

Electron Beam Machining

- The processes have been classified and grouped into seven categories:
 - • VAT Polymerisation
 - • Metal Jetting
 - • Binder Jetting
 - • Material Deposition
 - • Powder Bed Fusion
 - • Sheet Lamination
 - • Direct Energy Deposition (ISO/ASTM 52900, 2015)
- DMLS is contained within the Powder Bed Fusion (PBF) group along with Selective Laser Sintering (SLS), Electron Beam Melting (EBM), Selective Heat Sintering (SHS), and Selective Laser Melting (SLM). The PBF processes either melts or fuses powdered metal such as aluminium, stainless steel, titanium and some niche alloys using a precise high-powered laser.

ADDITIVE MANUFACTURING TECHNOLOGIES



Topics

- Electron Beam welding/melting/machining
- Stereolithography (SLA)
- Selective Laser Sintering (SLS)
- Laser Engineering Net Shaping (LENS)

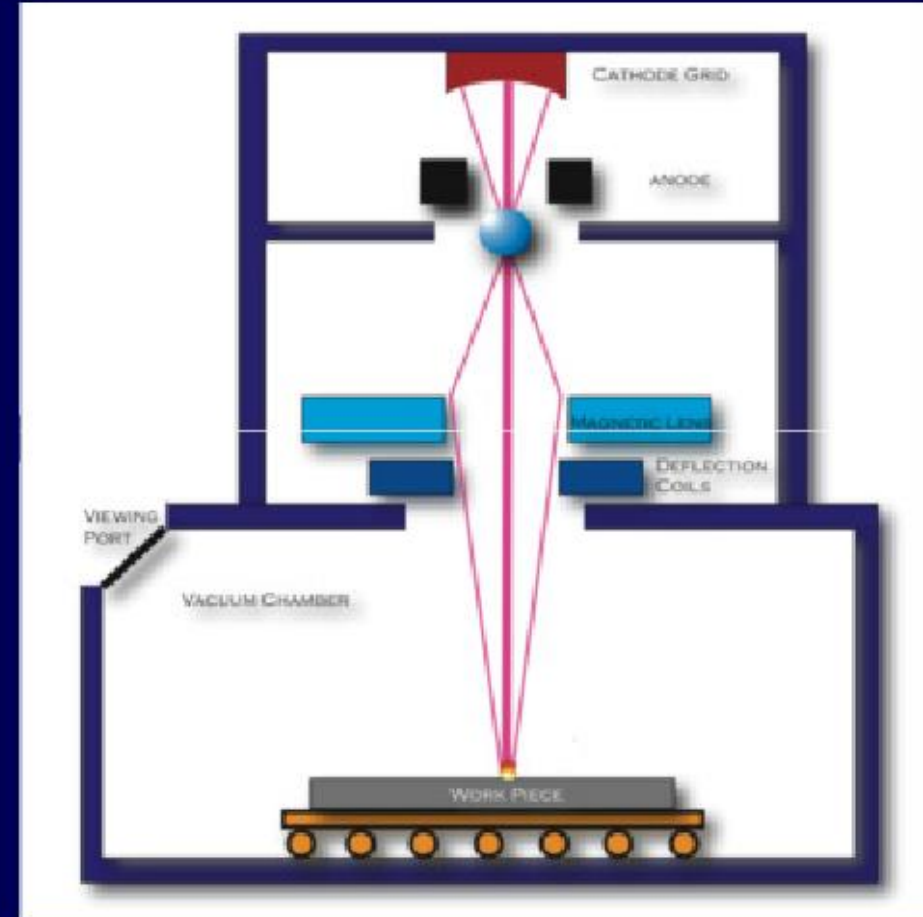
Videos

- Electron beam melting:

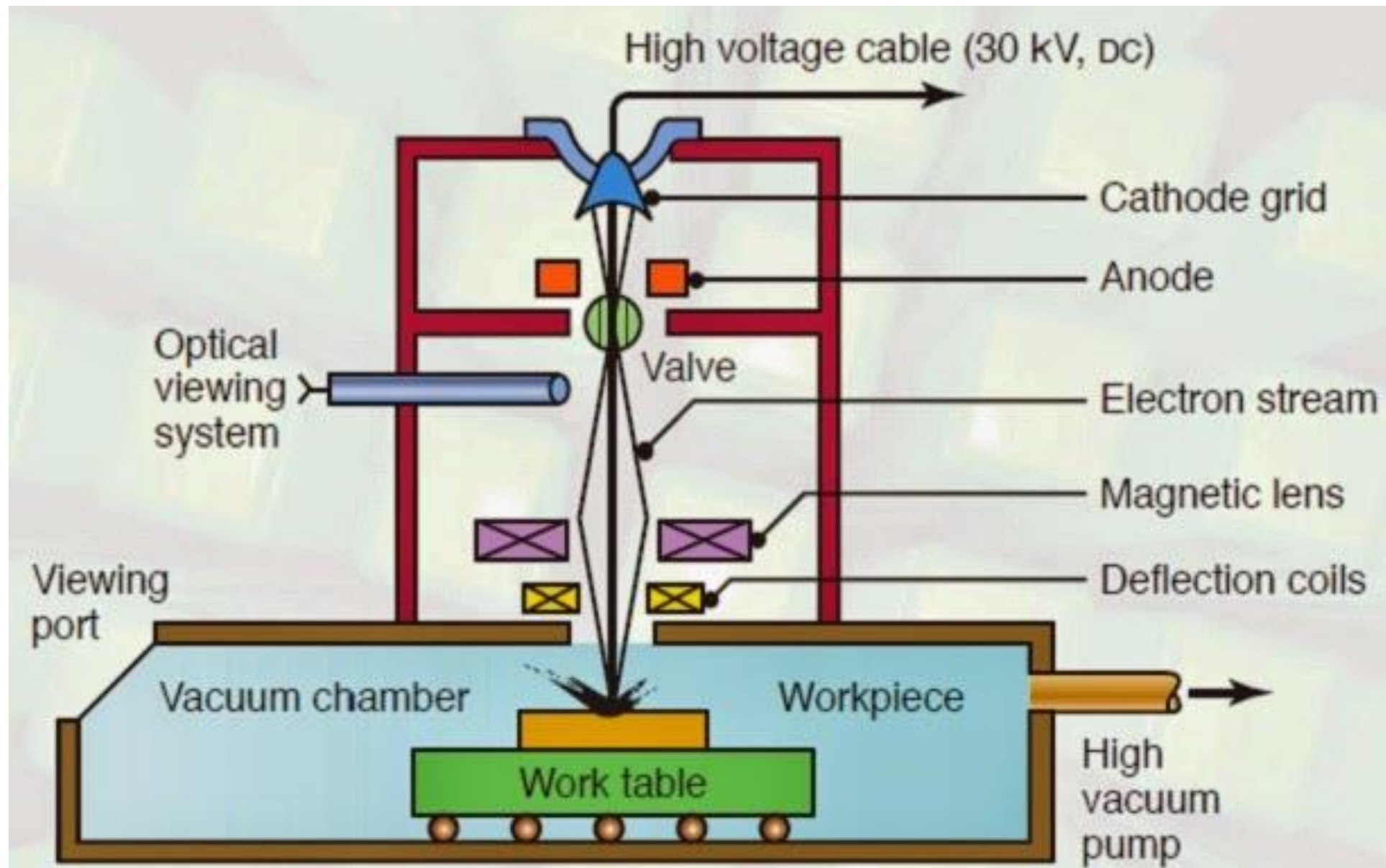
• <https://www.youtube.com/watch?v=uJQmFJCh7EM>
- Electron beam welding:
• <https://youtu.be/zX9tvdTEAEo>

Electron Beam Machining - Process

- A stream of electrons is started by a voltage differential at the cathode. The concave shape of the cathode grid concentrates the stream through the anode.
- The anode applies a potential field that accelerates the electrons.
- The electron stream is then forced through a valve in the electron beam machine.
- The beam is focused onto the surface of the work material, heating, melting, and vaporizing the material



Schematic Illustration of Electron-Beam Machining Process



- Electron Beam Machining (EBM) is a thermal process.
- Here a stream of high speed electrons impinges on the work surface so that the kinetic energy of electrons is transferred to work producing intense heating.
- Depending upon the intensity of heating the workpiece can melt and vaporize.
- The process of heating by electron beam is used for annealing, welding or metal removal.
- During EBM process very high velocities can be obtained by using enough voltage.
- 150,000 V can produce velocity of 228,478 km/sec focused on 10 – 200 μm diameter.
- Power density can go up to 6500 billion W/sq.mm. Such a power density can vaporize any substance immediately.
- Complex contours can be easily machined by manoeuvring the electron beam using magnetic deflection coils.
- To avoid a collision of the accelerating electrons with the air molecules, the process has to be conducted in vacuum. So EBM is not suitable for large work pieces.
- Process is accomplished with vacuum so no possibility of contamination.
- No effects on work piece because about 25-50 μm away from machining spot remains at room temperature and so no effects of high temperature on work.

Electron Beam Process Capability

- EBM can provide holes of diameter in the range of 100 μm to 2 mm with a depth up to 15 mm, i.e., with a l/d ratio of around 10.
- A wide range of materials such as steel, stainless steel, Ti and Ni super-alloys, aluminium as well as plastics, ceramics, leathers can be machined successfully using electron beam.
- As the mechanism of material removal is thermal in nature as for example in electro-discharge machining, there would be thermal damages associated with EBM.
- However, the heat-affected zone is rather narrow due to shorter pulse duration in EBM. Typically the heat-affected zone is around 20 to 30 μm .
- Some of the materials like Al and Ti alloys are more readily machined than steel.
- Number of holes drilled per second depends on the hole diameter, power density and depth of the hole as well as material type.

Electron Beam Machining – Advantages

- EBM provides very high drilling rates when small holes with large aspect ratio are to be drilled.
- Moreover it can machine almost any material irrespective of their mechanical properties. As it applies no mechanical cutting force, work holding and fixturing cost is very less.
- Further for the same reason fragile and brittle materials can also be processed. The heat affected zone in EBM is rather less due to shorter pulses.
- EBM can provide holes of any shape by combining beam deflection using electromagnetic coils and the CNC table with high accuracy.

Electron Beam Machining –Limitations

- However, EBM has its own share of limitations.
- The primary limitations are the high capital cost of the equipment and necessary regular maintenance applicable for any equipment using vacuum system.
- Moreover in EBM there is significant amount of non-productive pump down period for attaining desired vacuum.
- However this can be reduced to some extent using vacuum load locks.
- Though heat affected zone is rather less in EBM but recast layer formation cannot be avoided.

Advantages:

- Very small size holes can be produced.
- Surface finish produced is good.
- Highly reactive metals like Al and Mg can be machined very easily.
- EBM provides very high drilling rates when small holes with large aspect ratio are to be drilled.
- Can machine almost any material irrespective of their mechanical properties. As it applies no mechanical cutting force, work holding and fixturing cost is less.
- For the same reason fragile and brittle materials can also be processed. The heat affected zone in EBM is less due to shorter pulses.
- EBM can provide holes of any shape by combining beam deflection using electromagnetic coils and the CNC table with high accuracy.

Limitations:

- The primary limitations are the high capital cost of the equipment
- Must be done in a vacuum, very high specific energy consumption, expensive, slow, necessary regular maintenance applicable for any equipment using vacuum system.
- Maintaining perfect vacuum is very difficult.
- The entire process occurs in a vacuum chamber because a collision between an electron and an air molecule causes the electrons to veer off course.
- Material removal rate is very low compared to other unconventional machining processes.
- The machining process can't be seen by operator.
- Workpiece material should be electrically conducting.
- Moreover in EBM there is significant amount of non-productive pump down period for attaining desired vacuum.
- However this can be reduced to some extent using vacuum load locks.
- Though heat affected zone is rather less in EBM but recast layer formation cannot be avoided.

Applications:

- Used for producing very small size holes like holes in diesel injection nozzles, Air brakes etc.
- Used only for circular holes.
- Drilling fine holes, cutting contours in sheets, cutting narrow slots
- It is used for drilling synthetic jewels in the watch industry.
- Holes as small as 0.002 mm diameter can be produced in hard synthetic sapphires.
- Electron beam can be suitably used for welding small pieces of highly reactive and refractory metals.
- For making fine gas orifices in space nuclear reactors and turbine blades for supersonic aero engines, it is used
- Wire drawing dies, flow orifices could be produced by this process.
- Fine copper wire can be welded to in transistors.

Your turn!

MRR in EBM:

MRR power is $P = C.Q$

where

Q = area of slot or hole $\times$ speed of cutting = $A \times V$

Where power for 'Q' Where,

C = Specific power consumption

Thermal velocity acquired by an electron of the work material due to electron beam is

$$v_{th} = \sqrt{\frac{2k_B T}{m}}$$

Where, K_B = Boltzmann constant

m = mass of one atom of work.

T = rise in temperature

11. ¶ Electron beam guns are also provided with illumination facility and a telescope for alignment of the beam with the work piece. ¶ Work piece is mounted on a CNC table so that holes of any shape can be machined using the CNC control and beam deflection in-built in the gun. ¶ One of the major requirements of EBM operation of electron beam gun is maintenance of desired vacuum. ¶ Level of vacuum within the gun is in the order of 10^{-4} to 10^{-6} Torr. {1 Torr = 1mm of Hg} Maintenance of suitable vacuum is essential so that electrons do not loose their energy and a significant life of the cathode cartridge is obtained. ¶ Such vacuum is achieved and maintained using a combination of rotary pump and diffusion pump.
12. How Vacuum Creates? ¶ Main element for creating the vacuum is DIFFUSION PUMP. ¶ The oil diffusion pump is operated with an oil of low vapor pressure. Its purpose is to achieve higher vacuum. ¶ The features that make the diffusion pump attractive for high and ultra-high vacuum use are its high pumping speed for all gases and low cost per unit pumping speed when compared with other types of pump used in the same vacuum range. ¶ Diffusion pumps cannot discharge directly into the atmosphere, so a mechanical forepump is typically used to maintain an outlet pressure around 0.1 mbar.
13. ¶ Diffusion pump is essentially an oil heater. As the oil is heated the oil vapour rushes upward where gradually converging structure. ¶ The nozzles change the direction of motion of the oil vapour and the oil vapour starts moving downward at a high velocity as jet. ¶ Such high velocity jets of oil vapour entrain any air molecules present within the gun. ¶ This oil is evacuated by a rotary pump via the backing line. ¶ The oil vapour condenses due to presence of cooling water jacket around the diffusion pump. ¶ One major disadvantage of diffusion pumps is the tendency to back stream oil into the vacuum chamber. ¶ This oil can contaminate surfaces inside the chamber or upon contact with hot filaments or electrical discharges may result in carbonaceous or siliceous deposits.
14. Nozzles Water cooling coils Heater Boiler
15. Electron Beam Process – Parameters The process parameters, which directly affect the machining characteristics in Electron Beam Machining, are: • The accelerating voltage • The beam current • Pulse duration • Energy per pulse • Power per pulse • Lens current • Spot size • Power density

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Advantages

Very hard, heat resistant materials could be machined or welded easily

No physical or metallurgical damage results in the workpiece.

Close dimensional tolerance could be achieved since there is no cutting tool wear.

In electron beam welding there is virtually no contamination and close control of penetration is possible.

Holes as small as 0.002 mm diameter could be drilled.

Disadvantages

The equipment costs high and operator of high skill is required for carrying out operations.

The power consumption is exceedingly high

It is not very suitable for sinking deep holes, if the sides must be parallel. In other words, it is not possible to have perfectly cylindrical deep holes by this method.

Unless special care is taken the bottom of a thorough hole would become cone-shaped.

It is most suitable for machining operation where much less material is to be removed. The material removal rate being of the order of a fraction of a milligram per sec.

The electron beam operation can be carried out only in vacuum.

Applications

It is used for drilling synthetic jewels in the watch industry.

Holes as small as 0.002 mm diameter can be produced in hard synthetic sapphires.

Electron beam can be suitably used for welding small pieces of highly reactive and refractory metals.

For making fine gas orifices in space nuclear reactors and turbine blades for supersonic aero engines, it is used

Wire drawing dies, flow orifices could be produced by this process.

Fine copper wire can be welded to in transistors.

Subtractive Manufacturing

Electron Beam Machining (EBM)

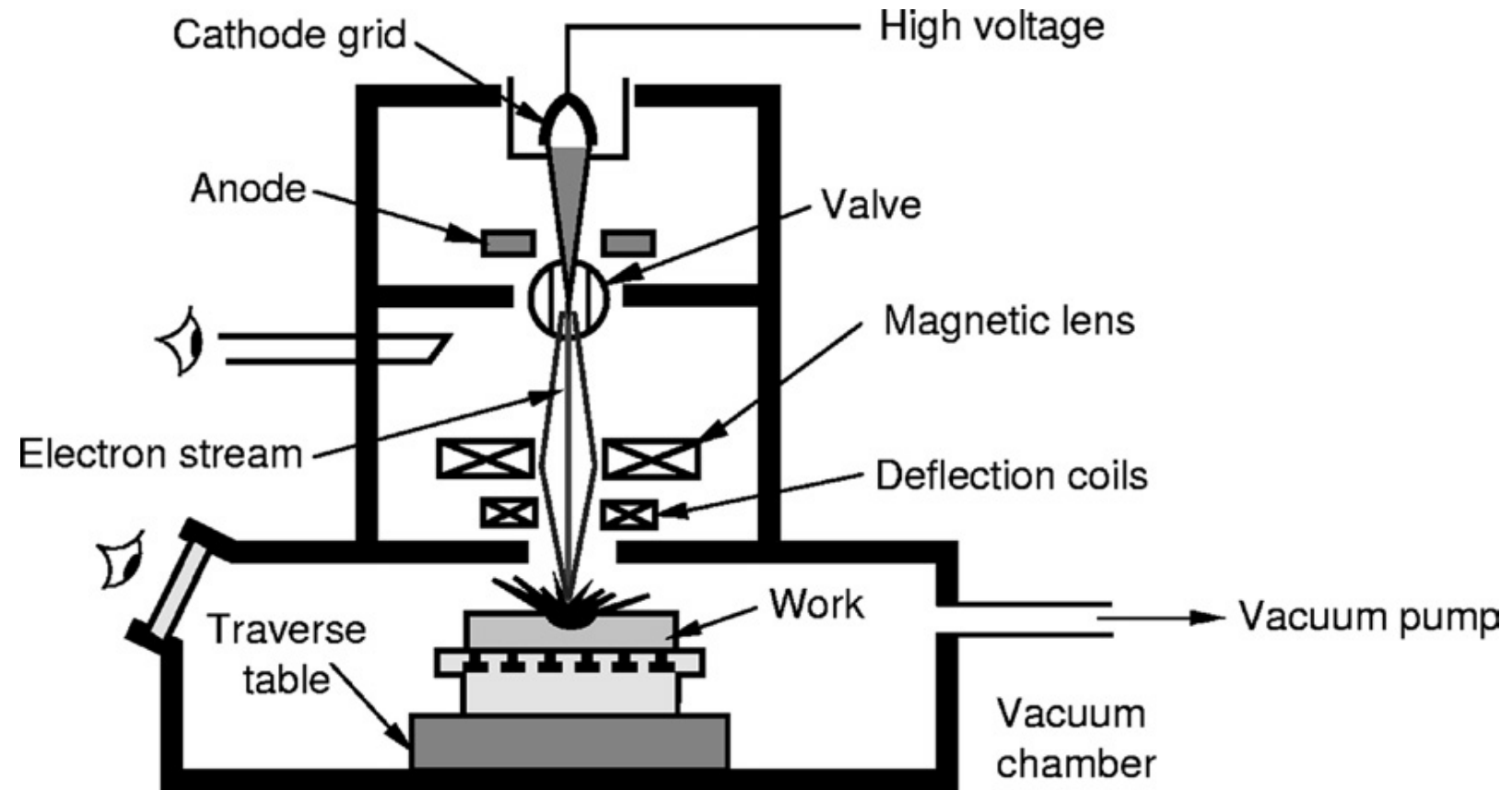
Manufacturing Processes Selection Handbook Swift,
Booker 2013
Fundamentals of Machining Processes – Conventional
and non-conventional Processes
El-Hofy CRC Press 2014

- EBM used in nuclear and aerospace industries since early 1960's
- Used for drilling small holes, cutting, engraving and heat treatment
- Used in semiconductor manufacture
- Used for micromachining

Electron Beam Machining (EBM)

Process Description

An electron gun bombards the workpiece with electrons up to 80% of the speed of light, generating localised heat and evaporating the workpiece surface. Magnetic lenses focus the electron beam and electromagnetic coils control its position. The workpiece is typically contained within a vacuum chamber



Material Removal Process

- The main components of EBM installation are housed in a vacuum chamber evacuated to about 10^{-4} torr
- 1 torr = $1/760$ of an atmosphere = 13.32 Pa $\sim$ 1 mmHg
- The tungsten filament cathode is heated to about 2500°C-3000°C to emit electrons
- Emission current varies between 20 and 100mA. It depends on cathode material, the temperature and the high voltage $\sim$ 150kV
- Current density is between 5 and 15 A/cm²

Process

- A stream of electrons are accelerated in the direction of the workpiece. After acceleration they are focused by the field and travel through a hole in the anode.
- The electron beam is then refocused by a magnetic or electronic lens system
- The beam is directed under control to the workpiece
- The electrons maintain the velocity (228×10^3 km/s) until they strike the workpiece in an area of 0.25mm diameter
- Their kinetic energy then transforms to heat causing a rapid increase in temperature of the workpiece to well above its boiling point
- The material is removed by evaporation

- Power densities of 1.55MW/mm^2 so all engineering materials can be machined
- Melted liquid rapidly ejected and vaporized causing MRR of $\sim 10\text{mm}^3/\text{min}$
- Pulsed electron beam at 104 Hz reduces the temperature of workpiece outside region being machined.
- Large depth:width ratio (100:1) meant fine hole drilling became feasible.
- Absence of mechanical contact and suitability for automation a plus
- Vacuum lengthens cycle time

Materials

Any material regardless of its type, electrical conductivity and hardness.

Process Variations

- Electron Beam Welding (EBW): used to weld a range of material of varying thicknesses giving a small weld area and heat-affected zone, with no flux or filler.
- The electron beam process can also be used for cutting, profiling, slotting and surface hardening, using the same equipment by varying process parameters.

Economic Considerations

- Production rates are dependent on size of vacuum chamber and by the ability to process a number of parts in batches at each loading cycle (less than 1 s per hole cycle time on thin workpieces).
- Parts should closely match size of chamber.

Material removal rates are low, typically 10 mm³/min. Penetration speeds up to 10 mm/s possible.

- Lead times can be several weeks.
- Set-up times can be short, but the time to create a vacuum in the chamber at each loading cycle is an important consideration.
- Material utilisation is good.
- High degree of automation possible.
- High energy consumption process.
- Economical with low to moderate production runs for thin parts requiring small cuts.
- Tooling costs are very high.
- Equipment costs are very high.
- Direct labour costs are high. Skilled labour required.
- Finishing costs are very low.

Typical Applications

- Multiple small-diameter holes in very thin and thick materials.
- Injector nozzle holes.
- Small extrusion die holes.
- Irregular-shaped holes and slots.
- Engraving.
- Features in silicon wafers for the electronics industry.

Design Aspects

- Electron beam path can be programmed to produce a desired pattern.
- Suitable for small-diameter, deep holes with length to diameter ratios up to 100:1.
- Possible to machine thin and delicate sections due to no mechanical processing forces.
- Sharp corners are difficult to produce.
- Better to have more small holes requiring less heat than a few large holes requiring considerable heat.
- Maximum thickness = 150 mm.
- Minimum hole size = 0.01 mm diameter.

Quality Issues

- Localised thermal stresses giving very small heat-affected zones, small recast layers and low distortion of thin parts possible.
 - Integrity of vacuum important. Beam dispersion occurs due to electron collision with air molecules.
- The reflectivity of the workpiece surface is important. Dull and unpolished surfaces are preferred.
- Hazardous X-rays are produced during processing and require lead shielding.
 - Produces slightly tapered holes, especially if deep holes are required.
 - Critical parameters to control during process are: voltage, beam current, beam diameter and work speed.
 - The melting temperature of the material may also have a bearing on quality of surface finish.
 - Surface roughness values are in the range 0.4–6.3 $\mu\text{m Ra}$.
 - Achievable tolerances are in the range ± 0.013 to ± 0.125 mm. (Process capability charts have not been included. Capability is not primarily driven by characteristic dimension.)

Advantages

- Machines small holes at a rate of 4000 holes per second
- No problem with acute angles
- No limitation to workpiece hardness, ductility or surface reflectivity
- Avoids mechanical distortion to the workpiece because there is no contact
- Achieves high accuracy and repeatability of $\pm 0.1\text{mm}$ for hole position and $\pm 5\%$ for the hole diameter
- Produces the best surface finish compared to other processes
- Ensures low cost compared to other processes

Disadvantages

- High Capital equipment cost
- Long production time due to the time needed to generate vacuum
- The presence of a thin recast layer
- Necessity for auxillary backing material

Additive Manufacturing

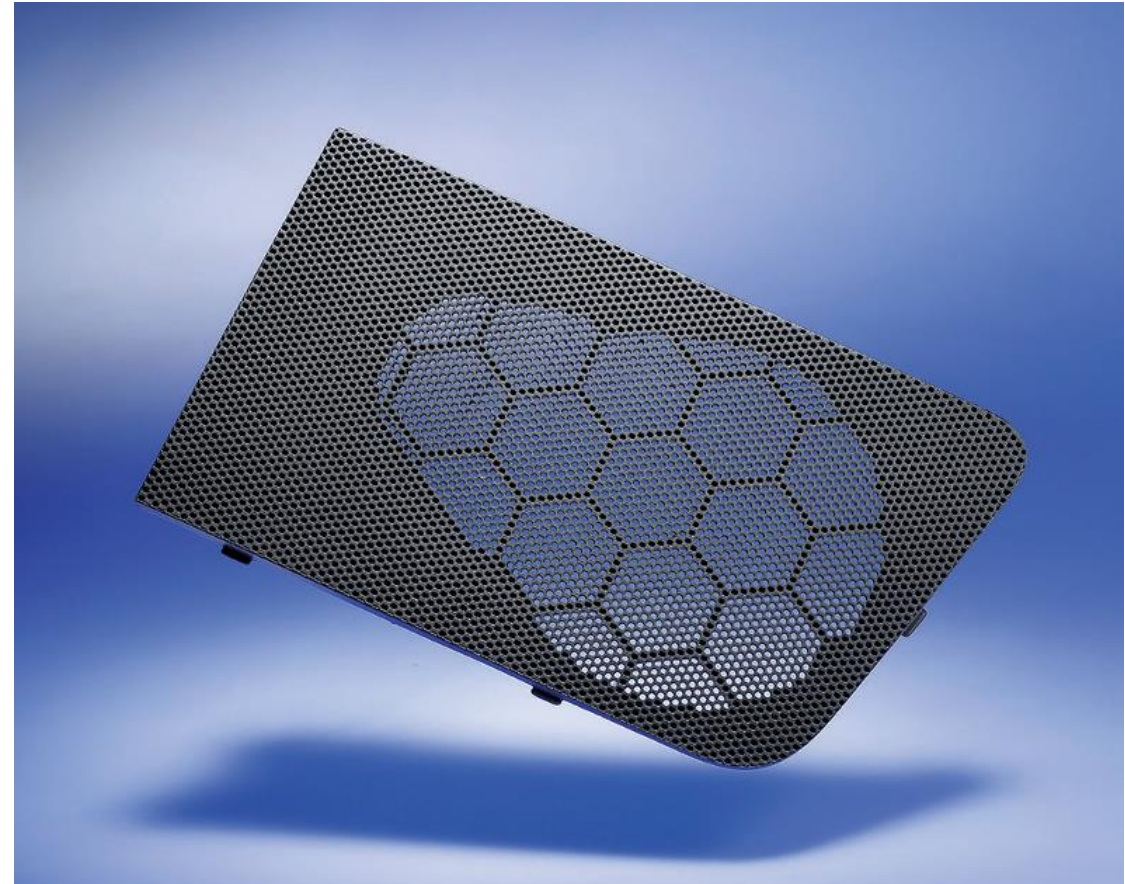
- Since the late 1980s, >25 years, Additive Manufacturing (AM) used in manufacturing.
- Initially the layer-based technology called Rapid Prototyping (RP).
- Technology could only make sticky and brittle prototypes.
- The process was not even “rapid,”
- But time- and money-consuming tools no longer needed with RP for creation of the first prototype
- significant amount of time and money saved.

Stereolithography

- Initial process named *stereolithography*
- based on photo-polymerization of acrylates and later epoxies.
- New layer-based processes developed and more materials could be used (all plastic)
- Metal parts were introduced about year 2000
- Focus changed from just prototyping to manufacturing because of improved processes, materials, software, and control. Attempts made to produce final parts.
- Today all classes of engineering materials, such as plastics, metals, ceramics, and even non-traditional materials, such as food, drugs, human tissue, and bones, can be processed using 3D printers.
- Huge 3D printing worldwide, this high-speed development is incomparable to the expansion
- of any fabrication technology in the past.

Rapid Prototyping Processes

Stereolithography (SLA)

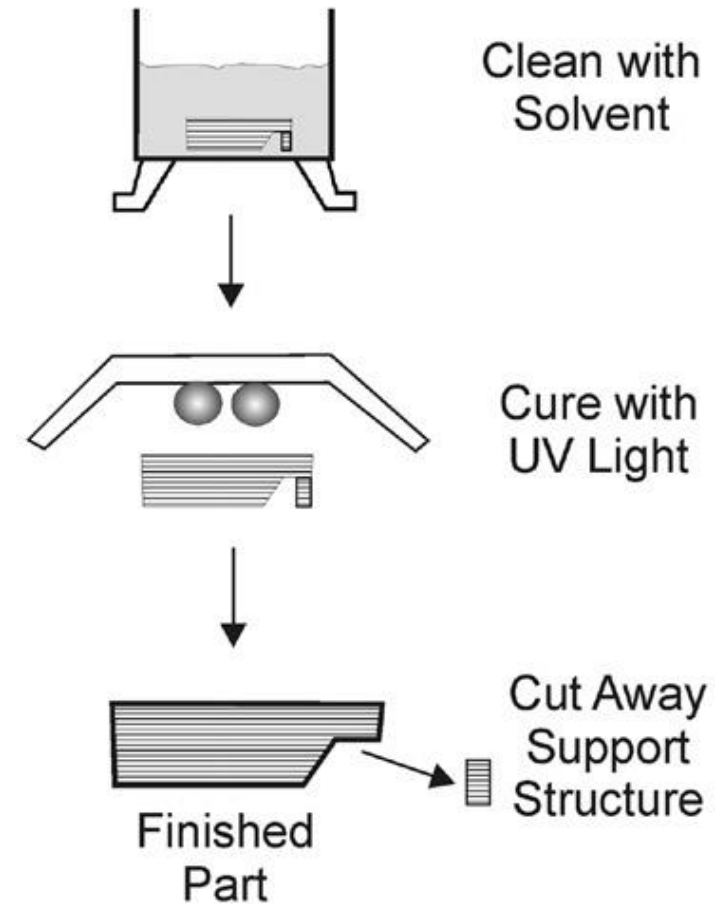
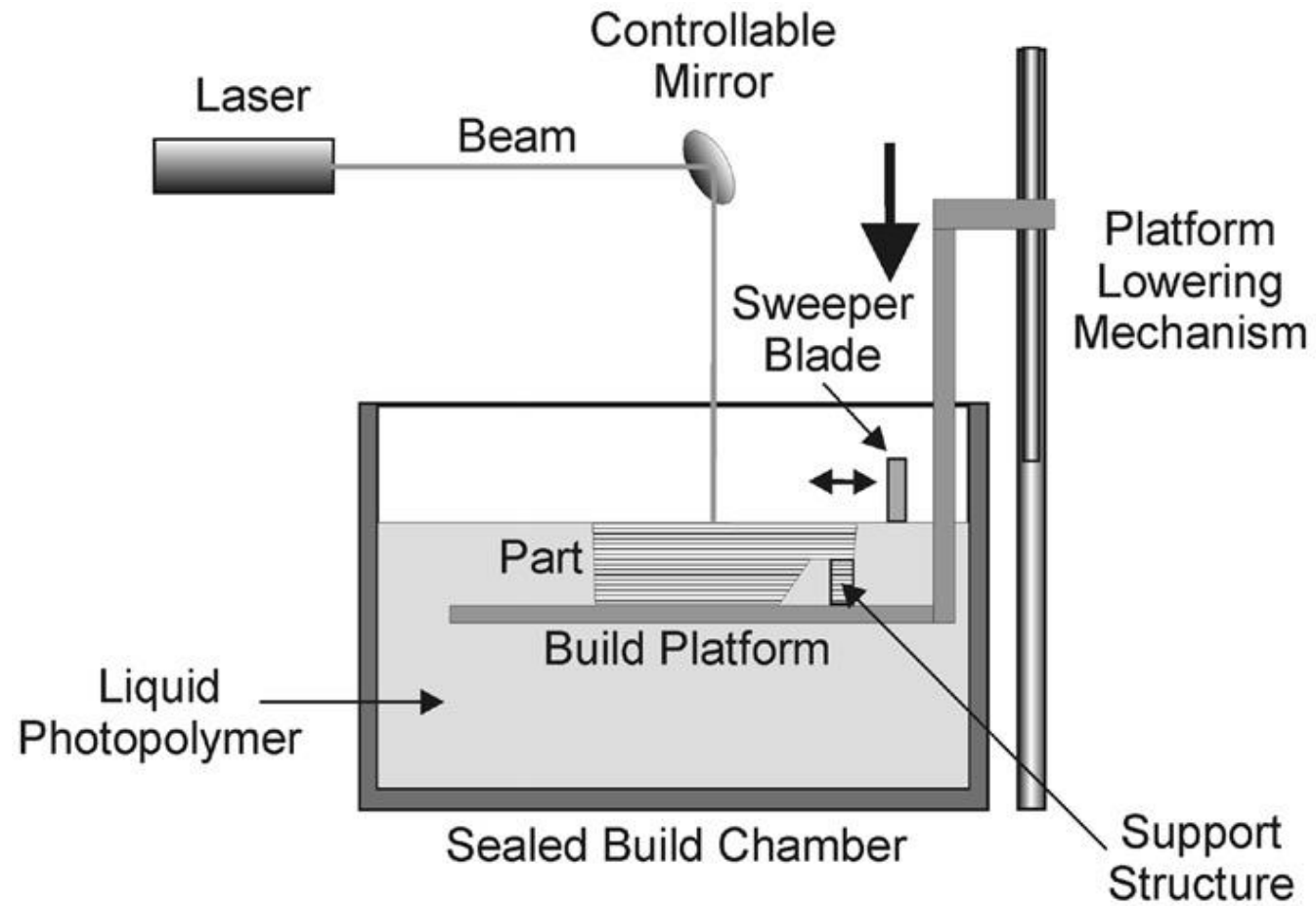


Stereolithography (SLA)

Process Description

- A low-power laser beam is directed by a mirror to trace a thin 2D cross-section in a liquid photopolymer resin that is stored in a build chamber.
- Through the process of photopolymerisation, a layer of hardened and cured 3D pixels of polymer are created, a process which only takes place near the surface due to absorption and scattering of the laser beam.
- The build platform is lowered down an amount equal to the thickness of the previously cured layer, and a sweeper blade moves across replenishing a layer of resin.
- The laser traces out the next 2D cross-section and the process is repeated.
- The self-adhesive property of the material used causes the layers to bond and, after many layers have been cured, a 3D part is built up.
- The completed part is drained, washed in solvent to remove excess resin and subjected to UV light to cure the component completely,
- Support constructions are removed by cutting

Stereolithography.



Materials

- Liquid form of photopolymers such as elastomer, epoxy, urethane, acrylate and vinyl ether.
- Liquid photopolymer can be clear or white.

Process Variations

- Laser types can be UV He:Cd or argon ion, up to 1 W in power.
- Solid Ground Curing (SGC): uses UV light to cure an entire layer of light-sensitive resin, the area being pre-defined by a photomask.
- Solid Object Ultraviolet Laser Plotter (SOUP): the laser is mounted and moved by a controlled mechanism in the horizontal plane above the build chamber of photopolymer, rather than being static and directed by mirrors.

Economic Considerations

- Moderately fast build speed, though large parts can take a day to fully complete.
- Automated process, but skilled labour required.
- Lead times are 1–2 weeks.
- Material utilisation is high. Support structures represent waste.
- Waste material must be disposed of properly. Cannot be recycled.
- Reworking costs are high.
- Photopolymers are expensive and the process requires that the whole build chamber is filled.
- Economical for low production runs 1–20 parts.
- Equipment costs are moderate.
- Direct labour costs are low.
- Some finishing may be required, but final curing also adds time.

Typical Applications

- Non-functional prototypes.
- Form and fit parts in assemblies.
- Product concept models.
- Medical models.
- Casting patterns.
- Snap fits and hinges.

Design Aspects

- Complex and intricate 3D parts created in CAD.
- Undercut features, cantilevered walls and overhangs require support structures to be designed as part of the CAD model or manually on the machine.

Part should be orientated in the build chamber in order to reduce the amount of support structures.

- Supports can take the form of gussets, ceilings, webs or points.
- Anisotropy in material properties exist due to the additive layer method. Strength weakest in vertical build direction.
- Tensile strengths up to 75 MPa are possible, depending on material used.
- Increased strength can be achieved at certain locations by increasing layer thickness.
- Conventional machining processes can be used for non-standard details, e.g. threads.
- The finished part is translucent.
- Layer thickness = 0.025–0.15 mm.
- Typical maximum dimensions of part = 600 mm × 500 mm × 500 mm.
- Minimum section = 0.1 mm.

Quality Issues

- Calibration of the laser is required periodically for some systems.
- Green creep distortion tests can help assess the dimensional stability of the laser-cured resins.
- Laser exposure and scan speeds need to balance full curing and process speed.
- Total thickness layer is related to the scanning speed and depth penetration factor of the photopolymer resin.
- A short delay called a 'dip delay' is required after laser curing of a layer, so that liquid photopolymer can settle flat and evenly, inhibiting bubble formation.
- The liquid photopolymer is difficult to work, toxic and pungent, and requires safe handling procedures.
- The selection of the correct photopolymer is associated with strength, shrinkage and distortion of the part that is tolerable post-curing.
- Material properties may change over time, accelerated by light, moisture, heat and chemical environments.
- The machine is sealed to prevent toxic fumes from escaping, generated by the laser solidifying the resin.
- Avoid the location of support structures on planes where good surface finish is required.
- Support structures must be removed from part manually, but the process is simple and quick.
- Additional post-processing may be required for part finishing.
- The durability of the part is limited when exposed to sunlight.
- Finished part can be painted.
- Tolerances achievable = ± 0.1 to ± 0.2 mm.
- Typical surface roughness = $2 \mu\text{m Ra}$.
- Surface finish is excellent in comparison to other rapid prototyping technologies.

Rapid Prototyping Processes

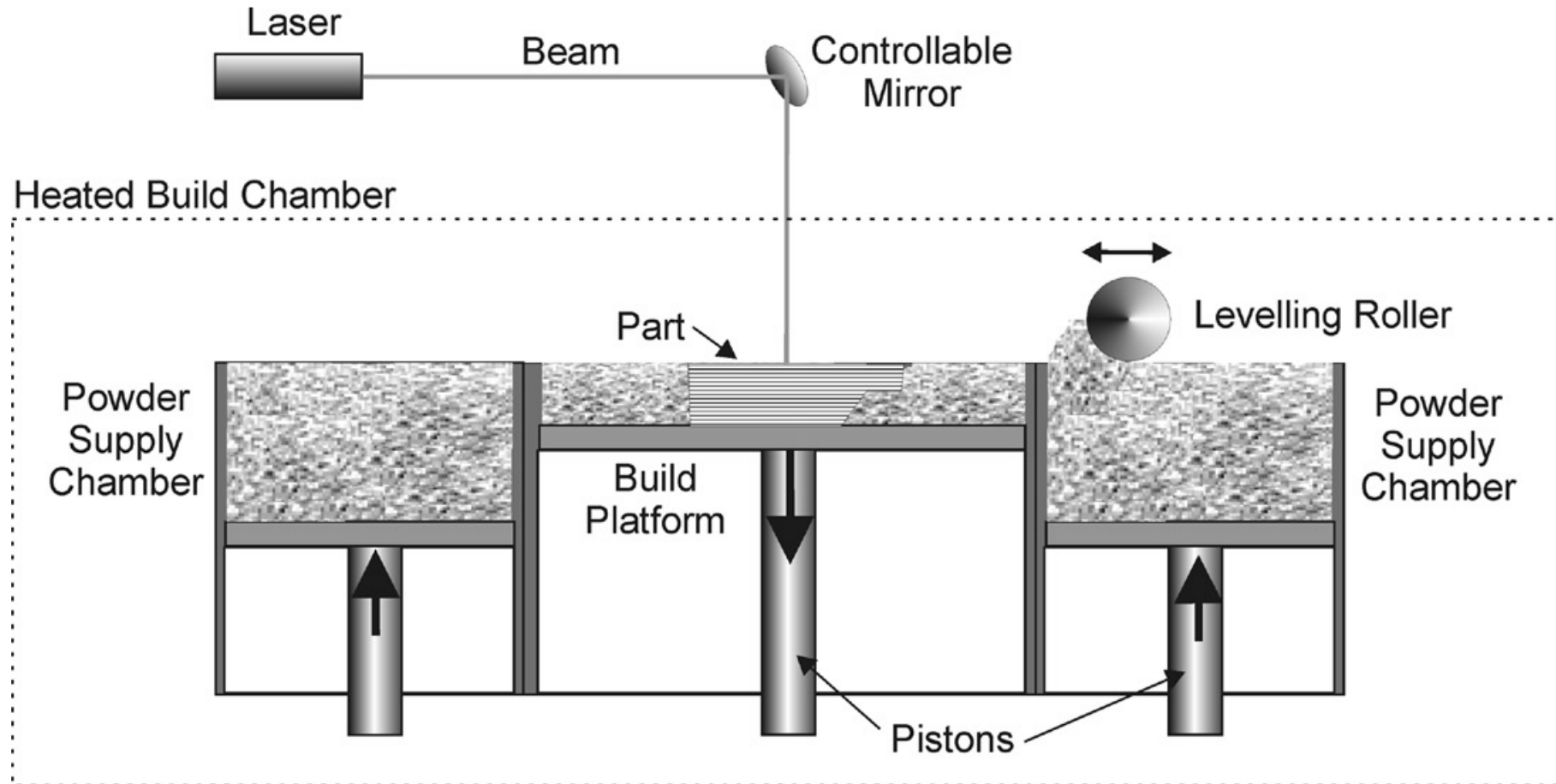
Selective Laser Sintering (SLS)



Process Description

- A high-power laser beam directed by a mirror is used to sinter powdered material in thin 2D cross-sections.
- The powder is in a sealed chamber with a nitrogen atmosphere to prevent oxidation.
- It is pre-heated using infrared heaters to a temperature just below the melting temperature of the powdered material.
- The build platform is lowered down an amount equal to the thickness of the sintered layer.
- A roller replenishes the layer of powder from adjacent powder supply chambers, the laser traces out the next 2D cross-section, and the process is repeated until a 3D structure is built up.
- Excess powder not sintered on each layer acts as a support for the part being built.
- The part is removed and excess powder is removed by brushing or vacuuming

Selective Laser Sintering (SLS)



Materials

- Powder form of heat-fusible thermoplastics (including glass filled), elastomers and wax.
- Powdered metals with binder, e.g. stainless steel, tools and alloy steels, titanium, tungsten, copper alloy, aluminium and nickel super alloys.
- Powdered ceramics and moulding sand (with binder).

Process Variations

- Direct Metal Laser Sintering (DMLS):
 - used for processing metal and ceramic composite parts using very fine powders
 - no binders
 - high-powered lasers to sinter the particles directly
 - in an inert atmosphere.
 - Achieves very high part densities,
 - Support structures are required for overhanging features. Typically parts will go through a number of post-processing stages, including support removal, shot peening (see PRIMA 9.6) and polishing, to improve fatigue resistance and finish.
- Laser types: Yb-fibre or CO₂, up to 100 W in power. Up to 200 W for DMLS.

Economic Considerations

- Medium build speed.
- Automated process, but skilled labour required.
- Lead times are typically 1 week.
- Material utilisation is high.
- Leftover powder material is directly reusable.
- Powdered material cost is low to moderate, depending on type.
- Economical for production runs of 1–50+, depending on size and complexity.

DMLS can be viable for larger volumes, 1,000+.

- Equipment costs are high.
- High energy requirement.
- Direct labour costs are low.
- Some finishing may be required.

Typical Applications

- Final functional components in low to moderate volumes, e.g. impellers, fuel nozzles for aerospace sector.
- Functional prototypes, e.g. for experimental testing, wind tunnels, etc.
- Form and fit parts in assemblies.
- Product concept models.
- Patterns, moulds and cores for casting and moulding.
- Rapid tooling.
- Medical and dental implants.
- Models for ergonomic testing.
- Snap fits and hinges.

Design Aspects

- Complex and intricate 3D parts created with CAD.
- Any powder material not sintered in the build chamber acts as a support medium for any overhanging or undercut features on the part.
- No additional support structures are therefore needed.
- Parts should be orientated in the build chamber with the height being the smallest dimension in order to reduce the number of layers created.
- Anisotropy in material properties exist due to additive layer method.
Strength weakest in vertical build direction.
- Approximately 50 MPa tensile strength for some thermoplastics, 300 MPa for bronze-impregnated steel, 1 GPa+ for titanium using DMLS.
- Parts can be machined using conventional processes.
- Layer thickness = 0.075–0.15 mm, depending on material used.
- Thinner layers can be achieved with DMLS >0.02 mm.
- Typical maximum dimensions of part = 450 mm × 375 mm × 325 mm.
- Minimum section = 0.4 mm.

Quality Issues

- Control of build chamber temperature just below the material's melting point is important to facilitate fusion between layers as the heat from the laser only needs to raise the temperature a small amount for sintering. Also important in order to minimise thermal distortions.
- Large parts can take many hours to cool before handling is possible.
- Machine needs thorough cleaning when changing material powder types to avoid contamination.
- Stress relieving and annealing may be required for metal parts to reduce internal residual stresses.
- Additional curing may be required when using ceramic materials.
- The nitrogen atmosphere maintained in the build chamber also prevents possibility of explosion of the powder.
- 'Stair-stepping' features on sloping surfaces in the vertical build plane can be created.
- Greater than 99% densities can be achieved after sintering; 100% density is achievable when impregnated with another material.
- Impregnation improves mechanical properties and surface finish. Typically a lower melting temperature metal alloy such as an alloy of copper is used for impregnation.
- Finished part can be painted and surface coated.
- Tolerances achievable = ± 0.05 to ± 0.25 mm.
- Typical surface roughness = 7–10 μm Ra.
- Finish is related to coarse powders used, and may require additional finishing processes. Powder diameter is usually between 20 and 100 μm .

Laser-Engineered Net Shaping

The laser-engineered net shaping (LENS) process is based on the principle of laser coating with the powder nozzle in a protective gas atmosphere.

The focus is on the material development and thereby on the manufacturing and repair of parts for the air and space industry and on applications in medical technology.

Tool concepts with conformal cooling and inserted cooling zones are rarely published.



LENS, cavity during the construction process (Source: Optomec)

Short Description

In laser-engineered net shaping (LENS), process powders are applied from different metals or alloys via powder nozzles locally on a workpiece and melted locally using a laser. In this way, material is generated in rows and layers, and so a component can be constructed or repaired. The process corresponds to laser generation.

Application

Functional prototypes, final products in metal

Development Status

Commercialized since May 1998

History

Optomec was founded in 1983 by Thomas Swann. The company supplies optomechanical systems to research institutions and universities and as an accessory for rapid prototyping systems. The LENS technology was invented and developed by David Keicherin in Sandia National Laboratories (SNL). He joined as a partner at Optomec in 1997.

Strategies/Development Partners

- LENS is a registered trademark of Sandia National Laboratories (SNL) and Sandia Corporation.
- In 1997 Optomec took over the LENS process as a license from SNL
- and developed an industrially applicable system.
- The strategic goal is the direct production of metal functional prototypes and identical components from a variety of metallic and ceramic materials. There is a development partnership with SNL.
- Optomec tracked their overall strategy to become a manufacturer of additive manufacturing systems for the processing of high-performance materials.,
- Metallurgy was therefore a priority
- For the production of microelectronic components, Optomec has mesoscale aerosol printing under the name Maskless Material Deposition (M3D), (see Section 3.6.6,
- “Maskless Mesoscale Material Deposition (M3D), Optomec”).

Data Format/Software

- The LENS system can read error-free STL data and CAD data via the usual neutral interfaces.
- The system software contains all elements that are necessary for the preparation and control of the additive manufacturing process.
- The system is operating optionally with SolidWorks rapid prototyping software.
- The system provides a modular assembly according to user requirements, such as additional axes, and process monitoring, which can be integrated into the machine control.

Principle of Layer Generation

- The powder is introduced through several nozzles that are distributed around the laser beam in the focus area of the laser, melted there, and applied to the molten component.
- The solidification after cooling occurs by heat conduction into the component.
- Cyclone powder feeders are used as a standard.
- The model is created line by line (raster process), wherein the line structure from layer to layer is rotated by 90°.
- The advanced scanning strategies are not known.
- The LENS 850-R has a fibre-coupled 1, 2, or 4 W fibre laser.
- The building process takes place in a fully closed process chamber. It can be viewed with a video camera.
- The trial chamber is flooded, depending on the material, with a suitable inert gas, normally argon. The system has a complex gas management system.
- A recirculation allows an exact flow in the process chamber.
- It is connected to a process gas cleaning system that constantly monitors the oxygen content, among others.

Design/Construction

- The company Optomec provides complete systems consisting of software and hardware for converting the CAD data and to control the process.
- It consists of a process chamber sealed against environmental influences and working under inert gas.
- The externally positioned laser, which is connected to the chamber via an optical fibre, the powder conveying and coating unit, and the build platform.
- In the LENS 850-R (Fig. 3.58), the dimensions of the process chamber are $x, y, z = 900, 1500, 900$ mm³. The substrate is clamped onto a rotary table that can be
- moved in the x and y directions. The x - y contour of the component is provided by a positioning system with a brushless servo drive.
- The laser head of the coating LENS 850-R is moved by an x - y portal system in the building plane and the entire portal in the z axis.
- The system has up to seven axes.
- Two powder feeders allow the adjustment of a material gradient. A front feed palletizing system supports the handling of large parts and bigger series.



LENS 850-R, view (left), process chamber (right) (Source: Optomec)

- A visual inspection system and a molten pool monitoring and control is integrated.
- The LENS 450 has a smaller construction space of $x, y, z = 100, 100, 100 \text{ mm}_3$ and a 400 W fiber laser.
- It is provided for small parts in small quantities.
- The MR-7 has a construction space of $x, y, z = 300, 300, 300 \text{ mm}_3$ and a 500 W, 1 kW, or 2 kW fiber laser.
- Most features of the 850-R are at least optionally available for the MR-7.

Material/Construction Time/Accuracies

- According to the manufacturer, fully dense components can arise from a variety of materials, including stainless steel, titanium, and special alloys, which are intended to have the physical and technological properties of standard parts.
- The manufacturers claim that due to the laser process a grain refinement of the resulting structure occurs and causes both the tensile strength and ductility of the parts produced with LENS to exceed the characteristics of the relevant materials [Kreicher, 98].
- So with the LENS process the steel 316S reaches a tensile strength of 500 MPa, compared to 243 MPa from nonadditive processing.
- This trend is also evident in Inconel 625 (584/403 MPa) and Ti6Al4V (973/834 MPa), in which the elongation at break values are at least 10 % higher than the comparative values, and the expected hardening thus does not occur.
- The manufacturer specifies that 0.08 mm details can be resolved and identified a tolerance of $\pm 1/10$ mm relative to the finished size.
- The LENS process has the fundamental advantage that components made of different materials can be built. It is obviously possible to provide the component with supports made of copper, both externally and in terms of internal cavities. More information about it does not exist.

Postprocessing

Optionally removing the supports, polishing

Typical Follow-up Processes

None

References:

1) Additive Manufacturing

3D Printing for Prototyping and Manufacturing

Andreas Gebhardt

Jan-Steffen Hötter

Hanser Publishers Munich 2016

ISBN: 978-1-56990-582-1

E-Book ISBN: 978-1-56990-583-8

2) Manufacturing Process Selection Handbook

K. G. Swift

Department of Engineering, University of Hull

J. D. Booker

Department of Mechanical Engineering,

University of Bristol

Butterworth-Heinemann (Elsevier)

Oxford 2013

ISBN: 978-0-08-099360-7

The Exam

LOCATION: SWANSEA

LEVEL 6

**EXAMINATION PERIOD
MAY 2017**

LLEOLIAD: ABERTAWE

LEFEL 6

**CYFNOD ARHOLIADAU
MAI 2017**

**MODULE CODE:
Advanced Processes**

TIME: 2 HOURS

INSTRUCTIONS TO CANDIDATES:

- **This paper contains FOUR questions. Attempt THREE questions.**
- **Electronic calculators may be used during this examination.**

Three questions and 2 hours – 40 minutes per question
33.3% of the exam marks can be earned on each question

Revision Questions

Question 1

Using a labelled diagram, explain the principles of **Stereolithography** (SLA) and how it works.

(10 marks)

Question 2

Discuss the strengths and weaknesses of **additive** manufacturing methods in relation to traditional methods giving appropriate examples of applications.

(10 marks)

Question 3

Discuss the strengths and weaknesses of **additive** manufacturing methods in relation to **subtractive** methods giving appropriate examples of applications.

(10 marks)

Question 4

Describe the process of **Electron Beam Machining (EBM)**

(10 marks)

Compare and contrast the following:

- i. **Selective Laser Sintering (SLS)**
- ii. **Laser Engineering Net Shaping (LENS)**

(10 Marks)

Question 5

A manufacturer is looking at updating its manufacturing processes, discuss in detail and evaluate how this industry could use **subtractive** and **additive** manufacturing for rapid prototyping. How will this give greater freedom of design and improve the “Time-to-market”?

(10 marks)

Model Answers

Revision question 1

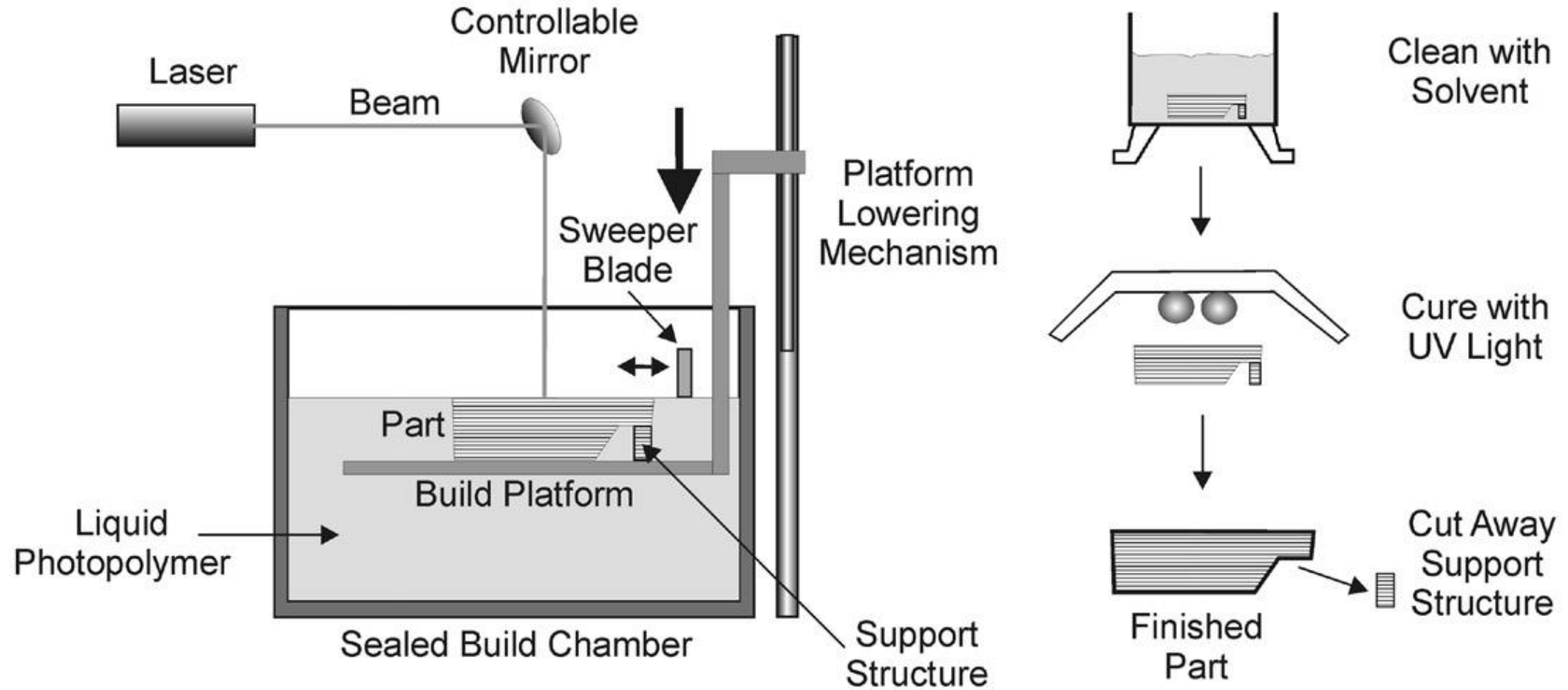
Using a labelled diagram, explain the principles of **Stereolithography** (SLA) and how it works.

(10 marks)

- ***Process Description***

- A low-power laser beam is directed by a mirror to trace a thin 2D cross-section in a liquid photopolymer resin that is stored in a build chamber.
- Through the process of photopolymerisation, a layer of hardened and cured 3D pixels of polymer are created, a process which only takes place near the surface due to absorption and scattering of the laser beam.
- The build platform is lowered down an amount equal to the thickness of the previously cured layer, and a sweeper blade moves across replenishing a layer of resin.
- The laser traces out the next 2D cross-section and the process is repeated.
- The self-adhesive property of the material used causes the layers to bond and, after many layers have been cured, a 3D part is built up.
- The completed part is drained, washed in solvent to remove excess resin and subjected to UV light to cure the component completely,
- Support constructions are removed by cutting

Stereolithography.



Revision question 2

Discuss the strengths and weaknesses of **additive** manufacturing methods in relation to traditional methods giving appropriate examples of applications.

(10 marks)

1. Additive methods build up the part in layers to the correct shape, therefore using less material than a traditional method such as milling, sawing, grinding, turning, that cuts away material from a block to achieve the required shape.
2. The waste material from traditional methods is the same as the workpiece, ie wood, metal and can therefore be recycled. However AM processes like Stereolithography(SLA) that require support structures will produce waste material from polymer resin that can not be recycled.
3. Surface finish in additive processes such as SLA is better than traditional processes without secondary processing such as polishing. This is due to tool wear, machine vibrations, material inhomogeneity and other tool related factors?
4. Traditional methods require direct contact of tool and workpiece therefore incurring tool wear
5. AM is more accurate and precise than traditional methods

6. There is no noise pollution with AM, unlike traditional methods

7. There is a long Tool life for AM as the tool does not contact the workpiece

8. AM has a complex set up so requires skilled operators

9 Spare parts easily available for traditional tools, unlike AM

10. The speed of subtractive processes such as EBM is superior to AM making it ideal for drilling many small diameter holes in both thin and thick materials. 4000 holes of 0.9mm diameter can be drilled in 60 minutes can be drilled with EBM, a large part may take a whole day in SLA

11. The minimum layer thickness in SLA is 0.025mm and the minimum section is 0.1mm. Subtractive methods like EBM can produce a cavity with a diameter of 35µm.

12. Achievable tolerances in EBM are in the range ± 0.013 to ± 0.125 mm.

13. SLS is only suitable for small production runs <50,

Revision question 3

Discuss the strengths and weaknesses of **additive** manufacturing methods in relation to **subtractive** methods giving appropriate examples of applications.

(10 marks)

1. Additive methods build up the part in layers to the correct shape, therefore using less material than a subtractive method such as EBM that cuts away material from a block to achieve the required shape.
2. However AM processes like Stereolithography that require support structures will produce waste material from polymer resin that can not be recycled.
3. Surface finish in additive processes such as SLA is not as good as in the subtractive EBM
4. The speed of subtractive processes such as EBM is superior to AM making it ideal for drilling many small diameter holes in both thin and thick materials. 4000 holes of 0.9mm diameter can be drilled in 60 minutes can be drilled with EBM, a large part may take a whole day in SLA
5. The minimum layer thickness in SLA is 0.025mm and the minimum section is 0.1mm. Subtractive methods like EBM can produce a cavity with a diameter of 35µm.
6. Achievable tolerances in EBM are in the range ± 0.013 to ± 0.125 mm.
7. SLS is only suitable for small production runs <50,

Revision question 4

Describe the process of **Electron Beam Machining (EBM)**
(10 marks)

Compare and contrast the following:

- i. **Selective Laser Sintering (SLS)**
- ii. **Laser Engineering Net Shaping (LENS)**

(10 Marks)

Revision question 5

A manufacturer is looking at updating its manufacturing processes, discuss in detail and evaluate how this industry could use **subtractive** and **additive** manufacturing for rapid prototyping. How will this give greater freedom of design and improve the “Time-to-market”? (10 marks)