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Fused Deposition Modeling

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Abstract - *Additive manufacturing (AM) technique using three-dimensional computer aided design (CAD) data. AM technique are mainly classified into solid based AM, liquid based AM, & powdered based AM system. From these various sorts of system solid based RP processes are mostly used thanks to effectiveness & their ability to creating impossible geometries possible. In this review paper an effort has been made to point out the small print of one of the solid based RP system process i.e. Fused Deposition Modeling*

***Key Words*: Fused Deposition Modelling (FDM), Filament, Extrusion, Additive Manufacturing (AM), Printing and etc.**

1. INTRODUCTION

The Manufacturing technology is basically moving towards unpredictable change over the century. Nowadays, product cycle life within the evolution stage itself is completely reduced to the minimum most level from years to months. This gives new development strategies likely to be in sequential development that's each individual component production time to scale back from months to weeks. The research and development team focus only on automation to travel in line with the fast phase growth. The current trend in the manufacturing industry is Additive Manufacturing (AM). It's been evolving in much high rate, the complex products are developed within the days and even this can be improved from one product to other product in the design phase itself instead of product testing phase.[1]

In today's modern manufacturing industry, the cycle time taken to produce the product is important along with the part quality. 'Rapid Tooling (RT)' is one of the prominent applications of Rapid Prototyping (RP). RT is an attempt to make the tools rapidly to produce the parts from these tools. The rapid tools like "molds, patterns and inserts etc." are produced using additive processes which reduces the time and cost drastically. The application of this new technology reduces the number of design iterations as well testing trials required before introducing a new product in to the market.

The rapid tooling can be mainly divided into two types i.e. Direct Tooling and Indirect Tooling.

In direct tooling the pattern or mold is made directly from CAD data and used for actual production of the parts where as in indirect tooling patterns are made from CAD data and are used as master pattern to produce molds through which actual production of the parts is achieved as in silicone rubber molding and epoxy resin molding etc. [2]

2. ADDITIVE MANUFACTURING KEY PROCESSES

Fig-1 shows the classification of the Additive Manufacturing Process

2.1 Fused Deposition Modeling

It involves heating of thermoplastic materials in form of filaments till their semi-solid phase, this is then deposited layer-by-layer on a bed [3].

2.2 Stereolithography

SLA may be a vat polymerization method, where layers of the liquid precursor during a vat are sequentially exposed to ultraviolet (UV) light and thereby selectively solidified. a photograph initiator (PI) molecule within the resin responds to incoming light and upon irradiation, locally activates the chemical polymerization reaction, which results in curing only within the exposed areas. After developing the primary layer therein manner, a fresh resin film is applied, irradiated, and cured. [4]

2.3 Polyjet

Polyjet 3D printing technology was first patented by the thing company, now a Stratasys brand. The photopolymer materials are jetted in ultra-thin layers onto a build tray during a similar fashion compared to inkjet document printing. Each photopolymer layer is cured by UV light immediately after being jetted. The repetition of jetting and curing steps, layer after layer produces fully cured models which will be handled and used immediately. The gel-like support material, which is specially designed to support complex geometries, can easily be removed by hand or by using water jetting. [5]

2.4 Laminated Object Manufacturing (LOM)

The Sheet Lamination (SL) 3D printing manufacturing technique, also known as Laminated Object Manufacturing (LOM) consists of super-positioning several layers of material composed of foil in order to manufacture an object. Each foil is cut to shape with a knife or laser in order to fit to the object's cross-section. [5]

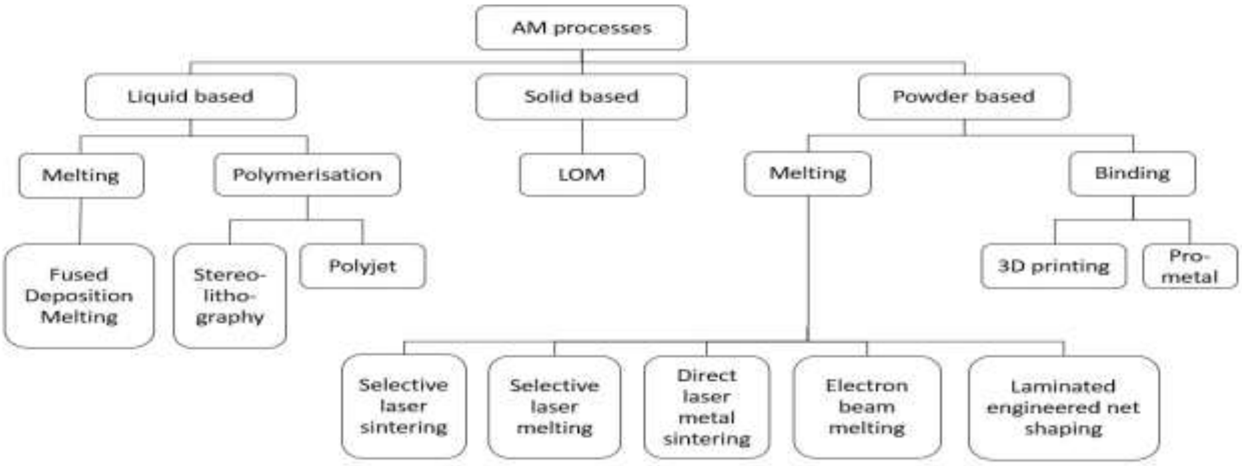

Fig - 1: Classification of Additive Manufacturing Processes. [8]

2.5 Selective Laser Sintering (SLS)

SLS 3D printing technology originated in the late 1980's at the University of Texas at Austin. Over the years, this technology has experienced remarkable advances. Basically, the process uses lasers to sinter, or coalesce, powdered material layer-by-layer to create a solid structure. The final product, rendered enveloped in loose powder, is then cleaned with brushes and pressurized air. The main materials used in the SLS 3D printing process include polyamide (Nylons), Alumide (a blend of gray aluminum powder and polyamide), and rubber-like materials. Nylons are strong and durable but do feature some flexibility, making them excellent for snap fits, brackets, clips, and spring features. Designers should take the susceptibility for shrinkage and warping of thin parts into consideration during the conceptual phase. [5]

2.6 Selective Laser Melting (SLM)

Selective Laser Melting (SLM), also called Direct Metal Laser Sintering (DMLS) The same technical principle is used to produce Selective Laser Melting (SLM) and Direct Metal Laser Sintering (DMLS) parts, but is exclusively used to produce metal parts. SLM achieves a full melt of the powder so that single-component metals, such as aluminum, can be used to create light, strong spare parts and prototypes. DMLS sinters the powders and is restricted to alloys, including titanium-based alloys. These methods require added support to compensate for the high residual stress and to limit the occurrence of distortion. Applications include jewelry and dental industries, spare parts, and prototypes. [5]

2.7 Direct Laser Metal Sintering

The Directed Energy Deposition (DED) 3D printing technology, also known as Direct Energy Deposition, creates parts by directly melting materials and deposing them on the workpiece, layer by layer. This additive manufacturing technique is mostly used with metal powders or wire source materials. Other popular terms for DED include laser engineered net shaping, directed light fabrication, direct metal deposition, Laser Deposition Welding (LDW) and 3D laser cladding. In addition to the capability to build parts from scratch (often with the hybridation of a mill/turn CNC tool), DED is also capable of fixing complex damaged parts, such as turbine blades or propellers. [5]

2.8 Electron Beam Melting

The EBM 3D printing technology attains fusion with the use of a high-energy electron beam and produces less residual stress resulting in less distortion. It uses less energy and can produce layers faster than SLS. This method is most useful in high-value industries such as aerospace and defence, motor sports, and medical prosthetics. [5]

2.9 Laminated Engineered Net Shaping (LENS)

LENS 3D manufacturing systems use lasers to build objects layer by layer directly from powdered metals, alloys, ceramics or composites. The LENS process must take place in a hermetically-sealed chamber which is filled with argon so that the oxygen and moisture levels stay very low. This keeps the part clean and prevents oxidation. The metal powder material is directly delivered to the material deposition head. Once a single layer has been deposited, the material deposition head moves on to the next layer. By building up successive layers, the whole part is constructed. When complete, the component is removed and can be heat-treated, hot isostatic pressed, machined, or finished in any required fashion. [5]

3. FUSED DEPOSITION MODELING

Material Extrusion 3D printing technology uses a continuous filament of a thermoplastic material as a base material. The filament is fed from a coil, through a moving heated printer extruder head, often abbreviated as an extruder. The molten material is forced out of the extruder's nozzle and is deposited first onto a 3D printing platform, which can be heated for extra adhesion. Once the first layer is completed, the extruder and the platform are parted away in one step, and the second layer can then be directly deposited onto the growing workpiece. The extruder head is moved under computer control. At least three axes are required for the extruder to move in Cartesian architectures, but polar and delta systems are also becoming increasingly popular. One layer is deposited on top of a previous layer until the object's fabrication is complete.

Material extrusion is known as Fused Filament Fabrication (FFF) and is one of the most popular processes for hobbyist-grade 3D printing. The proprietary term Fused Deposition Modeling (FDM) was coined by S. Scott Crump in the late 1980's and was commercialized in 1990 by the Stratasys company. With the expiration of this technology's patent, there's now an outsized open-source development community called RepRap, also as commercial and DIY variants, which utilize this sort of 3D printing technology. This has led to a measurable price decrease. However, the material extrusion technique has dimensional accuracy limitations and is very anisotropic. Fig-2 Shows the FDM Printing system.

A wide variety of materials can be extruded, the most popular being thermoplastics, such as Acrylonitrile Butadiene Styrene (ABS), Polylactic Acid (PLA), High-Impact Polystyrene (HIPS), Thermoplastic PolyUrethane (TPU), aliphatic PolyAmides (PA, also known as Nylon), and more recently high performance plastics such as Polyether Ether Ketone PEEK or Polyetherimide PEI. Additionally, paste-like materials such as ceramics, concrete and chocolate can be extruded using this 3D printing technique.

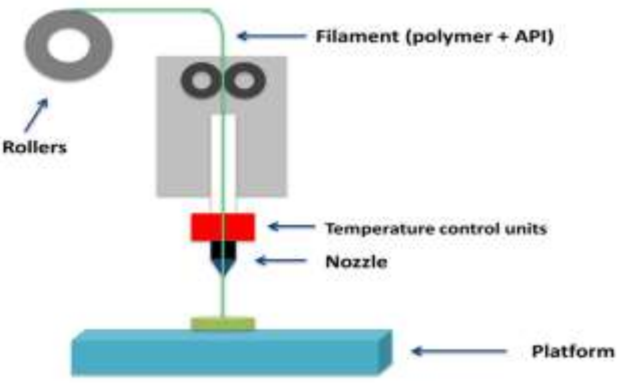

Fig - 2: FDM Printing system [6]

As it became possible to equip a 3D printer with multiple extruders, for speeding up the fabrication process or opening multi-material capabilities, the availability of composite fabrication became possible. Composite Filament Fabrication (CFF) is one of them. This term was coined by the company Mark forged and uses two print nozzles. One nozzle operates following the typical material extrusion process; it lays down a plastic filament that forms the outer shell and the internal matrix of the part. The second nozzle deposits endless strand of composite fiber (made with carbon, fiberglass, or Kevlar) on every layer. These continuous strands of composite fibers inside 3D printed parts add a strength to the built object that is comparable to parts made of metal. In addition to using composite materials for strong parts, the strategy wont to lay down layers can affect part strength. Mark-forged distinguishes two strategies: isotropic fiber fill or concentric fiber fill.

Even composites can be 3D printed with the material extrusion technique on machines equipped with only one extruder. The sole condition is that the base material (a thermoplastic) is present in sufficient quantities to guarantee a fusion between layers. Therefore, a mix of two materials within a single filament made wood 3D printing (wood particles embedded in PLA), metal 3D printing (metal particles embedded in thermoplastic) and even carbon 3D-printing (carbon fibers embedded in thermoplastic) possible.[5]

3.1 Process

The Principal of Fused Deposition Modeling Process is based on layer manufacturing technique. It involves three basic steps Pre-processing, Production & Post-processing. [9] Fig-3

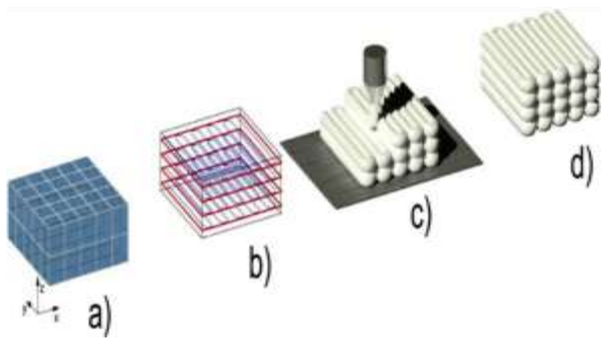

Fig - 3: Schematics of fused deposition modelling process: (a) CAD model, (b) slicing, (c) 3D printing, (d) post-processing. [7]

shows the schematics of fused deposition modelling process.

Pre-processing - Software first slices & position 3D STL file and calculates a path for extruding thermoplastic material and any necessary support structure needed.

Production – Head of the FDM heats the spool or cartage form thermoplastic material, into a semi-liquid state and deposited it in ultrafine beads along the extrusion path. While extruding from the nozzle, it cools & solidifies to form required model. When support is required, buffer head deposits water soluble or break-away support material.

Post-processing – This involves the removal of support materials. The part is ready to use.

3.2 Types of FDM 3DPrinters

Fig. 4. Shows the Cartesian, Polar and Delta type printers. **Cartesian FDM 3D Printer-** Cartesian 3D Printers are the most common FDM 3D printer found on the market. Based on the Cartesian coordinate system in mathematics, this technology uses three-axis: X, Y, and Z to determine the correct positions and direction of the print head. This type of printer, the printing bed usually moves only on the Z-axis, with the print head, working on the X-Y plane. [10]

Delta FDM Printers- These machines operate with Cartesian coordinates. This involves a round printing plate that is combined with an extruder that is fixed at three triangular points. Each of the three points then moves up and down, thereby determining the position and direction of the print head. Delta printers were designed to speed up the printing process. However, many believe that this type of printer is not as accurate as a conventional Cartesian printer. Cartesian and Delta 3D printers aren't hugely different. The difference is only in where each element can move in relation to the print bed. In Delta 3D printers, the printer head can move in any direction but the print tray doesn't move. [10]

Polar 3D FDM Printers- Polar 3D printers' positioning is not determined by the X, Y, and Z coordinates, but by an angle and length. This means that the plate rotates and moves at the same time, with the extruder moving up and down. The main advantage of Polar FDM 3D printers is they only two engines, whereas Cartesian printers need at least three. In the long term, the polar printer has greater energy efficiency and can make larger objects while using less

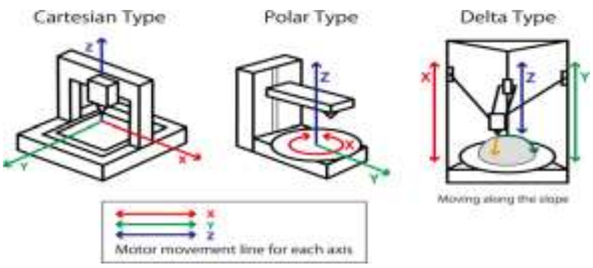

Fig - 2: Cartesian, Polar and Delta type printers [9].

space.[10]

FDM 3D Printing with Robotic Arms- Robotic arms are most commonly known for assembling components on industrial production lines, especially in large automotive plants. While 3D printing has begun to incorporate robotic arms into their production process, most notably seen in the 3D printing of homes and buildings, this technology still remains in the development stage. Although not a commonly used printing process, this FDM printing method is beginning to see an increase in use. This is because the process is not fixed to a printing plate, making it much more mobile. In addition, thanks to the flexibility when positioning the FDM 3D printer head, it is easier to create complex structures. It should be noted, however, that the final print quality is not as good as conventional Cartesian printers.[10]

3.3 Filament materials

Some of the common filament materials used are, **ABS** (and compounds):Acrylonitrile Butadiene Styrene, **PLA** Polylactic Acid, **PVA**:(Polyvinyl Alcohol) Because it is soluble, this material is generally used to manufacture supports, as they can be easily removed from the part after manufacture, **TPU**: Polyurethane: Used to create flexible parts, **ULTEM**: Heat-resistant material,**ABS** – PC: ABS and polycarbonate compound, **Nylon, ASA** (Acrylonitrile styrene acrylate), **PPSF**: (Polyphenylsulfone) and etc.

3.4 Benefits of FDM

- This type of 3D Printing technology is cost-effective to produce thermoplastic parts and model.
- FDM Technology is very fast printing process. So lead time will be reduced to make next day delivery.
- Due to availability of Wide range of material, it can be used in many fields.

3.5 Limitations of FDM

- This technology having low dimension accuracy compared to other technology. So it is not suitable for complex parts.
- Parts output have a layer line visible to our eyes. So Post processing is needed to remove these layer line.
- The layer attachment mechanics makes FDM parts inherently anisotropic.

3.6 Applications

- Prototyping
- Finished products
- Dentistry
- Jewellery
- Architecture models
- Educational Aids
- Household goods and crafts

4. CONCLUTION

Fused Deposition Modelling method allows the utilization of a good sort of thermoplastic materials with the feasibility of mixing them with the ceramic or metallic powders. This enables the development of composite materials with improved internal structure, as well as mechanical and thermal properties. This technology can also be used in medical applications such as bone tissue engineering, development of customized prostheses.

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