ME 482 – Rapid Product Development and Manufacturing

Chapter 6

Rapid Manufacturing (Part II)

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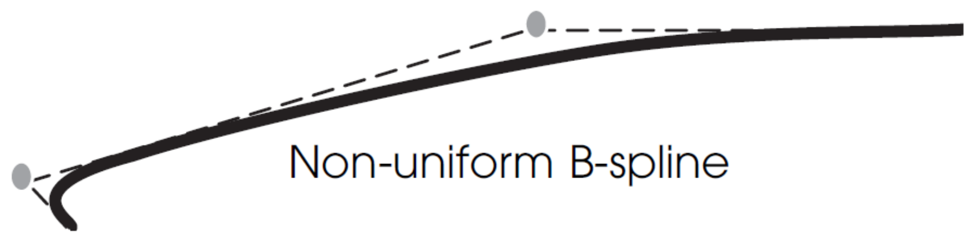
- The generation of three-dimensional curved shapes has always been a driving force in the development of CAD systems.
- This resulted in the development of ***NURBS*** (non-uniform rational B-spline) which represented a very efficient mathematical description of a three-dimensional curved line and subsequent surface.
- However, some calculations with these mathematical descriptions are difficult to achieve or at least are not very efficient, and for this reason some operations (such as milling path generation and shading) were carried out by using other internal formats, such as **‘tiles’** or **‘triangles’** that are generated from NURBS.

B-spline curve with control points



- When stereolithography was introduced in 1988 the **STL (Standard Triangulation Language)** file was chosen as a neutral format between the CAD systems and the software supporting the stereolithography system.
- The format was easily accepted in the following years. The STL format is now defined and accepted as a neutral format for all the RP (Rapid Prototyping), RT (Rapid Tooling) and RM systems.
- The quality of the STL file is not always perfect due to the fact that it depends on the quality of the underlying NURB surfaces and hence the generation of the triangles on these surfaces.
- However, there are enough STL repair tool-kits available to repair these STL files and increase their quality. From these STL files, the RP, RT and RM systems create their own format to feed the machine. Some of them use slice contour information, some pixels per slice, some transfer their data to G–codes (a format used on milling machines) or any other slice information.

The technologies can be divided into three different categories according to the raw material used in the process. These categories are:

- **Liquid-based systems**
- **Powder-based systems**
- **Solid-based systems**

Within each category the technologies are presented in terms of their maturity, so commercialised systems will precede those that are being developed in laboratories.

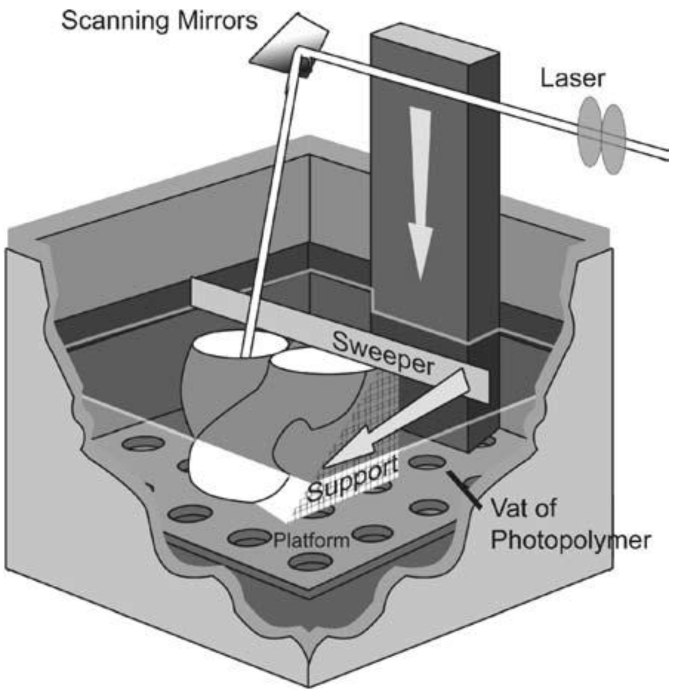
The technologies is not exhaustive but represents those that either currently show the best promise for widespread use to manufacture end-use products or those that have the best potential to become widely used for RM in the future.

Liquid-based Processes

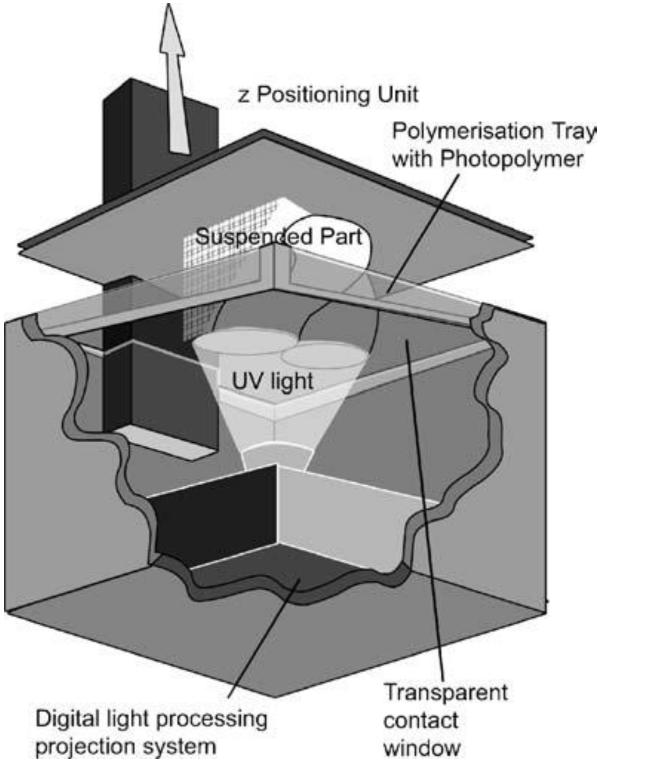
- Liquid-based layer additive manufacturing approaches involve the formation of a solid by selectively curing regions of photosensitive polymers.
- Liquid-based technologies, notably stereolithography, were the pioneering processes in Rapid Prototyping and have a number of distinct advantages for prototyping, including superior accuracy and definition when compared with other processes.
- However, the material properties of photocured parts tend to be relatively poor when compared with other processes, especially over a period of time when ageing, for example, by exposure to sunlight, which causes continued curing, can severely affect mechanical properties and appearance.
- Sensitivity to humidity can also be a problem with photocurable resins.

- **Stereolithography:** It is considered as the founding process within the field of Rapid Prototyping. The working principle of stereolithography is based on the using an ultraviolet (UV) laser to initiate a curing reaction in a photocurable resin. Using a CAD file to drive the laser, a selected portion of the surface of a vat of resin is cured and solidified on to a platform. The platform is then lowered, typically by 100 μm, and a fresh layer of liquid resin is deposited over the previous layer.

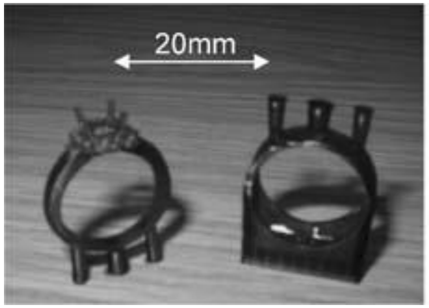
The laser then scans a new layer that bonds to the previous layer. In some areas where overhangs are created, supports are automatically generated by the machine's software. These supports need to be removed once the final part is made. Post-processing in a UV and/or thermal oven are used to cure any uncured resin.

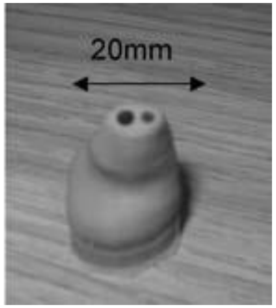


- **Direct Light Processing:** Direct light processing technology is a particularly interesting technology from the perspective of Rapid Manufacture. The process has a number of distinguishing aspects, starting with the fact that the process builds parts that 'grow' downwards rather than upwards. In order to cure a layer, the process uses Digital Mirror Devices (DMD) to selectively switch on and off mirrors that reflect UV light from a source on to the build area.



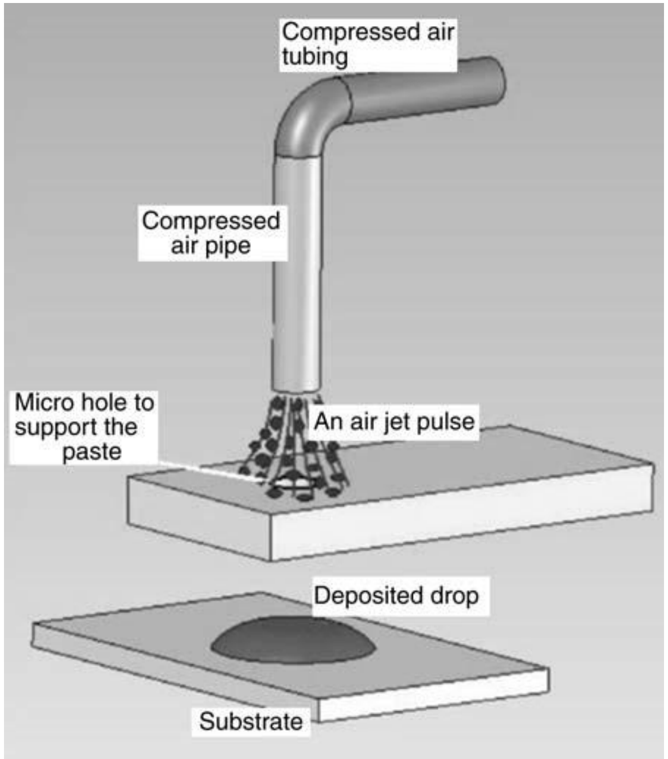
With a build speed of 10–15 seconds per layer the process is well suited to building parts quickly, but the use of a single DMD with a finite matrix of pixels limits the process to small parts if a fine resolution is maintained.



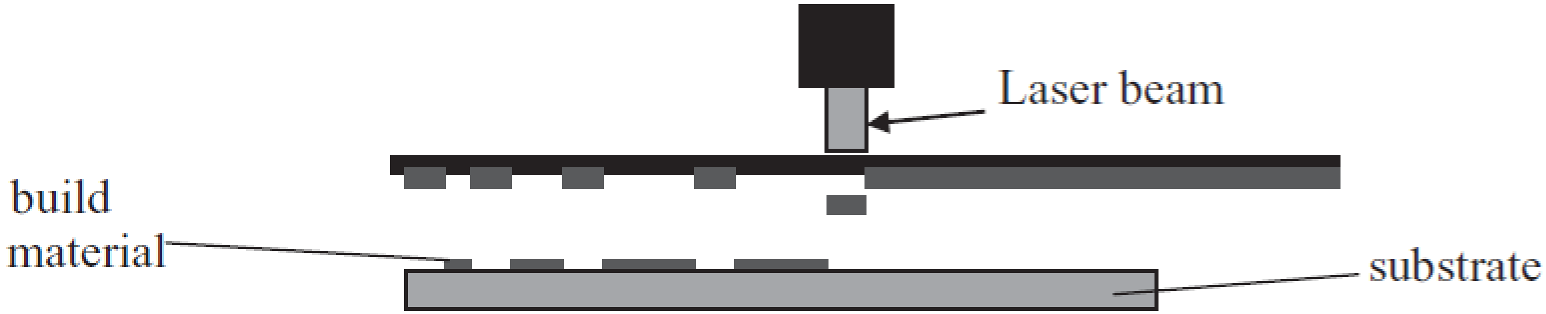


- **High Viscosity Jetting:** The principle involves continuous change in a layer's pattern (negative image of the layer) according to a very thin slice of the object to be printed. This uses a mechanism based on displacing a small drop of a printable material (powder-filled polymer paste) to a desired location on a substrate. The fundamental unit consists of a single jet, which is controlled by air jet pressure, the distance from the substrate and the length of the jetting pulse.

This process is still an emerging technology and can provide solutions to a number of problems and limitations known in conventional printing and existing RP machines. It also has flexibility in the degree of accuracy depending on the hole size being used for the jet. Production speed is similar to existing high-volume production methods.



- **The MAPLE Process:** MAPLE (Matrix Assisted Pulsed Laser Evaporation) uses a high-repetition-rate, 355nm UV laser beam which is focused on a transparent material or ‘ribbon’ that has a 1–10 μm thick layer of build material on the underside. As the laser energy is directed to the ribbon the build material transfers to the receiving substrate. This is analogous to a typewriter ribbon.

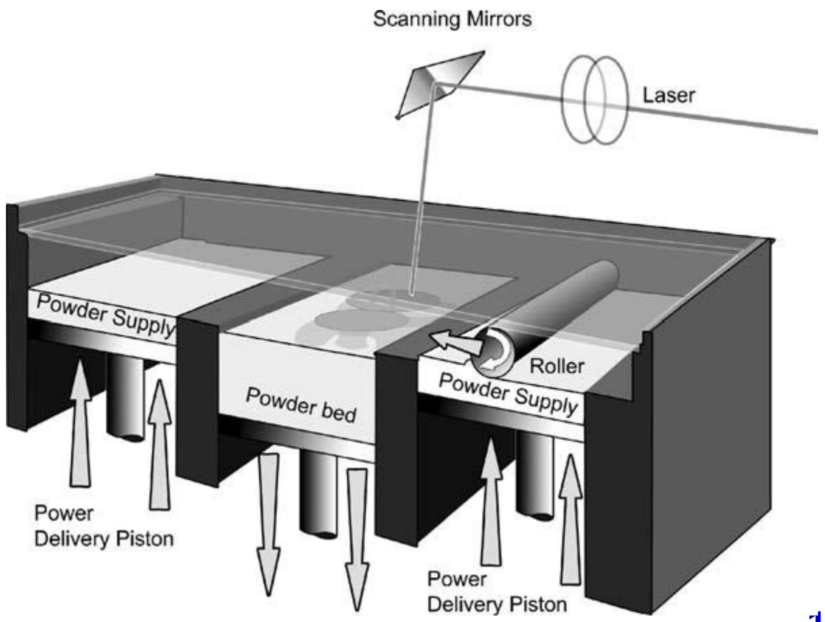


Powder-based Processes

- The material properties and stability of parts that may be achieved with powder-based processes means that, in the long run, they will be more suited to RM than the liquid-based systems.
- In the current RP systems, powder-based selective laser sintering is more widely used for Rapid Manufacture than its closest liquid counterpart, stereolithography.
- Powder-based processes also offer a wider variety of material possibilities with polymers, metals and ceramics all available on current commercial systems.
- Furthermore, combing powders and layer additive manufacturing, the possibility of functionally graded materials provides a unique potential for increased functionality of rapid manufactured components.

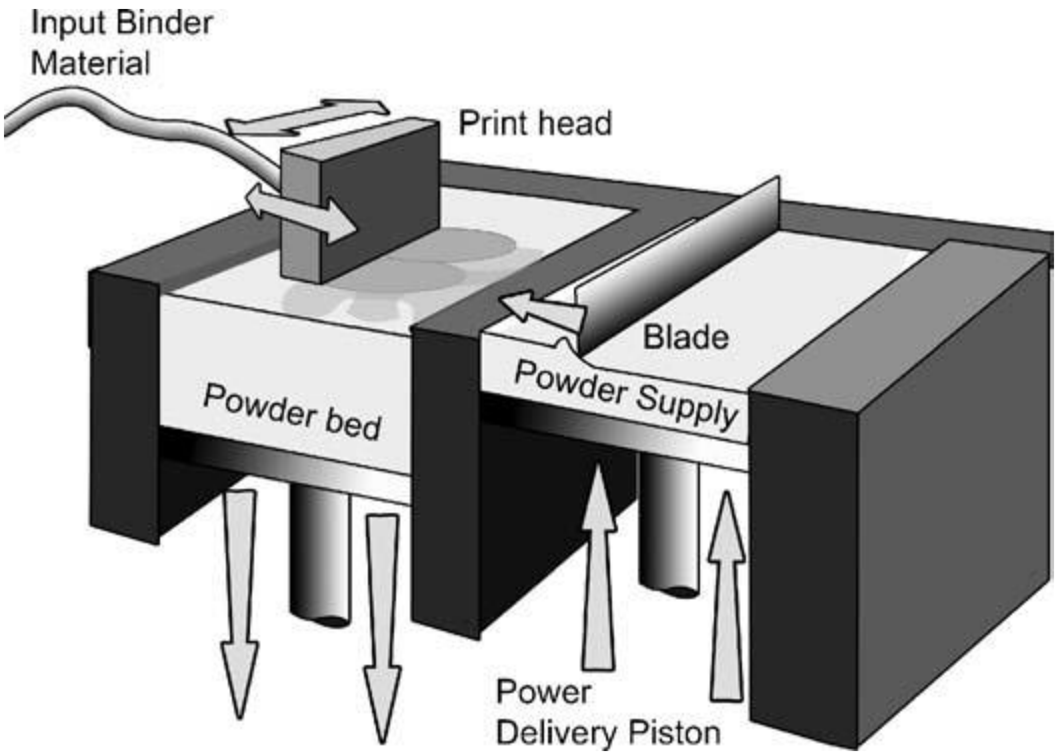
- **Selective Laser Sintering (Polymers):** The process is similar to stereolithography, but the powdered raw material is sintered or melted by a laser that scans the surface of a powder bed to create a two-dimensional solid shape. A fresh layer of powder is then added to the top of the bed so that a subsequent two-dimensional profile can be traced by the laser bonding it to the layer below. The process continues to create a full three dimensional object and the un-fused powder acts as a supporting material which obviates the need for support removal during post-processing.

  During the selective laser sintering process, the powder bed is heated prior to laser scanning to bring the temperature of the powder up to a temperature that is typically a few degrees Centigrade below the sintering temperature.

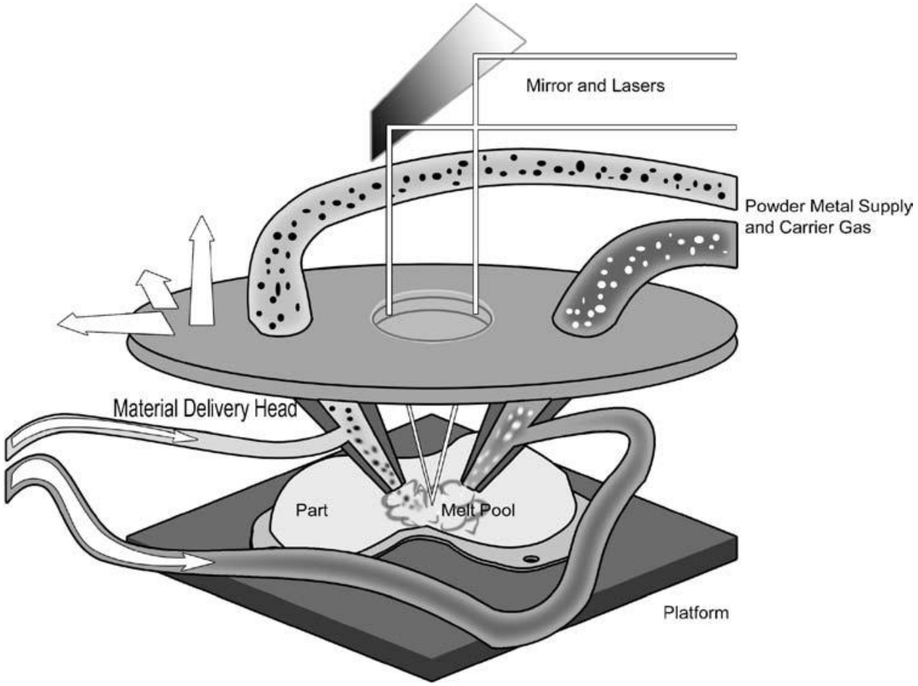


- **Selective Laser Sintering (Ceramic and Metals):** This process is very similar to polymer laser sintering but the materials used are completely different. By applying the concept of using coated powders of metals, the selective laser sintering machine could produce powder metallurgy steel parts in the green state. These parts could then be subjected to post-processing in a furnace to burn away the polymer binder, sinter the steel particles and finally infiltrate the porous parts with bronze. This process was largely aimed at producing tooling (such as cutting tool) but offers some potential for Rapid Manufacture of end-use products.
- **Direct Metal Laser Sintering:** Essentially the process involves either melting or liquid phase sintering of the metal powder directly by laser sintering without the need for a binder coating and the subsequent processing. The initial goal of direct metal laser sintering is to produce tooling, but the process has been used for end-use Rapid Manufacture.

- **Three-Dimensional Printing:** The process has a relatively high throughput in terms of creating green parts similar to those by metal selective laser sintering. Postprocessing is similar to that for selective laser sintered parts, but surface finish usually requires some form of machining to create a surface suitable for tooling.



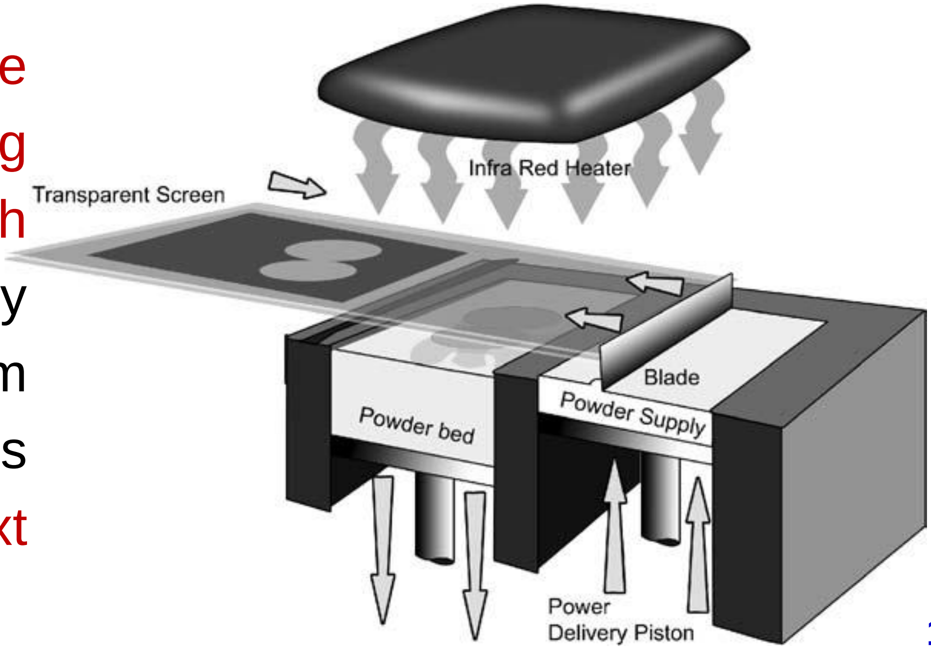
- **Fused Metal Deposition Systems:** This process has relatively slow deposition rates and produce parts with poor surface finish, but it offers the potential to process functionally graded materials in high melt temperature metals including titanium. That process has also proved to be particularly adopt at fixing broken parts such as mould tools by adding material where required. This may form an RM processes in the comparably high-added-value area of product repair/maintenance.



- **Electron Beam Melting:** The process uses a similar approach to selective laser sintering but replaces a laser with an electron beam. The electron beam may be directed by changing the electromagnetic field through which it passes. This eliminates the need for scanning mirrors and can significantly increase scanning speed. The power developed by the electron beam is very high, allowing the process to fully melt a wide range of metals including titanium alloy using a very fast scanning rate. However, the process is limited to conductive materials and surfaces, as with many other layer-based processes, often require extensive finishing-especially for tooling applications.
- **Selective Laser Melting:** This process uses a laser to fully melt stainless steel parts in a similar manner to laser sintering. The process is particularly adopt at producing very small components, including ones with complex lattice structures.

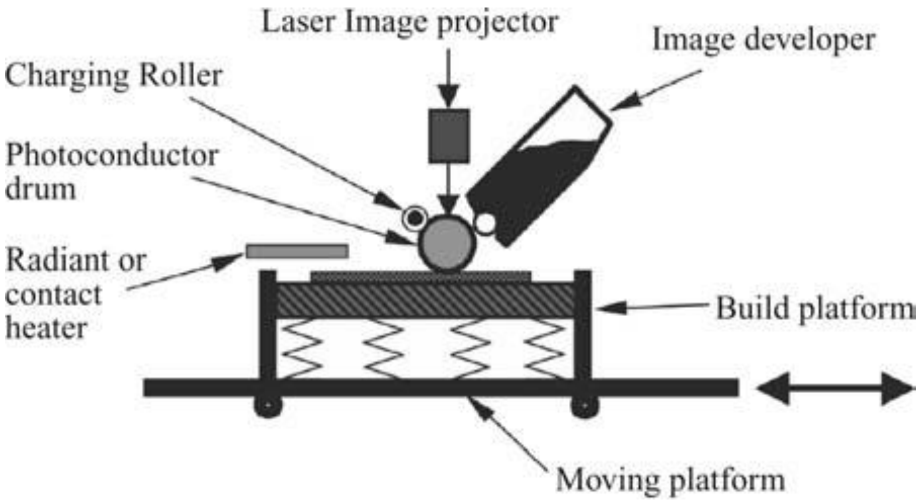
- **Selective Masking Sintering (SMS):** The SMS process involves printing a mask of infrared radiation reflecting material on to a glass sheet and placing the sheet over a powder bed. Infrared radiation is then applied to the glass sheet and allowed to selectively pass through the mask in order to sinter the powder directly below. This process eliminates the requirement for a laser and in instances where a significant portion of the surface needs to be sintered this should dramatically reduce processing times when compared with selective laser sintering.

This approach should have maximum benefits when being used for Rapid Manufacture in high volumes. The process was initially aimed at producing vacuum forming tools, but new materials may make this one of the next generation of RM machines.



- **Selective Inhibition Sintering:** The process provides to combine the benefits of SLS *(material properties)* and jetting processes *(build speed)* to address two of the major concerns behind Rapid Manufacture. However, Selective Inhibition Sintering is likely to achieve better resolution and definition as the inhibiting material is printed directly on to the powder and uses no mask that might allow for light diffusion.
- **High-Speed Sintering (HSS):** HSS is aimed at taking advantage of the mechanical properties given by SLS while achieving an increase machine throughput and reduced machine cost by eliminating the need for a laser. HSS defines the geometry of each layer by printing a material that promotes absorption of radiation (and hence promotes sintering) on to the powder bed surface, rather like a negative of SIS. The key to HSS is the ability to control the rate of sintering across the build surface.

- **Electrophotographic Layered Manufacturing:** This process uses mix of ideas that have been used for laser sintering. Figure shows how the process uses electrophotographic methods to deposit a part powder and then a support powder for each layer. The process focus on the idea of sintering each layer before the next layer is deposited. Some parts that have been sintered in the part bed.

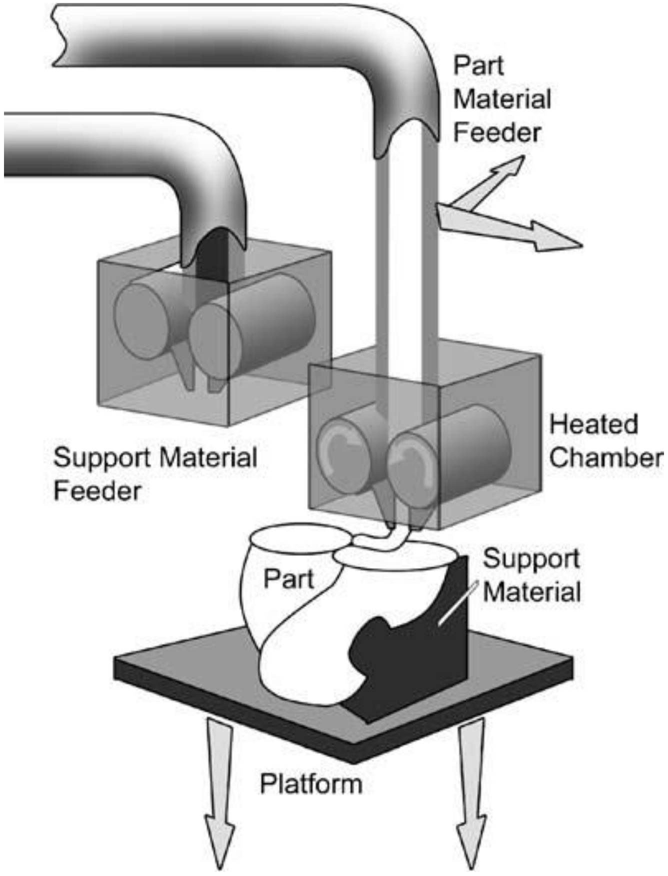


Solid-based Processes

- Processes that use a solid raw material in non-powder form have been an integral part of the RP industry since its formative years in the early 1990s.
- The two predominant forms of solid-based processes that are *fused deposition modelling* and *laminate object manufacturing* have been commercialised for some time, but incremental improvements continue by both the suppliers and academic institutions worldwide.

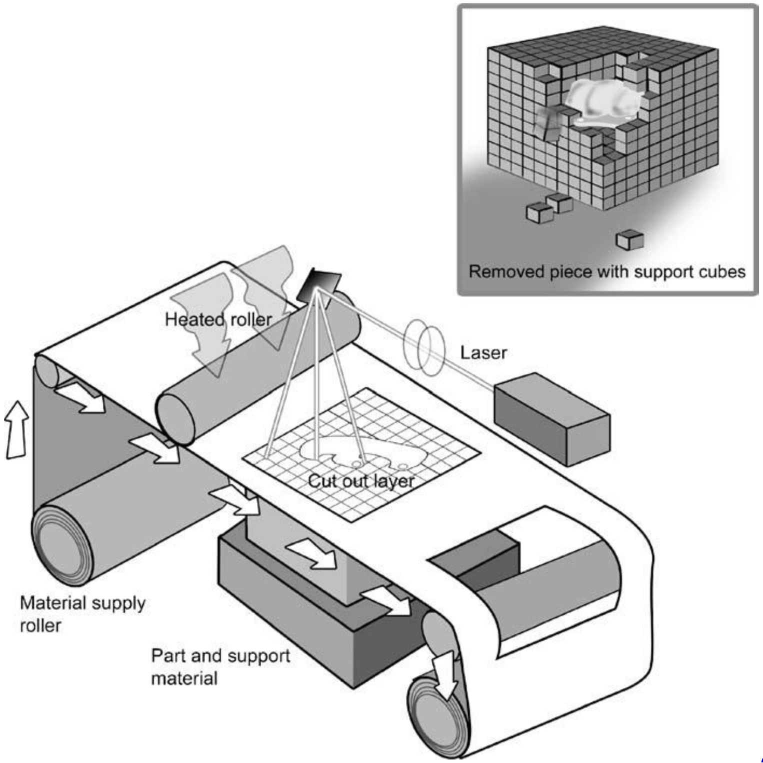
- **Fused Deposition Modelling:** The fused deposition modelling (FDM) process creates parts by extruding material (normally a thermoplastic polymer) through a nozzle that traverses in X and Y to create each two-dimensional layer. In each layer separate nozzles extrude and deposit actual part material and support material.

  Also the need for the nozzles to physically traverse the build area limits build speed, but the process is very easy to set up and can operate in an office or factory environment. Support removal can be manual or, when water soluble supports are employed, they may simply be dissolved. The simplicity of the process makes it suitable for the development of a wide variety of thermoplastic polymers, which may open up opportunities for Rapid Manufacture.



- **Laminate Object Manufacturing (Sheet Stacking Technology):** A number of sheet stacking technologies have been developed to create three-dimensional parts by cutting and stacking two-dimensional sheets of various materials. Different approaches have been used to cut sheets, bond them together and remove waste material from each sheet. It involves stacking layers of paper with a bonding material and creating the 3-D part profile.

Post-processing is required to remove the unwanted material and to reveal the part inside. The main problem for the process is that for complicated geometries, and especially those with thin walls, post-processing is difficult, time consuming and can damage the part.



Materials for Rapid Manufacturing

Researching and developing new materials for Rapid Manufacturing processes work continues, and new materials are being developed every day.

- **Stereolithography:** Proprietary epoxies, acrylate–epoxy hybrids. These materials offer low-ash, long vat life, optical clarity, smooth side walls, tack-free down faces, thin cured line width, low viscosity and low curing shrinkage.
- **Selective laser sintering:** Commercial materials are polymers, metal or ceramic binders and direct metal systems. The most popular material is polyamide in glass-reinforced formulations, aluminum-filled polyamide, polystyrene, resin-coated sand, nylon with glass reinforcement and methylmethacrylate.
- **Fused deposition modeling:** Extrusion filaments of ABS, polycarbonate and polyphenylsulfone.

Materials for Rapid Manufacturing

- **Fused metal deposition:** A variety of metal powders have been processed using direct powder techniques, including tool steel (A2, H13, H19, P20, P21, S7), stainless steel (304, 316, 420, 15-5PH, 17-4PH), nickel alloys (IN625, IN718, Hastelloy X), cobalt alloys (Stellite 6, Stellite 21, Stellite 706), aluminum alloy (4047), copper alloys and titanium alloys (CP Ti, Ti–6Al–4V, Ti–6Al–2Sn–4Zr–6Mo).
- **Three-dimensional printing:** Plaster–ceramic composite, starch-based material and straight plaster. Infiltrants include epoxy, urethane cyanoacrylates and low melting point wax.