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3D Printing Technology: Emerging Field of Development

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Abstract - *The following paper is on 3D printing & its other topics which become notable points in technological aspects. The 3D printing technique is a fast emerging technology. This technology can print the object layer by layer deposition of material directly from a CAD model. Prototyping can be classified into different processes such as FDM, SLA, SLS, DLF, LOM, DMLS. These processes can be use as per the requirement of models. The material used for the printing determines the quality of the model. Different processing parameters of printing affect the efficiency, quality, production rates of the parts, objects, components, etc. On the basis of optimized parameters the mechanical properties & manufacturing time can be enhanced. It is widely used across the world owing to its variety of applications in various sectors. As well as it will play vital role in day to day human life in future.*

Key Words: 3D-Printing, Processing, additive manufacturing types, material selection, process parameters, applications, market size, future scope.

1. INTRODUCTION

3D printing or rapid prototyping can also refer as additive manufacturing. It is the process of making a 3D object of different shape from a 3D CAD model or other electronic data sources. [1] In additive processes, successive layers of material are laying down under programming controls. Each of these layers is sliced in horizontal cross section of the object. It has ability to produce complex geometries, hollow parts, internal truss structure, etc. by scanning & then just click on print to build a physical reality.

3D printing technology was invented by Charles Hull in 1984. They gives a birth 3D technology which known as stereo-lithography. In this process, layers of 0.1mm depth are added by curing photopolymers by ultraviolet light to achieve melting & solidification effect. [2] In 1990, the Stratasys developed plastic extrusion technology which known as the Fused Deposition Modeling (FDM). After that there has been large growth in the 3D printing technology. The prices of printer machines & its processing drops gradually & increases the scope for rapid prototyping process.

3D printing process is advantageous compare to conventional processes. This process includes 11% of innovation of that manufacture, 16% consumes for product development in any 3D design software. After that 25% of work required during prototyping process. So it is helpful in increasing the efficiency up to 10% as well as cost reduction by 9%. Hence, it results in the overall development of industrial-technological factors.

Today, rapid prototyping has a wide range of applications in different fields of human life such as medical industry, research engineering, military, aerospace, construction, architecture, fashion, computer industry, electronics, robotics, education & many others.

2. LITERATURE REVIEW

Vinod G. Gokhare, Dr. D. N. Rather, Dr. D. K. Shinde studied on the 3D printing processes used in industries. They explain about the various materials & their properties which is important topic in technological aspects. They compare the properties of materials by different parameters. They also discuss about advantages, limitations & applications of 3D printing. They concluded that the advances in this technology can significantly change & improve the process of manufacture products & produce goods worldwide [3].

Dr. Muhammad Abu-Khaizaran & their group of students, elaborated the 3D printing technology in detail. They included the history of 3D printing as well as the components & operation of the 3D printer. At the end, they discussed about some printing technologies & their pros-cons. They gives aspects about 3D printer that these printers will be drive off a coming revolution that will change whole face of industry [4].

Mr. Mahesh S. Kadam & their team of students studied on process parameters of FDM 3D printer. They discuss about experiment on affect of layer thickness, shell thickness & fill density on the properties as like surface roughness, hardness & tensile strength which gives result that overall strength improve by decreasing the thickness & increasing fill density. They gives the information about Taguchi method of testing [5].

K. G. Jayant Christiyan, U. Chandrasekhar, K. Venkateswarlu studied on influence of process parameters on properties of 3d printed ABS composite. They followed the ASTM D638 & ASTM D760 standards for carrying out tensile tests & flexural tests. They studied tensile behavior of ABS composite at different printing speed & layer thickness. After doing experiment they concluded that ABS+anhydrous magnesium silicate composite material has maximum flexural & tensile strength at lower thickness of 0.2mm & printing speed of 30 mm/s [6].

Arup Dey & Nita Yodo did the systematic survey of FDM process parameters & their influence on part characteristics. They give the information about commercialization of FDM technology. They elaborated the how process parameters affect on the FDM produced products considering layer thickness, build orientation, raster width, printing speed. They implement the product development by controlling parameters. They concluded as the FDM process is very complex & it can compared with layer thickness, build orientation, raster width for getting consistency in production [7].

3. PROCESSING STEPS

3.1. Modelling / Pre-processing:

In modelling of 3D models forms by CAD model of a part which is to be manufacture is build up, then it is converted to .STL format i.e. Stereo lithography file format which will ready for printing process. The Pre-processing process of preparing geometric content for 3D computer graphics is as same as to method sculpting. 3D modeling is a process of analyzing, collecting data & information regarding to its shape, aesthetic and appearance of an object [3].

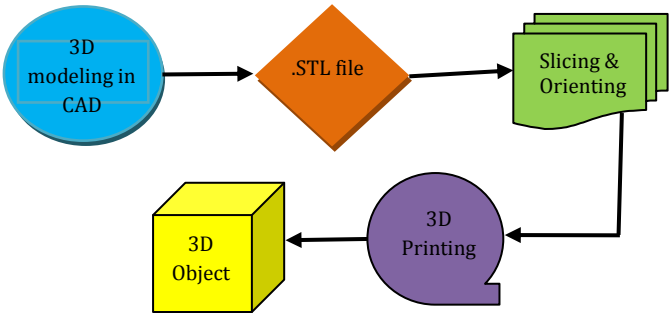


Fig -1: Processing Steps of 3D Printing

3.2. Production / Building Model :

During printing/building a model, we must have converted the .STL file into G-code file format by slicing and orienting process. By creating the sliced layers of the model, first layer of the solid model is formed. After that the model is lowered down by the thickness of the layer by layer & process is repeated upto completion of project model. This layers, which corresponding to the virtual cross sections from the CAD model & they are joined or fused to create the final shape of an object [10].

3.3. Finishing / Post Processing :

During printing the model, there will be chances of production of oversized version of object due to uncertainty, vibrations in nozzle of printer. For the achieving standard resolution & better precision, once the model completed the support columns are removed by washing. Then its surface keep cleaned & finished very well [3].

4. TYPES OF PRINTING PROCESSES

The different types of printing technologies used in additive process are done by large & expensive printers. Additive processes can be classified as-

a) **Photopolymer systems** starts with a liquid resin, which is then solidified by discriminating exposure to a specific wavelength of light.

b) **Thermoplastic systems** begins with a solid material, which is then melted & fuses upon cooling.

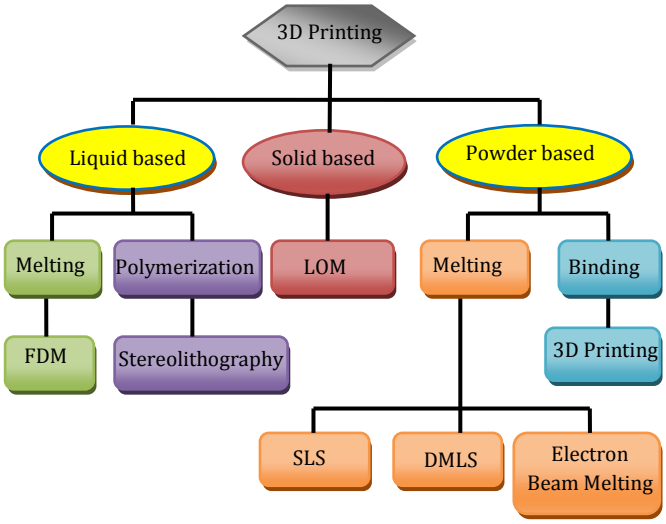


Fig -2: Classification of 3D Printing Processses

5. MATERIAL USED IN 3D PRINTING

For the manufacturing of 3D printed models different types of metals & non-metals are used like as Plastics, Photopolymers, Ceramic parts, Plaster & starch parts, Foundry sand parts, Metals. The following table shows the material used in different 3D printing processes.

Table -1: Material used as respective of the process [10]

Sr. No.	Type of Process	Material used
1.	Fused deposition modeling	Acrylonitrile butadine styrene (ABS), Polyamide, polycarbonate, thermoplastic beads, polyethylene, investment casting wax.
2.	Stereolithography	Liquid photopolymers, Acrylonitrile butadine styrene (ABS), Castable resins, ceramic micro particles, flexible resins.
3.	Selective laser sintering	ABS, polyamides, nylon, polycarbonate, aluminum, tool steel, titanium, stainless steel.

4.	Direct metal laser sintering	Aluminum alloys, nickel alloys, maraging steel, titanium alloy, cobalt chrome alloy, copper- chromium-zicronium-Beta Stage
5.	Laminated object manufacturing	Sheet of plastic, paper coated with adhesive, Thermoplastic as PVC, composite of ferrous & non-ferrous metals, ceramics.
6.	Directed light fabrication	Titanium powder, copper, aluminum, tungsten, molybdenum disilicide, nickel aluminides, stainless steel.

Material selection for the manufacturing of model is depend on their mechanical, physical, chemical properties like as durability, weight, toughness, hardness, heat resistance, composition of material, time requirement, cost, etc. The following table shows the comparison between different materials considering their properties.

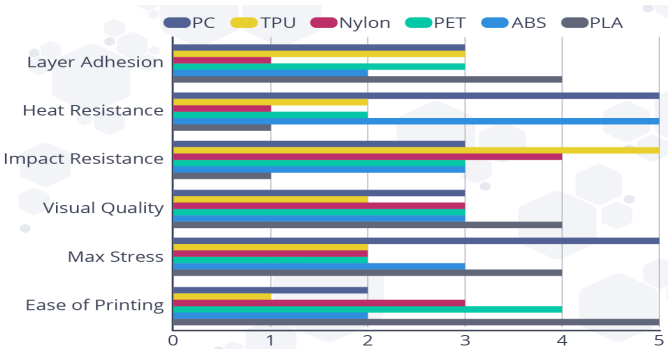
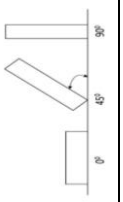
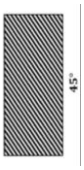
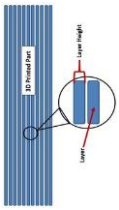
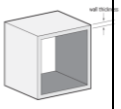
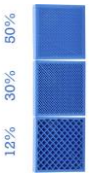


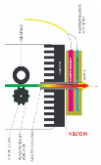
Chart -1: Comparison of properties of printing materials [Matmatch]

6. PROCESS PARAMETERS:

The 3D printing process has several process parameters & they have significant impact on efficiency of production, properties of models, etc. Depending on the parameters cost of production, production rate, quality of model, time requirement, and expenditure varies. Some of the common process parameters are given below.

Table -2: Process parameters of 3D printing

Sr. No.	Process Parameter	Principle sketch/ figures	Description	Effect
1.	Air gap		It is gap between adjacent roasters on deposited layer. When two adjacent layers are overlapped then, it is called as negative air gap [7].	Negative air gap improves the mechanical properties as like toughness, hardness, etc.
2.	Build orientation		It is defined as the way to orient the model in a build platform with respect to horizontal & vertical axes.	It affects on the compressive strength between the layers, model.
3.	Raster width & orientation		It is width of deposition bead which depends on extrusion nozzle diameter. Orientation is angle is given to nozzle direction during printing.	Smaller raster angle increases the tensile strength of model [11].
4.	Layer height		In AM method, layer by layer printing is done. It plays important role in mechanical, physical properties which varies from 0.06 to 0.4mm diagnosis.	Larger layer height will decrease the resolution as well as quality of the print [6].
5.	Shell thickness		It is the thickness of outer shell of the part. This helps in combination with fill density selected for printing [5].	Increasing the shell thickness helps in increase in strength of model & robust object printed.
6.	Infill density		It is percentage of infill volume of material to be printed. 100% for solid part & 0% for empty part is considered.	It reduces gap between printed lines & increased adhesion between layers [7].
7.	Infill pattern		Different patterns are used for produce a durable & strong internal	It affects on the print time, weight, quality & object

			structure.	strength.
8.	Printing speed		It is the speed of printing happens by movement of printing head. For good quality, printing speed must be slower. Well-adjusted printer has speed of 150mm/s [5].	Quality of the model is reduces due to higher printing speed [6] as shown in fig.
9.	Extrusion temperature		The temperature at which filament of material is heated & fused together [7].	Higher temperature improves layer bonding & make physically strong.

7. ADVANTAGES AND LIMITATIONS

7.1 Advantages:

- It helps to designers by realize their concepts beyond their virtual visualization & leads to innovation.
- There is possible to make changes in physical model instantly by asking customers feedback.
- It provides the fast rate of production to industry & gives proximity to market.
- The creation of tools & parts by 3D printing has lower rates than traditional machining. So, cost reduction is achieved [3,10,12].

7.2 Limitations:

- For the large size & large quantities of goods, AM will be difficult & require increase the spec of 3D printing.
- The replication of real product & system is fails by 3d printing.
- There is limitation of materials that can be used in printing due to insufficient research in process.
- Changes in atmospheric conditions, whether & temperature may affect the quality of model [3,10,12].

8. APPLICATIONS

3D printing technology is widely used in the various sectors of our day to day life. Following pie-chart gives different types of usage of 3D printing which includes motor vehicles, architecture, military, academic institutions, medical, consumer products, industrial machines, aerospace & other content.

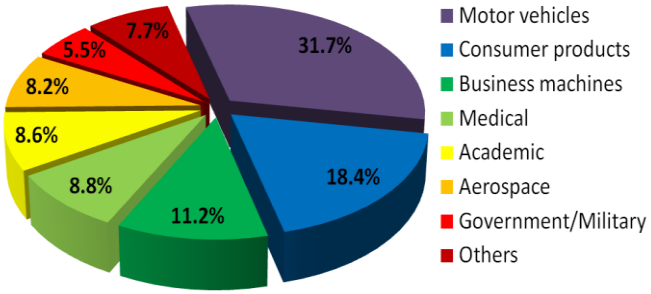


Chart -2: Usage of 3D printing [National Geographic Education Blog]

8.1. Architecture & construction :

3D printing is used to making models of buildings, infrastructure for taking the basic idea about the construction. They give the prior information about data collection, cost estimation, requirements for construction of houses, buildings, bridges, etc. In China, they build a house in a day & construct sky scrapers in few of weeks. Ex. Winsun Decoration Design Engineering was build a houses in Shanghai by 4 giant 3D printers [9].

8.2. Automobiles & Aeronautics industries :

3D printing software is used for model design, prototyping, testing & production for manufacturing more efficient car. The chassis, body work & other parts printed in less time by using large printers. 3D printing makes the vehicles lighter & stronger. Local motor Strati is the 1st 3D printed car manufactured with Cincinnati Incorporated and Oak Ridge National Laboratory [9].

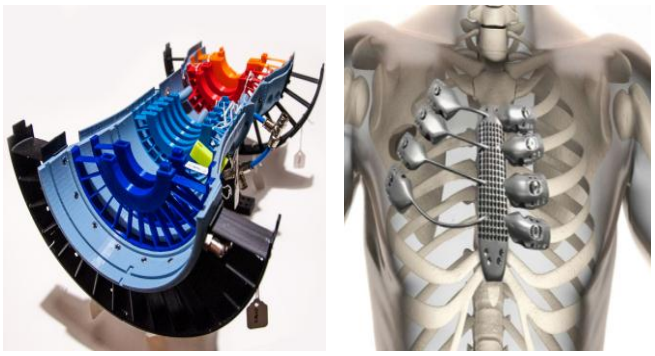


Fig -3: Aircraft engine model and Titanium rib cage surgery

8.3. Medical Applications :

3D printing plays important role in the medical sector. It is used for printing organs or body parts for educational purpose. Some of the parts used for implants over the actual body parts [9]. Now, people are used 3D printed organs as like fake teeth, hands & legs for a handicapped person.

9. FUTURE SCOPE

Building Materials and Automotive : MIT Media Lab is experimenting on printing huge moulds for construction by using spray poly-urethane foam. Contour Crafting proposes 3D printing entire house of 2500sq.foot in 20 hrs. It will help in the emergency housing system. Self-healing military vehicles, printed aircraft can be developed [10].

Healthcare : Organ transplant is possible due to 3D printing. Medical Instruments, Nano scales medicines can be produced. On the pandemic of Covid-19, Birla Institute of Technology & Science Pilani, Hydrabad [12] as well as Anatomiz 3D, Mumbai developed the art face shields masks to offer complete protection for essential workers. It has manufacturing cost about Rs.40 per shield.

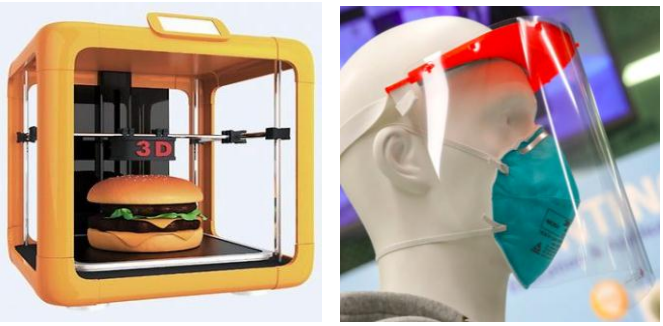


Fig -4: 3D printed Fast food[GrabCAD] and Face Shield[12]

The following figure shows the growth of 3D printing technologies in various process for the year of 2016 to 2027 in terms of USD Billion.

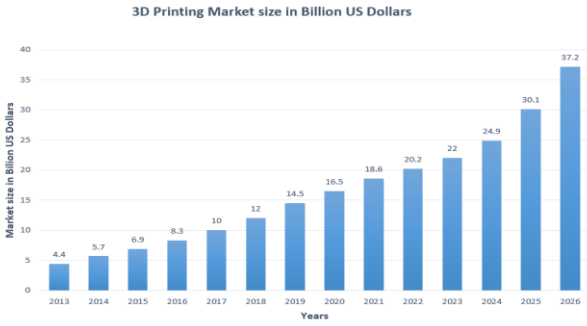


Chart -3: Growth of 3D printing [North America 3D Printing market]

10. CONCLUSIONS

In this paper, comprehensive information about 3D printing, their types as per different principles, controlling process parameters & its overall effect on the model characteristics was summarized. The various materials used in 3D printing in which PLA & ABS are most widely used materials due to its special properties. The process parameter such as layer thickness, printing speed, infill density, build orientation majorly affect on quality of the printed model. When the printing speed, layer thickness is less then production rate reduces but it gives maximum tensile & flexural strength. It results in increase in the quality as well as cost of production. If Infill density high, then weight increases & strength of object improves. 3D printed products consumed less energy and required less material. A shift to plastics & metals resulting in higher energy demands because of its negligible waste. 3D printing has limited size or scale of producing products but it forms reliable & durable things. 3D printing plays vital role in the automotive, defense, fashion, healthcare, food technology & construction sector. Nowadays, it is used in healthcare by manufacturing of face shield & face mask for prevention from Covid-19 to our Corona fighters. Prototyping has been wide scope in the future for utilizing human needs.

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