A Review on 3D printing Fused Deposition method technology

Sudeep Jain [1,a*], Vandana Somkuwar[2,b]
[1]Research Scholar, Dept. of Mechanical Engg, NITTTR Bhopal, India
[2]Associate Professor and Head, Dept. of Mechanical. Engg., NITTTR Bhopal, India

Abstract

The aim of this work is to investigate the effect of input parameters like filament diameter, extruder temperature, feed rate, raster angle, characteristic of working material, nozzle angle, distance between parallel faces on output parameters like surface finishing, moving speed or movement of nozzle head, material volumetric concentration, cooling of print, strength, number of shells and deposition rate in 3D printing through different optimization techniques. Considerable amount of work has been reported by the researchers on 3D printing and optimization of various input parameters. Several approaches are proposed in the literature to optimize these parameters hence it is felt that a review of the various approaches developed would help to compare their main features and their relative advantages and limitations to allow choose the most suitable approach for a particular application.

1. Introduction

The term 3D printing covers a host of processes and technologies that offer a full spectrum of capabilities for the production of parts and products in different materials. Essentially, what all of the processes and technologies have in common is the manner in which production is carried out layer by layer in an additive process, which is in contrast to traditional methods of production involving subtractive methods or moulding/casting processes. Applications of 3D printing are emerging almost by the day, and, as this technology continues to penetrate more widely and deeply across industrial, maker and consumer sectors, this is only set to increase. Most reputable commentators on this technology sector agree that, as of today, we are only just beginning to see the true potential of 3D printing. 3DPI, a reliable media source for 3D printing, brings you all of the latest news, views, process developments and applications as they emerge in this exciting field. This overview article aims to provide the 3DPI audience with a reliable backgrounder on 3D printing in terms of what it is technologies, processes and materials, its history, application areas and benefits.

3D Printing is a process for making a physical object from a three-dimensional digital model, typically by laying down many successive thin layers of a material. It brings a digital object (its CAD representation) into its physical form by adding layer by layer of materials. There are several different techniques to 3D Print an object. We will go in further details later in the Guide. 3D Printing brings two fundamental innovations: the manipulation of objects in their digital format and the manufacturing of new shapes by addition of material.

1.1 Additive Manufacturing.

Technology has affected recent human history probably more than any other field. Think of a light bulb, steam engine or, more latterly, cars and aeroplanes, not to mention the rise and rise of the World Wide Web. These technologies have made our lives better in many ways, opened up new avenues and possibilities, but usually it takes time, sometimes even decades, before the truly disruptive nature of the technology becomes apparent. It is widely believed that 3D printing or additive manufacturing (AM) has the vast potential to become one of these technologies. 3D printing has now been covered across many television channels, in mainstream newspapers and across online resources. What really is this 3D printing that some have claimed will put an end to traditional manufacturing as we know it, revolutionize design and impose geopolitical, economic, social, demographic, environmental and security implications to our everyday lives, The most basic, differentiating principle behind 3D printing is that it is an additive manufacturing process. And this is indeed the key because 3D printing is a radically different manufacturing method based on advanced technology that builds up parts, additively, in layers at the sub mm scale.

3D printing is an enabling technology that encourages and drives innovation with unprecedented design freedom while being a tool-less process that reduces prohibitive costs and lead times. Components can be designed specifically to avoid assembly requirements with intricate geometry and complex features created at no extra cost. 3D printing is also emerging as an energy-efficient technology that can provide environmental efficiencies in terms of both the manufacturing process itself, utilising up to 90% of standard materials, and throughout the products operating life, through lighter and stronger design. In recent years, 3D printing has gone beyond being an industrial prototyping and manufacturing process as the technology has become more accessible to small companies and even individuals. This has opened up the technology to a much wider audience, and as the exponential adoption rate continues apace on all fronts, more and more systems, materials, applications, services and ancillaries are emerging.

1.2 Types of 3D printers.

- Stereolithography (SLA)
- Digital Light Processing (DLP)

- Fused deposition modeling (FDM)
- Selective Laser Sintering (SLS)
- Selective laser melting (SLM)
- Electronic Beam Melting (EBM)

1.3 3D Printing Materials

- The materials available for 3D printing have come a long way since the early days of the technology. There is now a wide variety of different material types that are supplied in different states powder, filament, pellets, granules, resin etc. Specific materials are now generally developed for specific platforms performing dedicated applications an example would be the dental sector with material properties that more precisely suit the application. However, there are now way too many proprietary materials from the many different 3D printer vendors to cover them all here. Instead, this article will look at the most popular types of material in a more generic way. And also a couple of materials that stand out.

1.3.1 Plastics.

- Nylon, or Polyamide, is commonly used in powder form with the sintering process or in filament form with the FDM process. It is a strong, flexible and durable plastic material that has proved reliable for 3D printing. It is naturally white in colour but it can be coloured pre- or post-printing. This material can also be combined in powder format with powdered aluminium to produce another common 3D printing material for sintering Alumide.

1.3.2 Metals.

- A growing number of metals and metal composites are used for industrial grade 3D printing. Two of the most common are aluminium and cobalt derivatives. One of the strongest and therefore most commonly used metals for 3D printing is Stainless Steel in powder form for the sintering/melting/EBM processes. It is naturally silver, but can be plated with other materials to give a gold or bronze effect.

1.3.3 Ceramics.

- Ceramics are a relatively new group of materials that can be used for 3D printing with various levels of success. The particular thing to note with these materials is that, post printing, the ceramic parts need to undergo the same processes as any ceramic part made using traditional methods of production — namely firing and glazing.

1.3.4 Paper.

- Standard A4 copier paper is a 3D printing material employed by the proprietary SDL process supplied by Mcor Technologies. The company operates a notably different business model to other 3D printing vendors, whereby the capital outlay for the machine is in the mid-range, but the emphasis is very much on an easily obtainable, cost-effective material supply, that can be bought locally. 3D printed models made with paper are safe, environmentally friendly, easily recyclable and require no post-processing.

1.3.5 Bio Materials.

- There is a huge amount of research being conducted into the potential of 3D printing bio materials for a host of medical and other applications. Living tissue is being investigated at a number of leading institutions with a view to developing applications that include printing human organs for transplant, as well as external tissues for replacement body parts. Other research in this area is focused on developing food stuffs meat being the prime example.

1. Literature Survey

Many researcher have work toward the improvement of 3D printed components quality. So of the work is concluded in the below section.

1. **Yifan Jin et.al (2017)** Fused deposition modeling has become one of the most diffused rapid prototyping techniques, which is widely used to fabricate prototypes. On the other hand, further application of this technology is rigorously affected by poor surface roughness mainly due to staircase effect. It is necessary to adopt post-treatment operations to improve surface quality. Chemical finishing is typically employed to finish parts in fused deposition modeling. The main purpose of this paper is to make available a universal finishing method or solution for FDM parts made up of PLA, and to signify the evolution of surface topography between adjacent layers during the chemical finishing operation by constructing a geometrical model of the deposited filament.

2. **Szykiedans et.al (2016)** A new development of the 3-D printers, which has made them freely existing to the public at low costs. In order to make 3-D printed parts to be more useful for engineering applications the mechanical properties of the printed parts to be known must. This paper enumerates the elementary tensile strength and the elastic modulus of printed components produced with application of FDM and

SLA printers. The measurements showed a strong anisotropy of 3-D printed samples and the need to verify the data provided by the manufacturers. Acquired data verify that the parts printed by low cost 3-D printers can be considered mechanically functional in a extensive scope of applications. Mechanical properties including tensile test are to be tested further for different parameters of prints especially print orientation and infill ratio that determines amount of material inside printed part.

3. **Casavola et.al (2016)** The Fused Deposition Modelling (FDM) has become one of the most used techniques to 3D object rapid prototyping. In this process, the model is built as a layer-by-layer deposition of a feedstock wire. In the current years, the FDM grown from rapid prototyping technique to a rapid manufacturing method, varying the main purpose in producing finished components which is ready for use. Hence, the prediction of the mechanical properties of this new technology has an increasingly important role. In this paper, the mechanical behaviour of FDM parts has been defined by utilizing the classical laminate theory (CLT). In view of this aim, some mechanical parameters employed in CLT has been experimentally determined. The values of the Young's modulus in the longitudinal and transverse directions to the fiber (E1, E2) has been carried out by single layer tests conducted on specimens with 0° and 90° raster angles. The shear modulus (G12) has been determined according to the ASTM D3518. The Poisson's moduli have been dignified on five layers 0° specimens obtaining the longitudinal and transverse deformation by strain gauges.

4. **Jerez-Mesa et.al (2016)** The aim of this paper is to analyze the performance of a RepRap 3D printer liquefier by studying its thermal behaviour, concentrating on the convective heat dissipation developed beside the liquefier body all through the 3D printing process of a workpiece. More specifically, this work tackles with the influence of the airflow generated by a fan coupled to the extruder, on the heat transfer mechanisms during the printing process. The airflow is thus taken as the variable of study. The temperature at the top of the liquefier body, where a low temperature is desirable for the correct preservation of the 3D printer components, is analysed to assess the results for the different printing conditions. For the progress of this study, a finite elements model was used to conclude the theoretical temperature profile of the liquefier in a steady state working system. This mathematical model was then validated with experimental data registered with four thermocouples fixed on the tested extruder.

5. **Kousiatza et.al (2016)** The present work investigates the integration of fiber Bragg grating (FBG) sensors for continuous in-situ and in real-time monitoring of strain fields build up as well as of developed temperature profiles during the fabrication procedure of structures built via the Fused Deposition Modeling (FDM) technology. A methodology is presented for synchronized monitoring of strain and temperature profiles from the verified spectrum of an embedded optical sensor when the deposited material remains close by to its glass transition temperature. The used FBG sensors were embedded either longitudinally or transversely to the test samples' long axis and within different layers of the structures. The experimental results indicate that the magnitude of the induced residual strains, measured at a specific layer location within the specimen, is significant during material consolidation of deposited layers.

6. **Weng et.al (2016)** Organically modified nano fillers, including nano SiO2, montmorillonite and attapulgite were loaded to stereolithography resin (SLR). The surface of nanofillersm were modified using organic modifier of 3-(trimethoxysilyl)propyl methacrylate (γ-MPS) and (1-hexadecyl)dimethyl alkyl ammonium chloride (C16-DMAAC), and were characterized by FTIR and small angle XRD analysis. The morphology of Nano composites were observed by TEM. Viscosity and curing speed of SLR Nano composites at increasing nano fillers loading were also studied. The mechanical properties of printed samples fabricated by a home-made stereolithography apparatus (SLA) 3D printer were tested. The influence of nanoparticles on the accuracy was measured and discussed. Nano SiO2, ATP and OMMT were added into SLR to form nano composites. The morphology of nanoparticles in SLR matrix, rheology of SLR, curing kinetic and mechanical properties were studied. Rheology analysis showed that when nano filler loading increased to 10% w/w, the viscosity of SLR increased rapidly and are not suitable for current SLA 3D printer. It was found that the addition of nano SiO2 increased the curing speed of SLR, while the addition of OMMT and ATP decreased the curing speed.

7. **Islam et.al (2016)** has done an experimental investigation on the dimensional error produced in the parts manufactured from powder binder three dimensional printing. Initially ten replicates of a specific purpose specimen were produced using the method of powder binding. A general purpose coordinate machine was used to study the minute details of internal as well as external details of all the parts so produced. The results were than plotted on a common platform to compare the results with practical parts. Significant deviations were noticed regarding the bases of the replicates, instead of being flat in nature they were concave in nature and hence producing a flatness error. Most important thing to notice in the three dimensional printing printing is the curvature is usually convex in nature, which was in contrast with the results so produced in the paper.

8. **Galantucci et.al (2015)** in this paper has done an analytical dimensional evaluation and comparison using two different types of 3D printer using FDM technique. Optimum process parameters were taken to evaluate the results and improve the dimensional accuracy of the specimen. The paper is based on the experimental parameters to improve the accuracy and surface finish of the specimen based n fused deposition modelling technique. The key parameters were emphasized to balance the economy and dimensional tolerances of the produced parts

9. **Eitzlmayr et.al (2015)** Due to the complex geometry of the rotating screws and, typically, free surface flows in partially filled screw sections, first principles simulations of the flow in co-rotating intermeshing twin screw extruders using the well-established, mesh-based CFD computational fluid dynamics methods are so much puzzling. These problems can be determined via the smoothed particle hydrodynamics (SPH) method thanks to its mesh less nature and the integral capability to simulate free surface flows. In our earlier work, we developed a novel technique for modeling the boundary conditions through complex wall geometries, under which SPH could be efficiently applied to complex surfaces of typical screw geometries of extruders. In this work, we employed SPH and our boundary method to study the flow in a conveying element in detail.

10. **Dawei Li et.al (2015)** Physical modeling is a novel theory for 3D printing; this approach involves the use of a single material to control physical properties, such as centre of mass, total mass, and moment of inertia. In this work, we place a density of variable shape modeling method to encounter the required strength of 3D objects. We estimate an incessant density distribution that satisfies the noticed local stress distribution of 3D objects based on the cross-sectional stress analysis. We propose a physical modeling methodology to improve the structurally weak areas of 3D printed objects. The proposed method consists of two steps. Density distribution is first estimated to satisfy the detected stress of 3D objects. An internal cellular structure is then generated with a pure mathematical 3D implicit function to represent the density distribution. With this method, we optimize the structure of the model for 3D printing to increase its strength and minimize the use of materials. Finally, we demonstrate the effectiveness of our modeling method with numerous results.

11. **Lee et.al (2015)** Renewable energy has attracted considerable attention because the energy problem has become a worldwide issue. The development of pico-hydropower generation, as a component of circulated generation which has been a subject of good concern. In particular, the Archimedean screw generator (ASG) has more profitable, such as low cost, easy maintenance, and fish-friendly characteristic, as compared with different types of hydro turbine. In spite of these advantages, no proper design theory of ASG and Controllable-pitch Archimedean screw (CPAS) exists. Therefore, a design theory of ASG and CPAS was hypothetically examined and designed in this study. CPAS was designed for a small scale hydro-power generation system. The Archimedes screw turbine is a fish-friendly turbine that requires a low water head. Hence, such turbine is common for small power generation in Europe. To reduce the size and cost of this turbine, CPAS and 3D-printed blades are applied. The modified design theory of CPAS is suggested based on the simplified theory of Archimedean screw. The CPAS blade for small-scale generation is designed based on simplified theory. A 3D printer is used to manufacture a intricate CPAS.

12. **Melenka et.al (2015)** This paper aims to evaluate the material properties and dimensional protocol was applied to determine the effect of the following variables on the material properties of 3D printed part layer height, per cent infill and print alignment using a MakerBot Replicator 2 printer. Classical laminate plate theory was used to relate results from the DOE experiments with theoretically projected elastic moduli for the tensile samples. Dimensional accuracy of test samples was also investigated. DOE results recommend that per cent infill has an important effect on the longitudinal elastic modulus and ultimate strength of the test specimens, while print alignment and layer thickness fails to achieve significance. Dimensional analysis of test specimens shows that the test specimen varied significantly (p _ 0.05) from the nominal print dimensions. Although desktop 3D printers are an attractive manufacturing option to quickly produce functional components, this study suggests that users must be aware of this manufacturing process' inherent limitations, especially for components requiring high geometric tolerance or specific material properties.

13. **Carneiro et.al (2015)** This paper addresses the polypropylene potential (PP) as a candidate for fused deposition modelling (FDM) created 3D printing technique. The entire filament production chain is evaluated, starting with the PP pellets, filament production by extrusion and test samples printing. This approach allows a true comparison between parts printed with parts manufactured by compression moulding by using the same grade of raw material. Printed samples were mechanically characterized and the influence of filament orientation, layer thickness, infill degree and material was assessed. The approach used in this study enabled the full control over the complete process, from the extrusion of the

filaments to the printing of samples, and a fair comparison using exactly the same materials between competing technologies, avoiding many of the issues identified in other studies.

14. **Yang et.al (2015**) presented in his paper a novel method to produce 3D objects using smart memory polymer (SMP) as a material so that all the parameters involved in the quality production of the components can be optimised. The practical utility products involves lots of minute hurdeles. After making a sample SMP product its surface finish, dimensional accuracy tenacity and other parameters were verified. The fabrication method basically includes FDM (fused deposition modelling) in which the effect of printing parameters such as temperature of extruder, scanning speed and other parameters are studied. The speciality of the SMP material lies with its sensitivity to the thermal stimuli which have potential application in the field of aerospace applications.

15. **Taufik et.al (2015)** has done Surface roughness calculation studies in fused deposition modelling (FDM) process. The deposited layers were analysed with main focus on the profile perimeter of material. Basically the build edge profiles were scanned under categories to reduce any possibility of errors in the roughness models. The methodology involved some combinations of theoretical and empirical approaches to determine the randomness in the profile. Further a detailed comparison was made between the existing and proposed models to analyse the pros and cons of the process.

16. **Volpato et.al (2015)** polymer extrusion based additive manufacturing using continuous filament is very common. Perhaps these have the adverse effect on the economy and narrows the variation domain. These two issues are of prime importance and can be resolved by polymer pellets when used as feed stock. This paper describes how polypropylene granules can be extruded into a filament. The piston head was designed to reduce degradation of material and minimize the volume of material fused. Filament dimensions were characterized, followed by the analysis of materials by infrared spectroscopy and strength of the filament by tensile tests.

17. **Stewart et.al (2015)** has done analysis on fused deposition modelling using poly lactic acid as material, which reveals minute details of one among the various branches of 3D printing. To eliminate the part to part variation and to control the process parameter it is very important to study the temperature gradient of the material so produced in the liquefier. This work basically deals with the experimental analysis of

the output of resistive heat source and validation of liquefier temperature followed by the theoretical computation of the heat transfer coefficients. Simulation reveals the significant temperature difference in the proximity of the external heat source assembly and the top inlet of the PLA, which certainly rules out the method of providing heat source in constant heat flux and constant wall temperature.

18. **Kim et.al (2015)** The currently used plaster cast for wrist orthotic treatment is relatively heavy, non-removable, and unventilated. Because of wearing this cast can cause problems counting a variety of skin diseases, pilosis, joint and ligament injuries. This case study defines a hybrid manufacturing methodology that utilizes three-dimensional printing (3D printing) and injection moulding technology to generate a wrist orthosis that solves the problems of the plaster casts. Compared with the previously presented wrist orthosis using 3D printing and three-dimensional scanning (3D scanning) technology, the proposed hybrid model considerably decreases the manufacturing time and cost. The main concept of the hybrid model is to distinct the plastic cast into two parts such as an inner structure produced by 3D printing that surrounds the skin and an outer cover that is attached to the inner structure that keeps the injured part from external forces.

2. Conclusion drawn from literature survey

On the basis of above preliminary literature survey done in the area, following significant point are observed.

1. Following process parameters have influence on surface quality of a component:-

   Input Parameters:-

   - Feed Rate
   - Layer thickness
   - Raster angle
   - Material volumetric contraction
   - Distance between Parallel faces
   - Types of material
   - Temperature
   - Nozzle diameter

   Output Parameters:-

   - Surface Roughness
   - Strength

- Material Deposition rate

2. Research has been done on optimization of various input parameters for surface quality of different 3D printed part using following optimization techniques:-
    - Taguchi method
    - Analysis of variance (ANOVA)
    - Response Surface Method
3. No one has attempted to simulate the finite element method analysis in order to test the manufactured part Strength from depositing the first layer to until the last layer get deposited.
4. From literature survey it is also find that the strength of the deposited material or printed component made through fused deposition modeling depends on the pattern in which the material get deposited during the manufacturing.
5. It is also find that the orientation of the deposited layer one over the above also plays a very important role in strengthening the product.

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