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3-D Printing Technologies and Processes – A Review

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Abstract: Adaptation of 3-D printing technology in manufacturing of proto-typing is increasing rapidly in customized low volume components. 3-D printing encompasses a wide range of additive manufacturing technologies, each of these builds objects in successive layers that are typically about 0.1 mm thin.The medical application for this technology is a promising and its usefulness with various advantages makes it very close to real time ones. There have many researches carried out in this field but various names have been suggested for near and very similar technologies. In this review an attempt is made to make out clear classification and categorization of the processes among various researches down the history.

Key Words: *ASTM, 3-D Printing, Vat Photopolymerisation, Powder Bed Fusion, Binder Jetting, Material Jetting, Sheet Metal Lamination, Material Extrusion, Direct Energy Deposition.*

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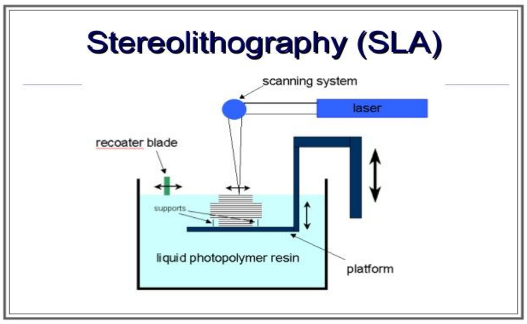
I. INTRODUCTION

Additive manufacturing process and equipment was initially developed by Hideo Kodama of Nagoya Municipal Industrial Research Institute invented two additive methods for fabricating three-dimensional plastic models with photo-hardening thermo set polymer, where the UV exposure area is controlled by a mask pattern or a scanning fiber transmitter however the patent was on name of chuck Hull. His patent was for a stereo lithography fabrication system, in which layers are added by curing photopolymers with ultraviolet light lasers. He defined the process as a "system for generating three-dimensional objects by creating a cross-sectional pattern of the object to be formed". Hull's contribution was the STL (Stereo lithography) file format and the digital slicing and infill strategies common to many processes today.Anddown the history many processes of additive manufacturing are explored and patented on different names. In 2012 year ASTM has classified the additive manufacturing technologies into seven categories depending on the raw material and energy used in the process. They are, i) Vat Photopolymerisation ii) Powder Bed Fusion iii) Binder Jetting iv) Material Jettiingv) Sheet Metal Laminationvi) Material Extrusion vii) Direct Energy Deposition. In the following sections they are discussed in detail.

1. VAT PHOTOPOLYMERISATION: A 3D printer based on the Vat Photopolymerisation method has a container filled with photopolymer resin which is then hardened with UV light source on selected path up to some depth.[4]. According ASTM F2792 standards the alternative names for VAT Photopolymerisation may be listed as,a). Stereo lithography Apparatus-SLA b). Digital Light Processing -DLP c). Scan, Spin, and Selectively Photo cure-3SP d). Continuous Liquid Interface Production-CLIP [5]. But there exist differences in methodological processes. The following section gives an oversight on them.

1.1. Stereo Lithography Apparatus (SLA): Using a single and optics. Blades or recoating blades pass over previous to ensure that there are no defects in the resin for the construction of the next layer. The photo-polymerization process and support material may have likely caused defects such as air gaps, which need to be filled with resin in order, achieve a high quality model. Typical layer thickness for the process is 0.025 – 0.5mm.[7]



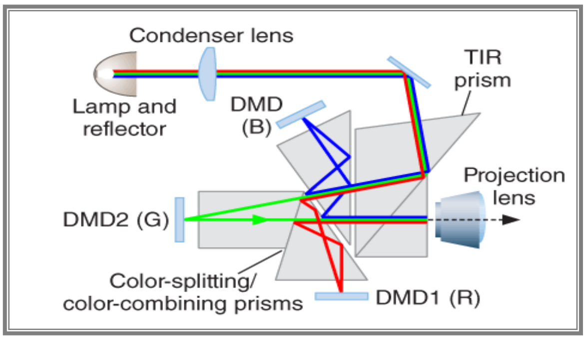


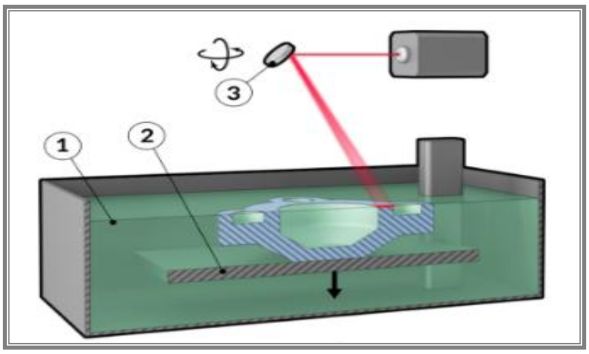
Fig. 1.1 Stereo Lithography **[**videoeffectsprod.com]

Fig. 1.2 Digital Light Processing

1.2. Digital Light Processing (DLP): In this process, once the 3D model is sent to the printer, a vat of liquid polymer is exposed to light from a DLP projector under safelight conditions. The DLP projector displays the image of the 3D model onto the liquid polymer. The exposed liquid polymer hardens and the build plate moves down and the liquid polymer is once more exposed to light. The process is repeated until the 3D model is complete and the vat is drained of liquid, revealing the solidified model. DLP 3D printing is faster and can print objects with a higher resolution. [6]. Larry Hornbeck of Texas Instruments created the technology for Digital Light Processing in 1987. DLP is used for projectors and uses digital micromirrors laid out in a matrix on a semiconductor chip called the Digital Micromirror Device. Each mirror represents a pixel in the image for display. Several applications use DLP technology including projectors, movie projectors, cell phones, and 3D printing.[6]

1.3. Scan, Spin, and Selectively Photo cure (SSP): SSP a group of 3D printingtechnologies enabling the generation of complex 3D structures for engineering applications[1].Objects are built in a tank filled with liquid photopolymer [1-**Fig 1.1(c):**], which is a plastic which reacts to light. An adjustable construction platform [2-**Fig 1.1(c):**] is initially placed in its highest position, only covered by a thin layer of photopolymer. A movable mirror [3-**Fig 1.1(c):**] controls the ultraviolet laser beam, and draw out the cross section of a CAD model on the platform which solidifies the plastic. The platform is lowered so that the previous layer is now covered by a new, thin layer of liquid. The laser beam solidifies a new layer which is then joined with the previous layer. Support structures can be created if needed, if the liquid cannot support the weight of the components overhanging parts. The process is repeated until the object is completed and the finished part is usually cleaned by ultrasound and alcohol. Support structures are removed and the object is cured in a UV oven. Non solidified liquid can be recycled to produce new items. Small tolerances and high surface finish minimizes the need for post-processing.

1.4.Continuous Liquid Interface Production (CLIP): Instead of printing objects by stacking thin layers on top of one another—a process that can take days, depending on what you're printing—they built a device that produces a complete object from a pool of goop. Their machine is called CLIP, which is an acronym for what it does: "continuous liquid interface production." It pulls a new, fully formed object out of liquid resin by shining an ultraviolet light beneath the pool. The UV projector is connected to a computerized blueprint of the object. One cross-section at a time, the light solidifies a silhouette of the object. The UV light moves through a contact lens-like window between the liquid and the light projector.Theprimaryadvantage of a CLIP fabrication is its ability to create almost any complx shape or geometric feature. [3]



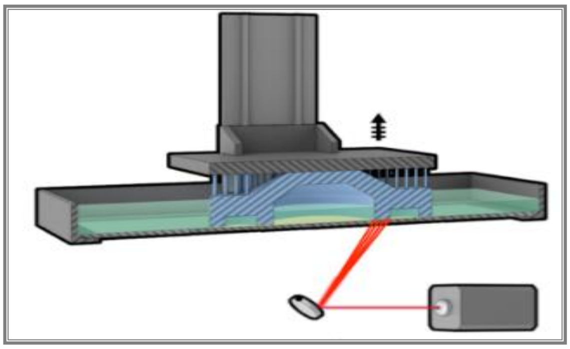


Fig 1.1(c): Scan, Spin & Selectively Photo cure

Fig1.1(d): Continuous Liquid Interface Production Source:www.manufacturingguide.com

II. POWDER BED FUSION

According ASTM F2792 standards the alternative names forPowder Bed Fusion may be listed as,1). Selective Laser Sintering2).Direct Metal Laser Sintering 3).Selective Laser Melting4).Electron Beam Melting5).Selective Heat Sintering. But there exist differences in methodological processes. The following section gives an oversight on them.

2.1. Selective Laser Sintering -SLS

Selective laser sintering is an intelligent manufacturing process based on the use of powdercoatedmetal additives, a process generally used forrapid prototyping and instrumentation. A continuousLaser beams are used or pulsating as heating source forscanning and aligning particles in predetermined sizesand shapes of the layers. The geometry of the scannedlayers corresponds to various sections of the modelsestablished by computer-aided design (CAD) or fromfiles produced by stereo-lithography (STL). Afterscanning the first layer, the scanning continues with thesecond layer which is placed over the first, repeatingthe process from the bottom to the top until the productis complete.[8]

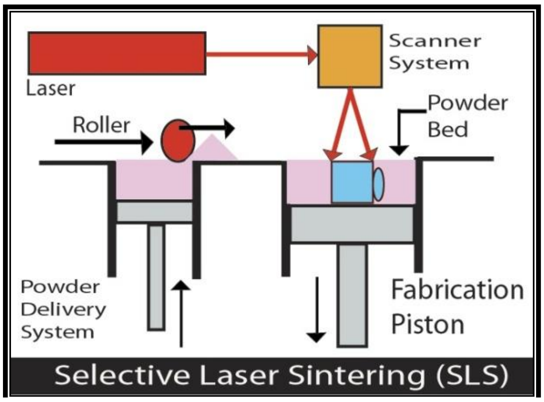


Figure 2.1: Selective Laser Sintering -SLS. (http://just3d.in/index.php/sls/)

2.2. Direct Metal Laser Sintering -DMLS

Selective Laser Sintering and Direct Metal Laser Sintering are essentially the same processes, with SLS used to refer to the process as applied to a variety of materials—plastics, glass, ceramics—whereas DMLS refers to the process as applied to metal alloys. But what sets sintering apart from melting or "Cusing" is that the sintering processes do not fully *melt* the powder, but heat it to the point that the powder can fuse together on a molecularlevel. And with sintering, the porosity of the material can be controlled.

2.3. Selective Laser Melting-SLM

Selective Laser Melting(SLM), on the other hand, can do the same as sintering--and go one further, by using the laser to achieve a full melt. Meaning the powder is not merely fused together, but is actually melted into a homogenous part. That makes melting the way to go for a mono material, as there's just one melting point. To nutshell it, SLS or DMLSare suitable for working of alloy of some sort; SLM.is suitable for working of single metal.[10]

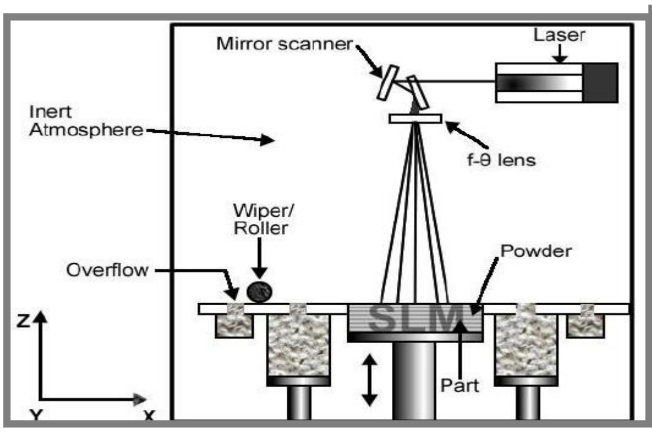


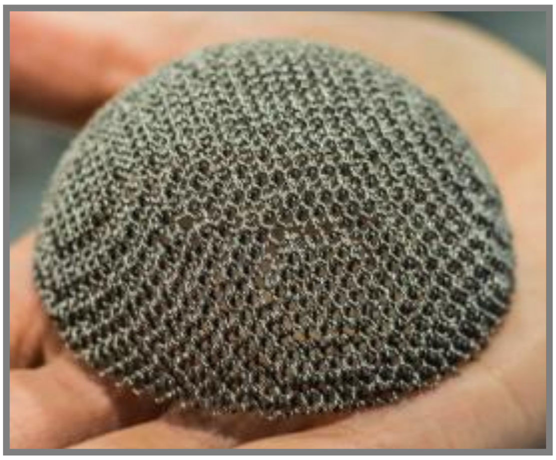
Fig.2.3(a). Schematic Diagram for LSM process Fig.2.3(b).Components produced by DMLS
(source: http://www.incept3d.com/dmls--metal.html)

2.4. Electron Beam Melting -EBM

Electron Beam Meltingis an additive manufacturing process same as Selective Laser Melting. But he energy source use is Electron beam gun to melt metal powder at 70 micron layer thickness, and builds solid details that have homogeneous material structure.[9]

2.5. Selective Heat Sintering- SHS

As shown Figure ---, the SHS process operates by selectively fusing a thin layer of polymer powder via a thermal print head assembly. This assembly, which operates bidirectionally, incorporates thermal printheads (a), powder deposition mechanisms (b), and layer heaters (c). Material is built up in an internal build volume (d), the floor of which is a vertically movable build platform (e). Fresh powder is supplied via scoops to the powder deposition mechanism from powder containers (f). The print head assembly is separated from the build surface by a thermally conductive sheet (g). This sheet is fed from a fresh sheet roll (h) to a used sheet roll (i) during the process.[11]



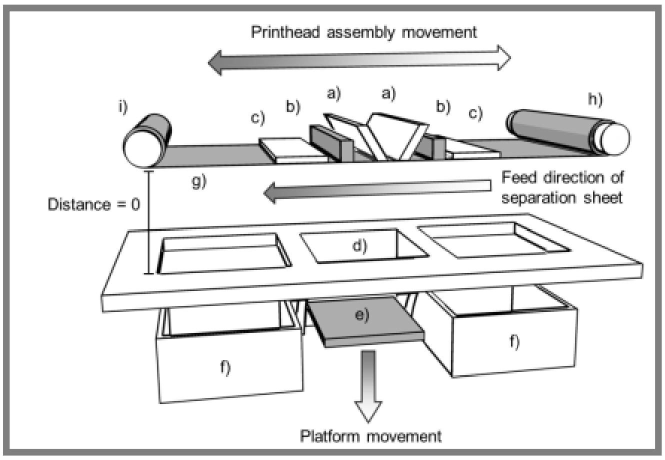


Fig.2.4. Components produced by EBM (https://additivemanufacturingllc.com)

Fig.2.5. Schematic of the SHS process(SHS1)

III. BINDER JETTING

Binder jetting uses a print head to selectively spray a binder (or in other words glue) onto successive layers of power. Many binder jetting 3D printers spray coloured inks as well as the binder onto their powder layers, so allowing them to produce full colour output. Most commonly the powder used in binder jetting is a gypsum-based composite that needs to have its surface coated after printout if a robust object is required. Yet other binder jetting hardware can build objects by sticking together sand or powdered metals. Where a binder is sprayed onto sand, the final object is used as a sand cast mold or pattern, into which molten metal is poured. Once the metal has cooled solid, the sand is then broken away[12].

Binder jetting metal printing has been developed by a company called Ex-One (who also make 3D printers that binder jet sand cast molds). Here a layer of bronze, stainless steel or Inconel powder is laid down and a print head moves across it to selectively spray on a binder solution. A heating lamp then dries the layer, a fresh layer of powder is rolled over it, and the process repeats. Once all layers have been output, the object is then placed in an oven to fully cure the binder. At this stage the object is still very fragile, but is put in a kiln where it is infused with additional metal powder. The final result is a very solid object that is a least 99.9 per cent solid metal.

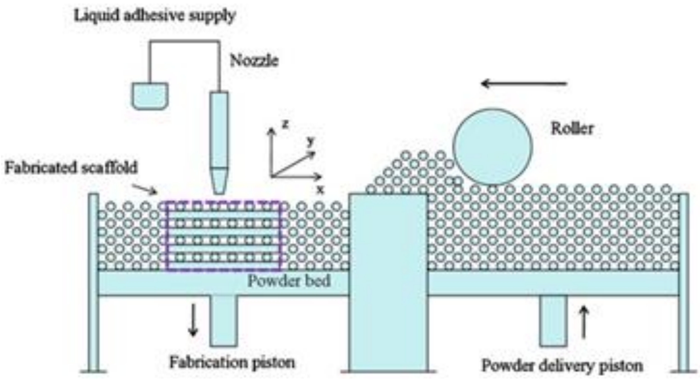


Fig.3.1. Schematic figure for Binder Jetting (Source:www.fuzehub.com)

IV. MATERIAL JETTIING

Material Jetting is one of the standard 3D printing technologies that has scope and design pattern suitable for the desktop version of 3D printers as industrial 3D printers. The technology fabricates a 3D part just like an inkjet printer prints a two-dimensional image. The 3D model is built on a target surface to which droplets or continuous fluids of the building material are dropped layer by layer and each layer is then cured with ultraviolet radiation to get it solidified[13]. The term "Drop on Demand (DOD)" is used for referring the drop by drop wise fabrication of 3D model in the technology's context.The synonyms of Material Jetting are Multi-jet modelling, Drop On Demand (DOD), Thermojet and Polyjetjet printing**.**

A typical apparatus for material jetting 3D printing has printer head consisting of two nozzles and an UV source. One nozzle is used to jet the building material while another nozzle is used for jetting the support material. The support material is not the part of the model but is usually deposited along the building material to keep the model in fixed orientation while it is 3D printed. Both the building material and support material deposit on a platform layer by layer. The support structure is built from such material choices that they can be removed after finishing the fabrication of the model. So the printer head deposits a computer controlled sequence of building material as well as support material layer by layer while the UV source directs radiation towards the immediately deposited material droplet (either building or support material) to solidify it with the adjacent droplet. Once the model is finished, it is allowed to cool and hardened. Later on, the support structures are scratched off. Support material can be removed using a sodium hydroxide solution or water jet.A common problem with these support materials is that their removal results in “witness marks” on the surfaces with which they are attached [14]. Materials used are Photopolymers/thermoset plastic or wax-like materials for investment casting patterns [15].

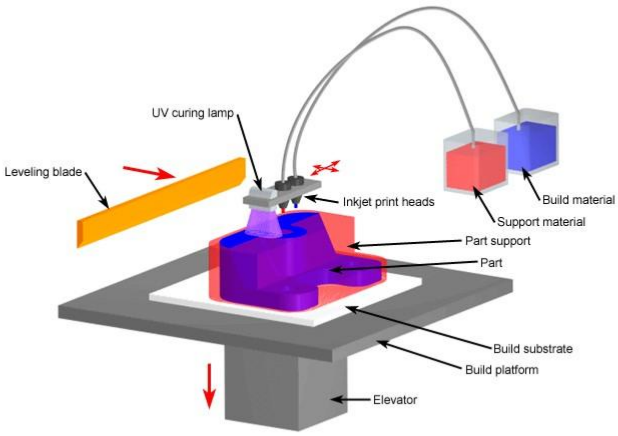


Fig.4.1. Schematic figure for Material Jetting

The Advantages byMaterial Jetting may be summarized as,this process benefits from a high accuracy of deposition of droplets and therefore low waste and the process allows for multiple material parts and colours under one process. And the Disadvantages are found as, the support material is often required and an high accuracy can be achieved but materials are limited and only polymers and waxes can be used.

4.1. Multi-Jet Modelling

There is another product of 3D Systems from the makers of the SLA system, Multi-Jet Modellinguses a 96-element print head to deposit molten plastic for layering. The system is fast compared to most other additive manufacturing techniques, and produces good appearance models with minimal operator effort [16]. The main market that this system is targeted at is the engineering office where the system must be non-toxic, quiet and small. The system is illustrated below.

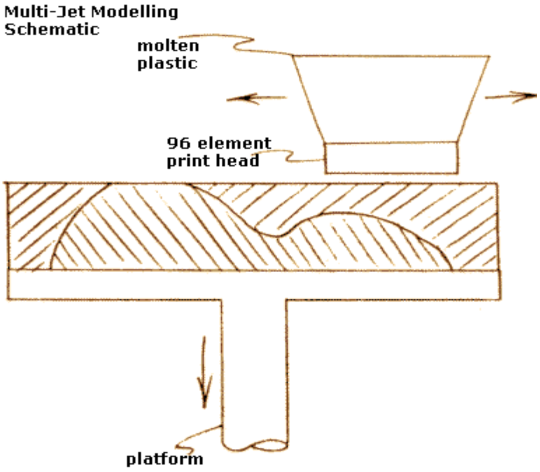


Fig.4.1.1. Schematic figure for Material Jetting

Fig.4.1.2. Objects made by Material Jetting Process.

V. SHEET LAMINATION

It is one of the seven recognized 3D Printing methods in which sheets of material are bonded to form an object. The sheets of building material are cut through laser or knife and then joined one after the other either by using an adhesive or by wielding to form the 3D object. The process is also called ultrasonic additive manufacturing (UAM) or Ultrasonic Consolidation (UC), in this process the building material used is metal sheets. But as per the researches available, if paper is used for making the 3D models then it is known by the name - Laminated Object Manufacturing (LOM).

5.1. Ultrasonic consolidation: It is a solid-state manufacturing process that combines additive joining of thin metal tapes with subtractive milling operations to generate near net shape metallic parts. A rotating sonotrode driven by piezoelectric transducers applies ultrasonic vibrations (>20 kHz) to a foil, creating a scrubbing action and plastic deformation between the foil and the material to which it is being welded, often a metallic base plate, a part, or other foils. The scrubbing action displaces surface oxides and contaminants while collapsing asperities, exposing nascent surfaces that instantaneously bond under a compressive force. A CNC stage allows for selective material removal and machining to final dimensions, though the low thermal loading in UAM implies that finished parts suffer no distortion, and hence no remedial machining is required. Similarly to ultrasonic welding, UC requires less thermal energy than other liquid-phase direct fabrication techniques and, as a result, there are less residual stresses and thermal distortion in the resulting components[17].

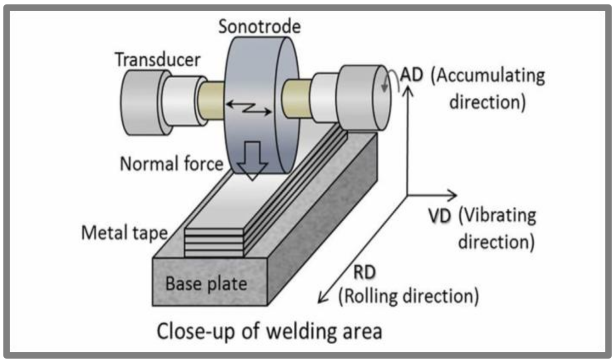


Fig. 5.1(a): Welding phase

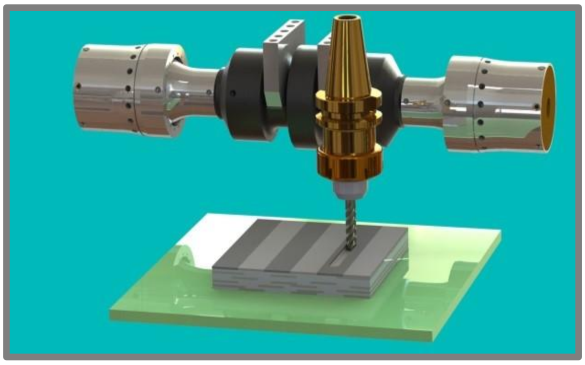
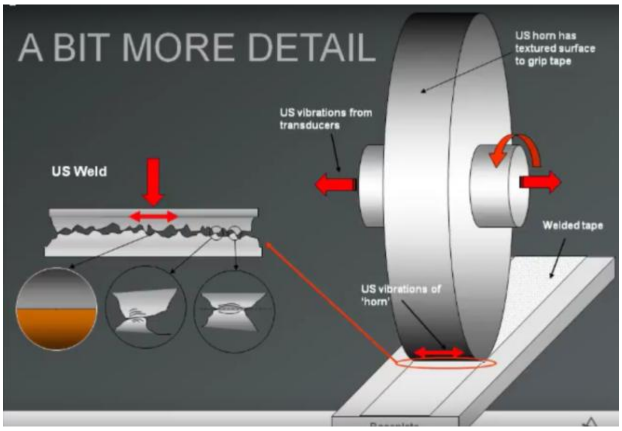


Fig. 5.1 (b): Machining phase



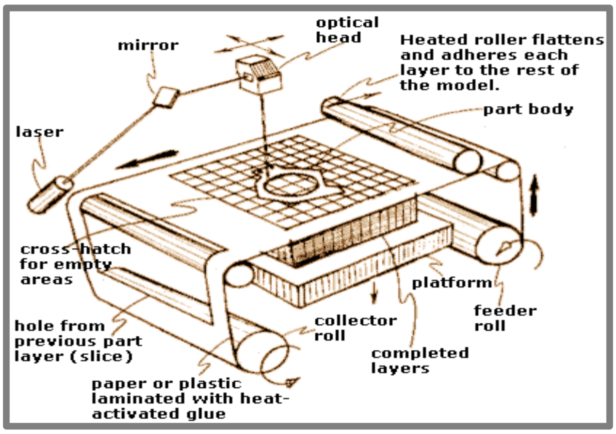


Fig. 5.2(a) Detail view of Ultrasonic WeldingFig.5.2(b) Schematic diagram of LOM.

5.2. Laminated object manufacturing -LOM: Itis a rapid prototyping system developed by Helisys Inc. Itis one of the first additive manufacturing techniques created and uses a variety of sheet material the paper which is readily available and inexpensive leading to a simple and inexpensive setup. Laminated object manufacturing uses layer by layer approach similar to UAM but uses paper as material and adhesive in place of welding. In it, layers of adhesive-coated paper, plastic, or metal laminates are successively glued together and cut to shape with a knife or laser cutter. Objects printed with this technique may be additionally modified by machining or drilling after printing. Laminated objects are often used for aesthetic and visual models and are not suitable for structural use.The LOM is usedextensively for tooling and manufacturing by producing patterns and masters for sand casting, investment casting, cavity moulds for injection, and tools for thermal forming and prototype stamping [18].

Fig. 5.3: Objects made from LOM process.

Advantages and Disadvantages of sheet lamination are listed as, a).Benefits include speed, low cost, ease of material handling, but the strength and integrity of models is reliant on the adhesive used. b). Cutting can be very fast due to the cutting route only being that of the shape outline, not the entire cross sectional area. c).Finishes can vary depending on paper or plastic material but may require post processing to achieve desired effect d). Use of material is limited and e). Fusion processes require more research to further advance the process into a more mainstream positioning.

5.3. Selective Deposition Lamination -SDL: SDL is a proprietary 3D printing process developed and manufactured by Mcor Technologies. There is a temptation to compare this process with the Laminated Object Manufacturing (LOM) process developed by Helisys in the 1990's due to similarities in layering and shaping paper to form the final part. The SDL 3D printing process builds components layer by layer using standard copier paper. Each new layer is fixed to the previous layer using an adhesive, which is applied selectively according to the 3D data supplied to the machine. This means that a much higher density of adhesive is deposited in the area that will become the part, and a much lower density of adhesive is applied in the surrounding area that will serve as the support, ensuring relatively easy "weeding," or support removal[19].After a new sheet of paper is fed into the 3D printer from the paper feed mechanism and placed on top of the selectively applied adhesive on the previous layer, the build plate is moved up to a heat plate and pressure is applied. This pressure ensures a positive bond between the two sheets of paper. The build plate then returns to the build height where an adjustable Tungsten carbide blade cuts one sheet of paper at a time, tracing the object outline to create the edges of the part. When this cutting sequence is complete, the 3D printer deposits the next layer of adhesive and so on until the part is complete.

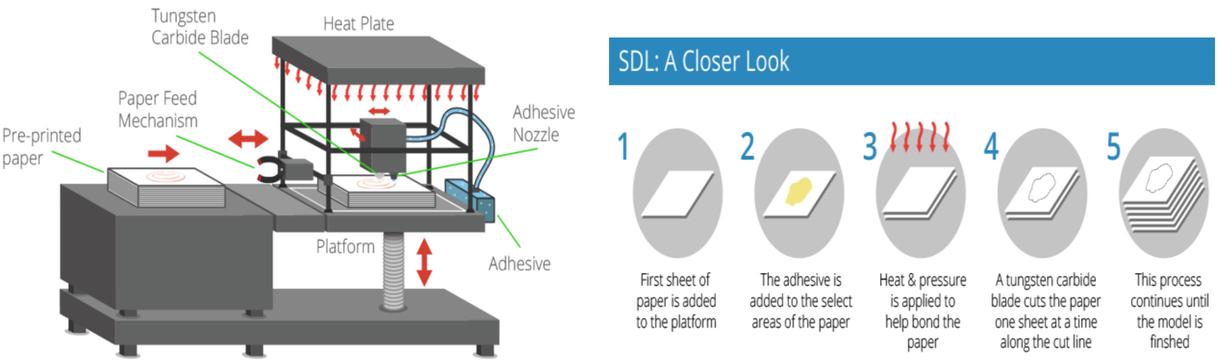


Fig:5.4(a) Selective Deposition Lamination

Fig:5.4(b) Parts made by SDL process.

To examine SDL more closely we further make a survey in detail in the details of the process in stages which justifies the name **Selective Deposition Lamination**- SDL. The terms in the name are named with the following meaning **i) Selective:** This is arguably the most important word in the phrase and refers to the selective method that the printer uses in depositing the adhesive to bond the sheets of paper. A much higher density of adhesive drops are deposited in the area that will become the part, and a much lower density of adhesive is applied in drops in the surrounding area that will serve as the support. This results in very quick and easy weeding or excavation of the part out of the supporting paper when printing is complete. In LOM process, *everything* was glued together, including the support material around the model with the same intensity. Excavating the model was an ordeal, often resulting in part breakage.**ii) Deposition:** Deposition refers to the method of applying the adhesive in droplets onto a sheet of ordinary paper following the cutting of the profile of the part in that sheet. This is quite different from the LOM process where the adhesive was pre-applied to the proprietary material in equal amounts across the entire surface of the material before cutting took place[20].**iii)**

Lamination: Lamination describes the process of building up successive layers of a substance – in our case, regular office paper – and bonding them to form a durable finished product. Although prototypes built with our printers are made from ordinary paper, they are incredibly durable! They don't have to be post-processed to make them strong; one can safely use them right out of the printer. They are not brittle and therefore don't break or shatter when dropped, and if desired, they can be drilled, threaded, tapped or made water resistant with a quick dip in a sealant.

VI. MATERIAL EXTRUSION

The 3D printer builds a 3D object, layer by layer, by melting a material from a computer controlled nozzle. The material extrusion of thermoplastics was developed by StratasysCompany. Stratasys named this technology as "fused deposition modeling- FDM", and has trademarked the term. Since then, the term FDM has become widely use to generally mean the extrusion of thermoplastics. The company 3D Systems also refer to the same technology as Plastic Jet Printing- PJP. Other names available in the literature for the material extrusion process are i).Fused Filament Modeling -FFMii). Melted and Extruded Modeling -MEM iii).Fused Filament Fabrication-FFF, and iv). Fused Deposition Method-FDM.[21].

6.1. Fused Filament Fabrication -FFF

Fused Filament Fabrication is a term coined byRep -Rap project which is an open source project for development of low-cost and affordable desktop 3D printers. This project supplies Free and Open Source Hardware (FOSH) to 3D printers. The process of Fused Filament Fabrication is almost similar to that of the Fused Deposition Modeling except that terms used to recognize various parts of the 3D printer and names for process specifications are different. The extrusion assembly where the feed is melted is referred as "Liquefier" and the layer paths deposited are called "Roads". In most of the FFF printers the thermal environment of the chamber is specifically maintained to a temperature only slightly lower than that of the glass transition temperature of the material.The Material Extrusion process uses polymers and plastics. Polymers in use are ABS, Nylon, PC, PC, AB. And the advantages ofMaterial Extrusion process may be listed as, a) Widespread and inexpensive process b). ABS plastic can be used, which has good structural properties and is easily accessible. And the Disadvantages of Material Extrusion process may be listed as, a).The nozzle radius limits and reduces the final quality. b). Accuracy and speed are low when compared to other processes and accuracy of the final model is limited to material nozzle thicknessc). Constant pressure of material is required in order to increase quality of finish. d). Main disadvantage that governs the FDM technique is the ineffectiveness of the system to produce part quickly as that of other technology.

6.3. Fused Deposition Modeling-FDM

The technology was developed and patented in 1980's by S. Scott Crump. Later, Crump started a company - Stratasys in 1988 which trademarked the term "Fused Deposition Modeling".Fuse deposition modeling (FDM) is a common material extrusion process in which material is drawn through a nozzle, where it is heated and is then deposited layer by layer. The nozzle can move horizontally and a platform moves up and down vertically after each new layer is deposited. It is a commonly used technique used on many inexpensive, domestic and hobby 3D printers.FDM uses two materials to execute a print job: modeling material, which constitutes the finished piece, and support material, which acts as scaffolding[22]. Support structures must be designed and fabricated for any overhanging geometries and are later removed in secondary operations. Several materials are available for the process including a nylon-like polymer and both machinable and investment casting waxes. The introduction of ABS plastic material led to much greater commercial acceptance of the method. It provided better layer to layer bonding than previous materials and consequently much more robust fabricated objects. Also a companion support material was introduced at that time which was easily removable by simply breaking it away from the object. Water-soluble support materials have also become available which can be removed simply by washing them away. The recent introduction of polycarbonate and poly(phenyl)sulfonemodelling materials have further extended the capabilities of the method in terms of strength and temperature range. Several other polymer systems as well as ceramic and metallic materials are under development.These materials are used for their heat resistance properties. Ultem 9085 also exhibits fire retardancy making it suitable for aerospace and aviation applications[23]. The disadvantage of the FDM technique is the ineffectiveness of the system to produce part quickly as that of other technology.The build time for a given print can be reduced by positively decreasing the layer thickness and negatively reducing the infill density[24].

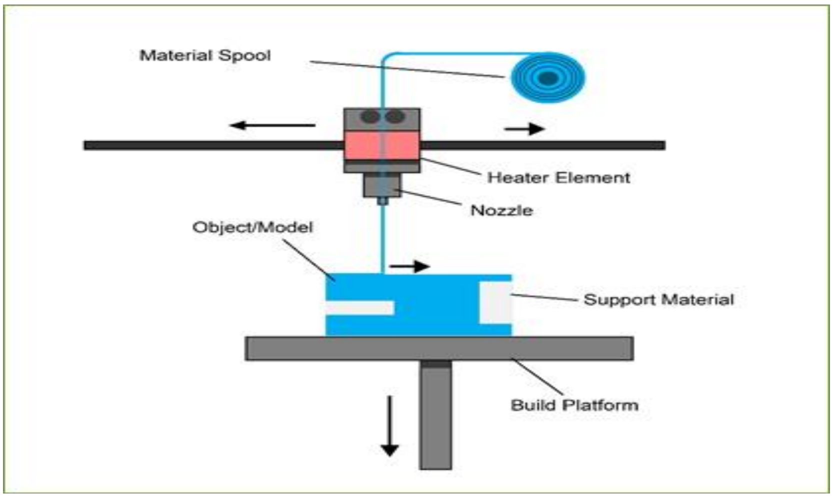


Fig. 6.1. Schematic diagram of FDM

Fig. 6.2. Parts made by FDM process.

VII. DIRECT ENERGY DEPOSITION-DED

It is one of the seven categories of AM processes; directed energy deposition (DED) is suitable for producing metal parts via the layer-by-layer deposition of molten metal powders or filament. It employs energy-intensive source (e.g. normally a laser or an electron beam) to generate a melt pool on the substrate into which metal powder or filament is injected. The molten pool follows a specified route to move on and fill the top of substrate and progressively build up and deposit the part according to designed CAD geometry. Many AM technologies involve in this standard category, such as laser metal deposition (LMD), laser-engineering net shaping (LENS), direct metal deposition (DMD), Direct Laser Deposition (DLD), laser consolidation, laser cladding, laser deposition welding and powder fusion welding, many of which are trademarks of various machine manufacturers or research establishments. It is worthy to note that the local high-energy in DED process will affect the microstructure, deposited material properties, residual stress state and thermal-induced distortion of the final part.Inconel 625 is a promising material that can be used in a hybrid process with DED and cutting [25].

7.1. Laser metal deposition -LMD

Laser metal deposition is a technology to create a metallurgically bonded material deposition on a substrate. The technology is shown in figure 1. A laser beam is used to melt the surface of a specimen. A powdery filler material is injected in the molten pool. After solidification, the filler material forms single weld beads[26].

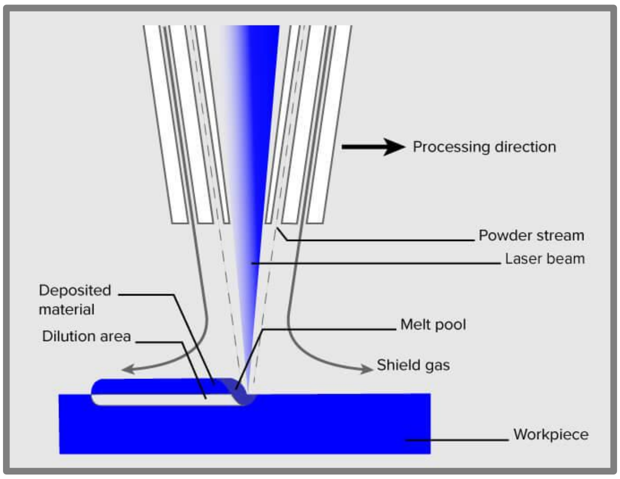


Fig.7.1. Laser Metal Deposition

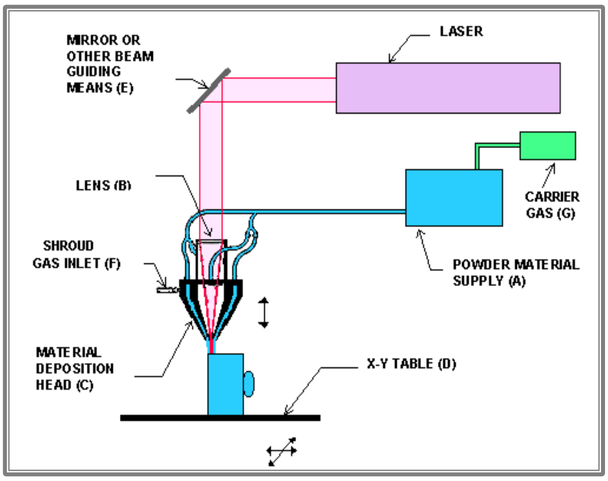


Fig.7.2. Schematic diagram of LENS (http://ac.els-cdn.com/)

7.2. Laser Engineered Net Shaping –LENS

Laser engineered net shaping is a laser additive manufacturing process that uses highpower laser as a heat source to create a melt pool on the surface of a solid substrate and melt metal alloy powders through powder feeding nozzles. Not only can it fabricate a complex, functional, and structural part, but also can be used for surface treatment such as coating, hard facing, as well as repairing worn and damaged parts. Additionally, it has shown excellent metallurgical bonding to the substrate with a minimum heat affected zone (HAZ) compared to other surface coating processes such as high-velocity oxy fuel spraying (HVOF), plasma spraying (PS), or tungsten inert gas (TIG) welding[27].

In this additive manufacturing process, a part is built bymelting metal powder that is injected into a specific location. It becomes molten with the use of a high-powered laser beam. The material solidifies when it is cooled down. Theprocess occurs in a closed chamber with an argon atmosphere. This process permits the use of a high variety of metals and combination of them like stainless steel, nickel based alloys, titanium-6 aluminium-4 vanadium, tooling steel, copper alloys, and so forth. Alumina can be used too. This process is also used to repair parts that by other processes will be impossible or more expensive to do. One problem in this process could be the residual stresses by uneven heating and cooling processes that can be significant in high precision processes like turbine blades repair [28].

7.3. Direct metal deposition –DMD

Direct metal depositioncombines powder metallurgy, laser, nozzle and numeric control technologies. Similar to SLS and SLM, laser metal deposition uses a high-power laser beam for layer fabrication. However, instead of dispensing beds of powder over a movable platform inside a containing chamber, the powder is delivered remotely to a metallic substrate via a supply nozzle [29]. This characteristic implies that the powder, same as the laser beam, can be freely delivered in any orientation, be it vertical, horizontal or inclined. A robotic arm can be used for these purposes. A high power CO2 laser beam is made to scan over a metal base. As the laser beam generates a small melt pool on the substrate, the powder delivered through a nozzle is melted and fused to the melt pool and bonded to the substrate as a line or track of newly added material. The process continues with the laser scanning according to pre-defined programming of the CNC system or robotic arm without the need for intermediate operations.It is worth noting that the DMD technology developedbyMazumder's group at the University of Michigan is equipped with a feedback system that provides a closed loop control of dimensional accuracy during the deposition process. The feedback loop is, thus, regarded as a unique feature of DMD.

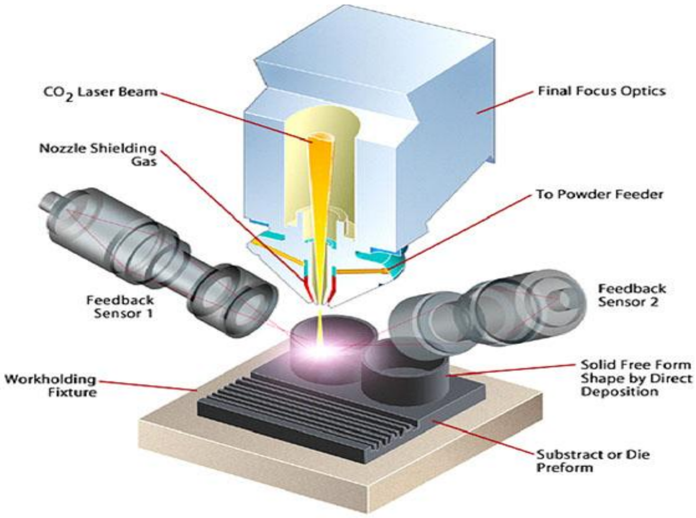


Fig.7.3 (a).**Direct metal deposition –DMD**

Experimental researches have been carried out using the metal powder of the base alloys: nickel,including heat resistant (Inconel 625), cobalt, including high strength (Stellite 6), chromium, iron, copper and titanium[30]. The future plans are to include studies of process with powders based on aluminium alloys. Examples of samples of deposition of products are presented in below figure 7.3 (b).

The DMD process can be used for prototype or production tooling in a variety of industrial applications, including:

• **DIE REPAIR AND REFURBISHMENT** - Downtime costs can mount quickly when a mould or die cracks or becomes worn. The DMD process is the only existing method that can repair, reconfigure or resurface existing parts, moulds or dies by adding metal that matches the parent tool.

• **THERMAL MANAGEMENT** - The DMD process provides the ability to produce cooling channels, for injection moulding and aluminium die cast cavities.

• **DIRECT METAL PROTOTYPES** - Manufacturing companies can now produce rapid metal prototypes instead of plastic SLA (steriolithography) models. Using DMD, it is possible to make a fully functional prototype directly from the CAD design.

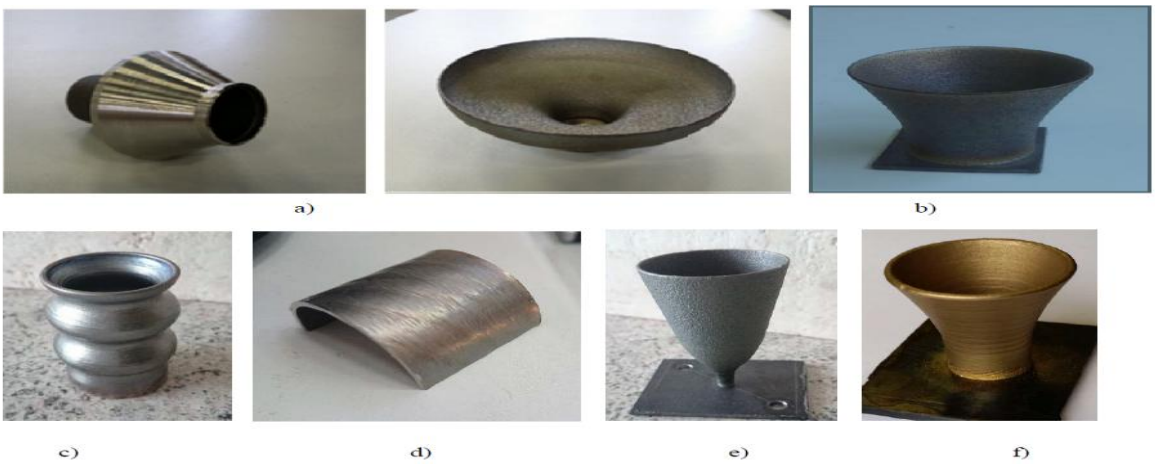


Fig.7.3 (b).**Samples of the deposition products**
a) Fe alloy: EuTroloy 16316.04; b) Co alloy: EuTroloy 16006.04;
c) Ni alloy :EuTroloy 16496.04; d) Ni alloy (experimental alloy of ODC);
e) Ni alloy: EuTroloy 16625.04; f) Cu alloy: BronzeTec 19868 (80Cu-15Al-5Ni).

• **SURFACE MODIFICATION AND COATINGS -** DMD can improve wear resistance, corrosion resistance, and heat checking of part surfaces through the deposition of a wear resistanthard-facing layer.

• **AEROSPACE AND AIRCRAFT COMPONENT REPAIR** - The DMD process is ideally suited for repair work in the aerospace industry, due to the strong metallurgical bond and fine, uniform microstructures it can produce.

VIII. CONCLUSIONS:

In the content of the paper an effort is made to highlight the importance of 3-D printing after thorough review among the research contributors in the field and the following conclusions are drawn.
i).The clear classification for additive manufacturing is identified and studied accordingly.
ii).The advantages and disadvantages among various methods are clearly identified.
iii).The suitability for the type of product manufacturing is marked out clearly.

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