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A Review in 3D Printing Technique: Types, Applications and Process Parameters

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Abstract

For the fabrication of engineering components, 3D printing has proven to be a feasible technology because it is an additive process, unlike previous manufacturing methods. The advantages of 3D printing for industrial use include little material wastage, simple manufacturing, minimal human participation, minimal post-processing, and energy efficiency. The advantage and disadvantage of various 3D printing techniques are covered in the study. There is a detailed explanation of various materials that work with each sort of 3D printing procedure. The report also lists the many contexts in which each process type is applied. The research on literature showed that even if the fields of 3D printing have advanced significantly, there are a problems that required to solve, like material incompatibility and material cost. In future, this could be done to improve the procedures and adapt them to work with a variety of materials. More effort must be put into creating affordable printing technologies and materials, that work with these printers because 3D printed products have a wider range of uses.

Keywords: 3D Printing, FDM, Process Parameters, Thermoplastic.

1. Introduction

The initial thought that comes to our minds is related the field of manufacturing, How are things made? Or how can transform raw resources into something desire to buy, use, or consume?. The initial method of making something is subtractive fabrication- that is to start with a raw material and go ahead forward towards the required product. The following manufacturing process is known as forming, in which a bulk of material are subjected to modifications to its size with force applied. The third method of producing things is casting, which involves melting the material to transform it from a solid state to a liquid state before pouring the liquid metal into a specific template to produce the desired product. Additive manufacturing (AM), the fourth type of manufacturing, involves layer-by-layer fabrication of the parts [1, 2]. Additive manufacturing and 3D printing are general terms that cover a vast domain of processes form creating 3D prototypes and structures from digital files. The solid modelling component of Computer Aided Design (CAD) is the basic for additive manufacturing. This modelling data is used by additive models to create layers of very thin cross section areas, which is used to manufacturing of complex shapes and surfaces that are very difficult to obtain by using conventional methods [3]. A machine will be recognized as 3-dimension printer if it possesses the three characteristics of 3 dimensions, additive manufacturing, and layers based construction. An additive process means adding different layer of substances to make the desired shape. Let's use baking cupcakes as an

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example. To make the batter, add the ingredients one at a time to an empty bowl until have the desired consistency. A large cake can be purchased and the top portion of it can be removed to create the shape of a cupcakes. That process is a subtractive procedure where usually start with a larger part and remove everything that is unnecessary. Wood engraving by hands, CNC machining, laser cutting, and other forms of production are examples of subtractive processes.

The basic design of the part is the first step to create in 3D printing, which is essentially an additive fabrication method [4]. The aforementioned design is produced using computer software that can be connected to 3D printers. A unique file type is then produced by this software and transmitted to the printer. By adhering one layer over another, the 3D printer builds the thing after reading that file [5]. To create a part, almost all 3D printing procedures require layers. Instead of reading the parts as a whole, 3D printers interpret them as separate, two-dimensional layers. The fact that 3D printers are built to read the (STL) Standard Tessellation Language file types, as depicted in Figure 1, is the foundation for how they function. The advantages of 3D printing, such as minimal material waste, extremely low cost, and minimal post processing even when producing complex pieces, make it a technology of the future. The use of 3D printing to recycle and reuse plastics and lower emission are two further factors.

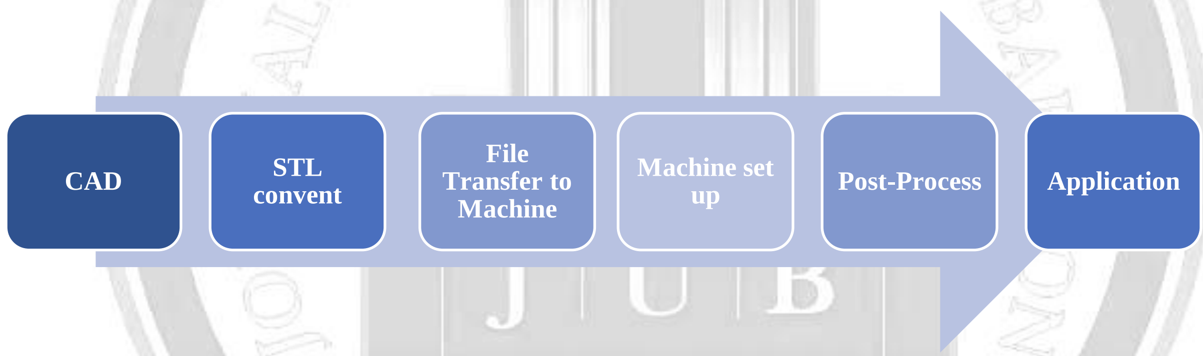

Figure 1: The basic steps of 3D printer.

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2. Types of 3D Printing

The development of additive manufacturing techniques has been made in response to the demand for printing intricate models at high resolutions. An crucial factor in the development of AM technology is rapid prototyping. There are three main types of additive manufacturing technologies: sintering, which involves raising the material's temperature without turning it into a liquid to create complex prototypes, melting, which involves using electron beams to melt the powder, and stereolithography, also known as photo polymerization and utilizing an associated ultraviolet laser. So the ceramic components are prepared to withstand the highest temperature, that laser is projected upon a bowl of photopolymer resins. [6]. There are seven AM techniques as shown in figure 2, according to ASTM (American Society for Testing and Materials), including material jetting, VAT photopolymerization, binder jetting, powder bed fusion, material extrusion, direct energy deposition, and sheet lamination. [7]. In the sections that follow, some of the key techniques are covered in more detail, with an emphasis on the tasks involved in each approach, the materials utilized in each method, the benefits and limitations of each method, and the various uses of 3D printing.

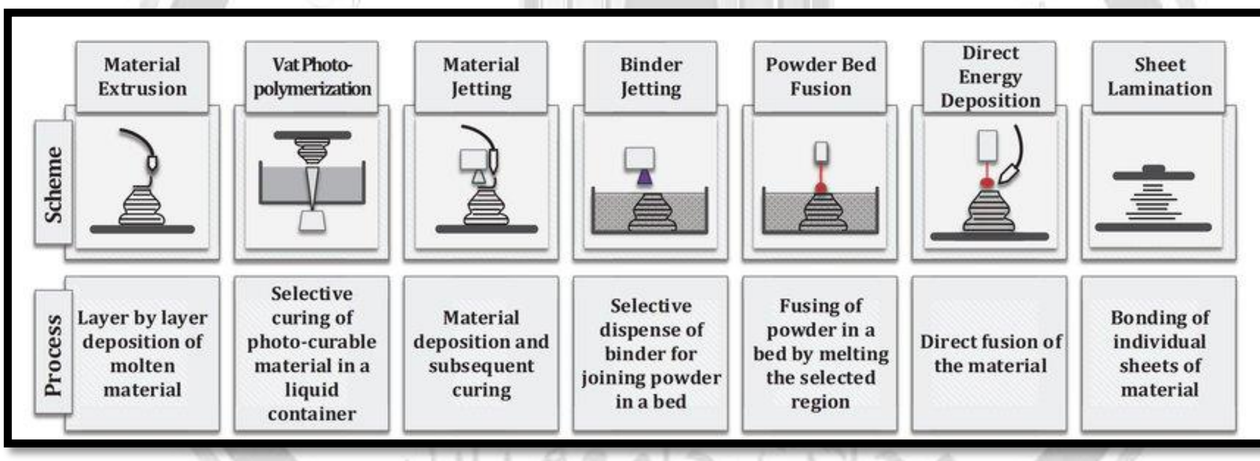

Figure 2: Types of 3D Printing Process [7].

2.1 Fused Deposition Modelling (FDM)

Thermoplastic filament is heated to its melting point and then extruded out layer by layer in the process known as FDM to create 3D objects [8]. The FDM technique was developed by Scott Crump for Stratasys INC in the USA in the early 1990s. The backing base of 3D printers that use FDM has a design that allows it to move vertically and with a certain degree of mobility. The filament is connected to a support extruder that is mounted on the bottom plate. It is heated to the filament's freeze point and then extruded layer over layer with the help of a nozzle to create the desired shape. There is enough supply for the extruder to move in (x, y and z) directions. Because the adjacent layers are fused together as the extruder completes the deposition, the process is known as fused deposition modeling (FDM) and the 3D printer is in charge of modeling the object [9]. The finished component is submerged in resin, same like with the SL process, depending on the required surface end.

2.2 Stereolithography (SL)

The first 3D printers were stereolithographic (SL) machine, which were used to create 3D models, 3D parts, and 3D prototypes, in the late 20th century. This was the first 3D printing technology to be commercially available. Even though 3D printing was the topic of numerous investigations in the 1970s, Charles Hull invented it and had it patented in 1984 [10]. One must comprehend the method of stereolithography before defining the phrase. A CAD files are created to begin the process, and this files is then converted to an STL file format. This STL files contains the information a 3D printer needs to create an item. Photopolymer liquid curable with ultraviolet (UV) light, a laser source, a perforated table, and a computer that regulates the process are the four main components that go into the formation. 3D printers begin to function by submerging a perforated table in a liquid tank later than reading the STL file type. The liquid polymers meet the table through the openings as the table descends. The UV laser strikes the upper face of the liquid polymer as it comes into contact with the table, instantly hardening it. Once more moving below, this table creates layer over layer geometry, fusing each successive layer starting with the base layer. The final layer is completed, and the 3D printed component is then submerged in another resin to separate the sculpture from the liquid polymer. Following this step, a UV curing oven is used to cure the 3D printed item because all the layers of the specific resin have a strong link to one another. All of the layers in this oven harden and become stronger at the set temperature, resulting in the desired surface finish. As a result, the end result of all these procedures is the final item. Now that the term SL has been defined, it can be summed up as a 3D printing technique in which liquid photopolymers is transformed to 3D objects with the aid of a stereolithographics (SL) machines.

2.3 Binder Jetting (BJ)

A modified form of inkjet technique is used for binder jetting. This procedure was introduced Massachusetts Institute of Technology (MIT) [11]. An inkjet is utilized to bond the objects in this method instead of lasers. It begins with a 2D printing method using an inkjet printer and builds up layers to create a 3D item. A liquid binder is deposited during this operation in addition to the print head moving in two directions. Like all other 3D printing processes, this one starts with the creation of a 3D drawing and the importation of that drawing into the printer software. A distributor adds powder that will be utilized in it since printing requires a consistent supply. After applying a powder with a range of thicknesses, the head of printing affixes the binder in accordance with the specifications. The solvent containing the binder is dried using fluorescent or electrical lights before moving on to the next layer. The powder bed is then thinned out and a fresh layer of powder is added. The binder is placed in a furnace when the cycle is finished. The binder is influenced by variables like temperature and time. Before usage, the metal and ceramic components need to undergo sintering, heat treatment, infiltration, or hot equal static pressure. The majority of metal and plastic components, however, don't need any additional processing and they are ready for use as soon as it finishes printing [12, 13].

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2.4 Powder Bed Fusion (PBF)

A thin layers of powder is used in a PBF process to create a plate, and an energy source, like laser or electron beam, is used to fuse the powder in accordance with the geometry of the components being created [14]. Through this method, the powders could be built up layer by layer by the laser until a three-dimensional shape is achieved. Every layer is attached to adjacent layers using PBF processes, which produce discrete output as opposed to continuous output by detecting powder material over the previously joined layers and preparing it to the next following layer's process. The powder is dispersed evenly over the powder bed by a brush or roller after being delivered by a hopper. Conditions of the procedure and powder content determine the thickness of the sheet. Other names for Powder Bed Fusion (PBF) include Direct Metal Laser Sintering (DMLS) and Direct Metal Laser Melting (DMLM), as well as Selective Laser Sintering (SLS), Selective Laser Melting (SLM), Electron Beam Melting (EBM), and Selective Laser Sintering (SLM) [6].

2.5 Laminated Object Manufacturing (LOM)

Laminated Object Manufacturing (LOM) it is a quick prototyping method that creates models out of laminates made of plastic, paper or metal that are successfully linked together. The model or item is then cut out using a laser cutter in the appropriate shape. The procedure begins with a sheets being bonded to a substrates using heated rolling. Next, using a mechanical or laser cutter, the next layers are accurately cut and then adhesives it together one after the other, either first bonding and then shaping, or vice versa [3]. The platform with the finished layers descends, the next metal sheet is rolled into place, and the platform returns to its initial positions to receives the following layer. The procedure must be followed till the prototype is created. Ultrasonic Additive Manufacturing (UAM), which merge laminations with ultrasonic metals seam joining and CNC cutting, may be a subset of LOM [15].

2.6 Direct Energy Deposition (DED)

This 3D printing technique, in contrast to others, is used for maintenance and repair rather than component production. Through melting the material as it is deposited, DED methods facilitate the creation of materials [16]. The deposition heads, which integrate an energy sources and two power feed nozzles, is the main piece of equipment utilized in the DED process. In this technique, a thin wire may also be supplied, in addition to the metal powder. A platform with inert gas tubing and the specific part that needs to be manufactured are sometimes also present. The deposition heads, which deposit the laser beams and powder beams simultaneously, are a 4 or 5 axis machine. In the DED process, a focused heat source (such as an electron beam or laser) is used, and as the materials solidifies, it is attached layer by layer to the existing products to repair and create new materials items.

3. Advantage, Disadvantage and Application of Different Processes in 3D Printing

After identifying the types of 3D printing process, in this part will be recognized the advantage, disadvantage and application of these types will be discussed in this part, see table 1.

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Methods	Advantage	Disadvantage	Applications
(FDM) Fused Deposition Modelling	• High surface finish. • It is simple to create complex shapes. • cannot be recycling • good flexibility • less cost • High speed	• A slow process • The finishing is inferior than that of SL or SLS • poor mechanical properties • Used for thermoplastics only	• Rapid prototyping • Toys • Advanced composite parts
Stereolithography	• High surface finishing. • Complex parts can easily fabricated. • Good accuracy. • High thermal toughness.	• Slow process. • Expensive process. • Hanging parts are difficult to make. • Dealing with limited materials	• Biomedical application
Binder Jetting	• High decision. • Good surface quality. • post-processing not required • Large area for Printing. • More than one printings at one time.	• There are few materials available. • Low strength. • required an substrate for printing.	• casting molds and cores • Medicine • Electronics
Powder Bed Fusion	• Less costs. • Outer support not required. • Widely material choice. • Powder can be recycling.	• Treatment is wanted after finishing • Obtained parts have a weak structural properties • Slow process.	• Heat exchangers Biomedical • Aerospace • Electronics • Lightweight structures
Laminated Object Manufacturing	• Low cost. • Outer support not required. • Rapid process. • Suitable for big parts.	• Required a post-processing • Low dimensional accuracy. • low surface finish • hard to manufacture the Complex parts.	• Paper manufacturin g • Foundry industries • Electronics • Smart structures
Direct Energy Deposition	• Good mechanical properties • repair and retrofitting are possible	• Slow process • Poor accuracy and surface quality. • Limited material is available. • Support structure is need	• Aerospace • Biomedical

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4. 3D Printing Process Materials

4.1 General Materials

4.1.1 Metals

Metal feedstock (powder or wire) is often melted using a laser or an electron beam as part of the 3D printing process for metals. To create a solid portion, the melted materials is changed layer by layer. Powder beds fusion (PBF) and direct energy deposition (DED) are the two most widely used methods for printing metals, but other methods, including binder jetting [17], cold spraying [18], friction stir welding [19], direct metal writing [20], and diode-based processes [21], have recently been developed. Higher accuracy or speed can be attained through these procedures. PBF-based AM methods can be used to produce a wide variety of metallic materials, including stainless and tool steels, certain aluminum alloys, titanium alloys and nickel based alloys [22].In general, strong metallic parts made with AM presents comparable quality, if not better, to conventionally manufactured parts [22]. Porosity and microstructures must be under control in order to achieve this outcome. Porosity is the main fault that causes fracture to spread. [23], which can be regulated by adjusting the applied volume energy [22] and feedstock quality [24]. The creation of voids with irregular shapes in the material is controlled by small quantities of applied energy [25]. On the other hand, too much energy results in the formation of spherical pores [23]. Thicker powder beds and smaller, regular, spherical particles can be used to increase flowability and homogeneity while also enhancing feedstock quality [24]. Controlling the amount of impurities and the alloy's purity is also necessary.

4.1.2 Polymers and Composites

Due to polymers versatility and adaptability to various 3D printing techniques, are regarded as the most widely used materials in the 3D printing industry. Thermoplastics filaments, reactive monomers, resin, and powder are the most common forms of polymers used in additive manufacturing. On the other hand, due to their intrinsic weakness and lack of usefulness, pure polymer items created by 3D printers are typically only utilized for conceptual prototypes [26]. The second-most crucial class for 3D printing, on the other hand, is reportedly plastic for selective laser sintering (SLS). Polystyrene, polyamides, and thermoplastic elastomers are SLS polymers [27]. A variety of 3D printing techniques could be used to process thermoplastics polymers, like acrylonitrile-butadiene-styrene copolymers (ABS) [28], polycarbonate (PC) [29], and polylactic acid (PLA) [30]. Currently, 3D-printed tissue engineering scaffolds are made using composite blends based on PLA. For the fabrication of polymers and composites, a number of 3D printing processes are available, including stereolithography, SLS, FDM, 3D bio-printing, and inkjet printing. The manufacturing of thermoplastics with low melting temperatures and polymer composites is where FDM is most frequently utilized [26]. Nanomaterials, which can lower sintering temperatures and enhance mechanical and electrical properties, are another class of developing materials for 3D printing [31–35].

4.1.3 Ceramics

For the production of sophisticated ceramics for biomaterials and engineering tissue, like scaffolds for teeth and bones, AM has become a crucial process [36]. The biggest difficulties with 3D printing ceramics, notwithstanding the precision of printing, are layer over layer appearance and a small variety of materials [37]. Sintered ceramic pieces must be post-processed in order to take the correct shape, which takes time and money. As a result, the process of 3D printing complexes shapes, followed by sintering, to create ceramics with complex shapes has gained a lot of appeal. Moreover, by creating sophisticated lightweight materials that are specifically designed for various uses, 3D printing of porous ceramics or lattices brought about a number of advantages. When compared to conventional casting and sintering techniques, ceramics scaffolds utilized in tissue engineering have become more practical and quick [36]. Inkjet (suspension), powder bed fusion, paste extrusion, and stereolithography are the primary techniques for 3D printing ceramics [37]. For 3D printing ceramic powders, a typical technique is selective laser sintering (SLS). For ceramic-matrix composites, selective laser gelation (SLG), which combines SLS and the sol-gel method, has also been introduced. A binder with a lower melting temperature is utilized for ceramics powder that do not readily fuse or melt at a minimal temperature of laser heating [38].

4.2 Materials Classification According to 3D Printer's Type

After being acquainted with the different types of printing, as well as the materials used in printing in general, now it comes to our minds, can all materials be used in 3D printing processes, and is each printer limited to specific types of materials? This is what will address in this part in addition to the applications of these materials see Table 2.

Table 2: Materials and Application in Different 3D Printing Method

3D printer method	materials	application
Fused Deposition Modelling	• Thermoplastic Polymer(PLA, ABS), • Ceramic Slurries and Clay • Green Ceramic (Alumina, Zirconia) • Green Metal (Stainless steel, Titanium) • Food pastes (Sugars and Chocolates)	• Aerospace, aerodynamics, and Constructional application. • dental field • bone substitute • manufacturing of mechanical parts • Cooking
Stereolithography	• DC 100, DC 500, DM 210	• jewelry industry • general purpose
Binder Jetting	• Stainless steel • Ceramic beads • Inconel alloy • Iron	• Parts of pump, drilling and mining machinery. • gas turbine blades, • pressure vessels,

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		• Aerospace industry.
Powder Bed Fusion	• Titanium (Ti) • Stainless Steel • Aluminum (Al) • Cobalt-Chrome • Nickel based alloys	• medical, dental field, automotive, aerospace, marine industry, and jewelry industries, • tool making • racing fields • power generation • orthopedics
Laminated Object Manufacturing	• Polymers • Composite • Ceramic • Papers • Metal files tapes and metal rolls	• Paper industry • Foundry and forging industry • Electronics industry. • Applicable in smart structures.
Direct Energy Deposition	• Titanium • Aluminum • Stainless steel • Copper • Inconel, Ceramics	• Repair projects in the aerospace and automation sectors. • Industrial applications. • Aerospace, biomedical applications.

5. Applications in 3D Printing Process

All the 3D printing processes that were mentioned are of benefit to achieve the manufacture of product in the minimum feasible time with less waste. These processes are used to manufacture complex shapes with high quality and with great ease. Table 3 shows some applications for different processes.

Table 3: Different Application of 3D Printing Process

3D Printing Process	Application
Fused Deposition Modelling	• Drug delivery • Pattem making
Stereolithography	• Lithium disilicate glass-ceramic • manufacturing of heart valve scaffold
Binder Jetting	• Bone scaffold • Pharmaceutical fabrication
Powder Bed Fusion	• Light weight robotic parts • Smart parts
Laminated Object Manufacturing	• Biodegradable polymers • Rapid tooling
Direct Energy Deposition	• Preparing stainless steel • Preparing automotive dies

6. Parameters of 3D Printing Machines

Process parameters determine the characteristics, quality, and accuracy of manufactured products. Additionally, there are various parameters that affect FDM printing. In light of their geometry, processes, and structural characteristics, these parameters can be divided into three groups figure 3. Orientation, layer thickness, raster angle, air gap and raster width was investigated by Anoop Kumar Sood et al. [39] they found that the number of heating and cooling cycles increased with number of layers increases. Small raster angle means strength will improve. Thick raster resulted with strong bond formation. The zero air gap will improve the diffusion between adjacent raster. A.W. Fatimatuzahraa et al. [40] they used two raster orientations and found that crisscross (45°,-45°) orientations provides better material strength. The effect of feed rate on mechanical properties was studies by K.G. Jaya Christiyana [41] and they found that tensile strength decreased with feed rate increase. Max. tensile strength realized at lower layer thickness. They clarified that low feed rate and lower thickness will gives a great tensile and flexural strength. Fuda Ning et al. [42] studied the effects of infill speed, raster angle, layer thickness and nozzle temperature) on mechanical properties of FDM process. They found tensile strength decrease with infill speed, layers thickness and nozzle temperature increase. The tensile strength was substantially higher for raster angles between 0 and 90.

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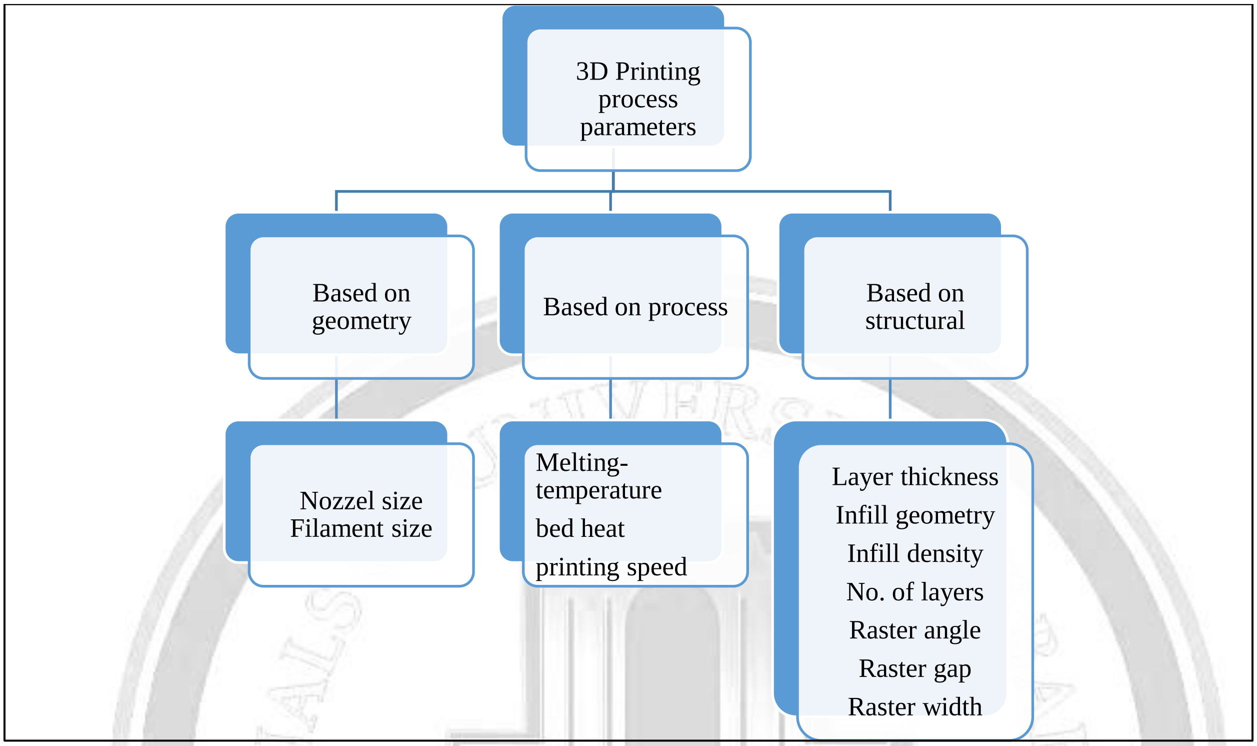

Figure 3: Classifications of Process Parameters

6.1 Geometry Based Parameters

6.1.1. The Size of Nozzle

On a 3D printer, the part that extrudes the filament to make the component is known as the nozzle. The diameters of the nozzle ranges from 10 to 100 mm. Because print speed and precision can be balanced, the typical nozzle size is about 0.4 mm.

6.1.2 Filament Size

The thermoplastic raw used to produce fused deposition materials in 3D printers is known as 3D filament. There are many different filament with varied properties that demand differents printing temperatures. The filaments come in two standard sizes of (1.75 mm and 2.85 mm). The 2.85 mm filament is known as the "3 mm" filament.

6.2 Process Based Parameters

6.2.1 Bed Temperature

The use of heated beds is crucial of 3D printing. Even while not every printer has them, those that do must always be set to a specific temperature. For instance, the ideal temperature range is 55 to 70° C.

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6.2.2 Printing speed

The most important level setting for 3D printing technology is print speed. Print speed, as the name suggests, refers to how quickly the printer's motors move. It consists of the extruder motor as well as the electric X- and Y-axis control motors.

6.3 Structural Based Parameters

6.3.1 Layer Thickness

Is each subsequent addition of the material used in additive manufacturing or 3D printing. One of the key technical aspects of a 3D printer is the layer height, which represents the vertical resolution of the z-axis. The X, Y, and Z axes are dealt with when constructing a project employing additions.

6.3.2 Infill Geometry

Another name for infill geometry is an infill pattern. In 3D printing, the pattern refers to this infill. The picture was printed inside the building. Slice software can be used to describe the infilling pattern for an object with variable proportions and morphologies. Printing duration, print speed, object toughness and mechanical qualities are all impacted by patterns. There are typically four different kinds of infill patterns: triangle, rectangle, hexagonal or honeycomb, and wiggly.

6.3.3 Infill Density

The amount of materials that fills the piece's interior. Programs are often rolled from 0% (empty part) to 100% to change the quantity of content (total solid part).

6.3.4 Raster Angle

The nozzle direction's angle of the FDM printer board with X-axis is referred to as the raster angle. There is a 90° difference in raster angles between two following levels. The precision of the sample's shape and mechanical effectiveness are impacted by the raster angle.

6.3.5 Raster Gap

The raster gap is the space between two adjoining filaments that were deposited in very same layer. The quantity of filaments located at the outside edge equals the number of contours.

7. Conclusions

3D printing is a sustainable process unlike traditional manufacturing processes. Because it is an effective and inexpensive process, in addition to being environmentally friendly, it can help reduce environmental pollution. Based on the previous research that was mentioned, 3D printing has developed greatly in terms of the materials used, it was not limited to polymeric materials only. Each type of 3D printing has different advantages and disadvantages. 3D printing can handle both complex and uncomplicated materials. The FDM process is the most typical process, but it is considered further suitable for polymeric materials than other materials. One of the problems facing the SLS process is the difficulty of transporting and storing powders.

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ARTICLE

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مراجعة في تقنية الطباعة ثلاثية الأبعاد: الأنواع ,التطبيقات ومتغيرات العملية

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الخلاصة

تعتبر الطباعة ثلاثية الابعاد من العمليات المضافة والقابلة للتطبيق في تصنيع المنتجات الهندسية على عكس العمليات التقليدية الأخرى. تتميز الطباعة ثلاثية الابعاد بعدة جوانب تجعلها الخيار الأول في عمليات التصنيع ومن هذه الجوانب هي التقليل من اهدار المواد المستخدمة، سهولة التصنيع، مشاركة اقل من جانب الانسان، المنتج النهائي لا يحتاج الى عمليات إضافية وكذلك تعتبر من العمليات الكفؤة. في هذه الدراسة سوف تتم مناقشة أنواع عمليات الطباعة ثلاثية الابعاد وكذلك مزاياها وعيوبها. يتم تقديم وصف شامل للمواد المستخدمة في الطباعة الثلاثية الابعاد مع ذكر المواد التي تلائم كل نوع من أنواع الطباعة. أيضا يتم ذكر التطبيقات التي تستخدم فيها كل نوع من أنواع الطباعة. من خلال البحوث السابقة التي تمت دراستها تبين انه على الرغم من تطور مجال الطباعة ثلاثية الابعاد بشكل كبير، لكن لاتزال هناك مشكلات تحتاج الى معالجة ودراسة أكثر مثل عدم توافق المواد المستخدمة مع نوع العملية وكذلك تكلفة المواد. يمكن اجراء البحوث المستقبلية عن تطوير وتعديل العمليات لتناسب مجموعة واسعة من المواد وذلك لتطبيقها في مجالات أكثر.

الكلمات الدالة: الطباعة ثلاثية الابعاد, FDM, متغيرات العملية, اللدائن الحرارية.

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