is removed from the powder bin and the unbound, excess powder is cleaned via pressurized air.
- Depending on the material, a post-processing step is usually required. For example, metal Binder Jetting parts need to be sintered(or otherwise heat treated) or infiltrated with a low-melting-temperature metal (typically bronze).

Benefits of Binder Jetting

- Binder Jetting produces metal parts and full-color prototypes at a fraction of the cost compared to DMLS/SLM and Material Jetting respectively.
- Binder Jetting can manufacture very large parts and complex metal geometries, as it is not limited by any thermal effects (e.g. warping).
- The manufacturing capabilities of Binder Jetting are excellent for low to medium batch production.
- High Printing speed
- Established process

Limitations of Binder Jetting

- Only rough details can be printed with Binder Jetting, as the parts are very brittle in their green state and may fracture during post processing.
- Compared to other 3D printing processes, Binder Jetting offers a limited material selection.
- Degrading Inkjet process.
- Post Processing adds time and cost.

- Non- engineering materials composite.
- Surface finish usually requires post processing.

Materials used in Binder Jetting

- Metals and ceramics are widely used materials in binder jetting applications, although it is also possible to use other powdered materials, like sand. In addition, polymers like ABS or PLA can also be used in binder jetting operations.
- Metal alloys, including titanium, stainless steels and copper, are used regularly due to their characteristics, which allow for the manufacture of strong yet light parts.
- Outside of industrial applications, binder jetting type processes have even found their way into baking, with businesses like The Sugar Lab using 3D printing with granules of sugar and water to create complex culinary structures.

Compare BJ(Binder Jetting)and MJ(Material Jetting).

Parameters	BJ(Binder Jetting)	MJ(Material Jetting)
Working Principle	Depositing a binder on a powder bed	Deposition of photopolymer droplets which are then solidified by UV light.
Materials	Ceramic, Polymer, metal and sand	Photopolymers
Advantages	Multi-materials, multi-color surface	Multi-color print area, no need for support structures.
Limitations	Brittle parts mechanical properties	Post-processing brittle parts
Applications	Aesthetic prototypes, Anatomical models, Design	Foundry molds, Tooling

Questions

- *Explain Fused Deposition Modelling (FDM) w.r.t. extrude of fibers.*
- *Explain Laser-Stereolithography (SL).*
- *Explain the steps used in the process of Binder Jetting*
- *Compare BJ(Binder Jetting)and MJ(Material Jetting).*
- *Explain Selective laser sintering is an additive manufacturing technology.*
- *Additive manufacturing process is used in the Healthcare domain, Explain.*
- *Explain in detail the use of additive manufacturing process in construction Technology.*
- *Explain the Benefits & Limitations of Binder Jetting.*
- *Explain the materials used for Binder jetting technology in detail*