A REVIEW ON FUSED DEPOSITION MODELING AND PERFORMANCE PARAMETERS ON WHICH THE 3D PRINTING MAINLY DEPENDS

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Abstract: 3D printing id the process in which the material get deposited layer by layer to manufacture the product. In 3D printing fused deposition, modelling is the process mainly used for the manufacturing of the polymer component. The surface finish of the 3D printed component depends on the different parameter. the surface finish of the 3D printed component also depends on the different input parameters, therefore it is necessary to review the 3D printing process.

1. Introduction

Among the most widely used and rapidly growing rapid prototyping or additive manufacturing (AM) technologies are extrusion deposition processes such as fused deposition modeling (FDM®), fused filament fabrication and melt extrusion manufacturing (MEM) (Wohlers, 2011). In a typical process, a filament of material is fed into a machine via a pinch roller mechanism. The feedstock is melted in a heated liquefier with the solid portion of the filament acting as a piston to push the melt through a print nozzle. A gantry moves the print nozzle in the horizontal *x–y* plane as the material is deposited on a build surface that can be moved in the vertical *z* -direction. This enables complex 3D objects to be produced as the melted bead leaving the nozzle solidifies. The most common materials used in this type of process are amorphous thermoplastics, with acrylonitrile butadiene styrene (ABS) being the most common.

Many of the researchers have optimized the different process parameters of the 3D printing process. Some of the research works in this field is shown in the below section

2.1 Existing Research Efforts

1. Thomas et.al [2014] has done study on the errors which were encountered during the fabrication process of 3D models by 3D printing method. The work basically deals with the patient specific adult female mandible which was produced using computer numerically controlled G-code and it was evaluated further to calculate the errors involved in the simulated process. The results revealed that the process was as accurate as ±3% having surface deviation of ±200 µm and that too because of the plastic shrinkage of the poly lactic acid which was extruded through 200-µm bore nozzle. Earlier processes used for these purpose were selective laser sintering (SLS) method which being primitive was time taking as well as expensive. The evolved process helped surgeons to pre frame the model so that the delicate operations can be evaluated with ease and successful operations can be performed. PLA plastic produces hollow honeycomb like internal structures with almost accurate duplicacy.

2. 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 involve 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.

3. Vaezi et.al [2012] has analyzed the various processes involved in the aided manufacturing (AM) process by classifying them in three broad categories, scalable micro-AM systems, 3D direct writing and hybrid processes and detail analysis is done. The results of individual processes and their advantage and disadvantage were plotted on single platform. The conclusion debunked the need of the society to keep abreast with the growing trend. Among the numerous papers and intensive research the optimised MSL and EFAB processes have shown the promising potential and satisfactory results for the AM 3D modelling.

4. Taufik et.al [2015] it 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. The results reveal that variations in the built edge profile causes roughness in the FDM process and also their profiles vary from each other too in different orientation. Most important conclusion is the variation in height and base length are the major factors contributing roughness in FDM.

5. Casavola et.al [2015] in this paper orthotropic mechanical property of fused deposition modelling is analysed using classical laminate theory. A feed stock wire is used in layer by layer form by FDM process to produce 3D object rapid prototyping. The mechanical behaviour of the produced parts were analysed by using CLT (classical laminate theory) in which the properties were evaluated such as elastic modulus in transverse direction, Poisson's ratio and shear modulus. The specimens having significant vertical dimensions are not included due to the limitation of FDM techniques to produce vertical specimens. Ultimately two different materials ABS and PLA were used to validate the authenticity of CLT. The results reveal that PLA has young's modulus and UTS values computed were almost double to that of the ABS even PLA being brittle nature.

6. Boschetto et.at [2014] has done study regarding accuracy prediction in fused deposition modelling technique [FDM] to fabricate physical prototypes without undergoing complications involved in the geometry modelling. The most important drawback in this process is its obtainable accuracy. The dimensional deviations show only few indications of the errors and they are also conflicting in nature making flak in the AM process. To overcome these drawbacks a geometrical filament which is a function of deposition angle and layer thickness to predict the accuracy of the part dimensions. Further the model was validated by experimental crusade. The experimental method made the use of profilometer to observe the minute deviations. The results reveal that the dimensional tolerances were absolute functions of the deposition angle; even the experimental data were synchronous to the obtained results.

7. Islam et.al [2013] they have 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. All external surfaces investigated in this study showed positive deviation from nominal values, especially in the z-axis. After compensation of the datum surface error average total height of specimen were reduced to 75%. The results revealed the nature of the surface in PBP and the availability of two different kinds of z axis dimensional errors namely cumulative and constant.

8. Galantucci et.al [2014] 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. Further a comparison was made between two 3D printers and the results reveal that the Fab@Home Model 1 printer gave acceptable results for the same material used in both the printers. The parameters which needed to be controlled are reducing the path speed and increasing the building model time.

9. Ahn et.al [2005] determined the fabrication direction while producing the parts using FDM process to reduce the post machining processes. The parts so produced by aided manufacturing technique have some limitations regarding surface finish and micro level dimensional tolerances. The main reason behind these limitation are these manufacturing processes incorporate layered deposition of the material which may be the function of the diameter of produced flow volume and fusion of the inter layer. Though the cycle involved in these manufacturing processes are very small and mere modelling of the parts to be produced on the CAD can simply replicate the physical model. To implement the present work and to enhance the accuracy and computational speed a surface roughness model with non linear characteristic. A new post machining volume as a objective function was produced. To prove the reliability of the solution a genetic algorithm was applied. The results reveal that with the developed intelligent technique the best fabrication direction to reduce the post machining volume was done. By applying GA best possible directions was acquired without falling into local optima.

10. Bellini et.al [2004] they have studied the liquefier dynamics in the fused deposition modelling which is a sub branch of layered manufacturing technique. In FDM technique the building blocks are deposited on the surface in the vector style. In recent development domain the process has reached beyond the building of model to a finished product. In this paper the liquefier dynamics is studied to synchronise the flow control with the control strategies in the extrusion phase. The results reveal that there is a good agreement between the applied flow rate i.e. theoretical curve and the physical response of the system i.e. experimental curve for small magnitudes. The suggestion of the paper reveal that A shift from ‘‘prototyping’’ to ‘‘manufacturing’’ necessitates the following improvements such as to meet the desired specification there should be an agreement between the core part input parameters, improved surface quality. To have a clear image of the peculiar phenomena that happens in the liquefier, a mathematical model based on physical assumptions was developed. After comparison of the results with the experimental devices the slip phenomena between the roller and the filament at top is the reason for the error in the steady deposition rate of the material.

11. Vaezi et.al [2010] In this work has studied the effects of deposited layer thickness and binder saturation level on the specimen. The 3D printed objects are basically the functions of various parameters such as layer thickness, size of the deposited powders and the level of saturation level of binder. In this paper the author has basically taken two key parameter of layer thickness and saturation level and studied its impact on the mechanical properties, integrity, smoothness and dimensional tolerances. The paper made the use of Zcorp's ZP102 powder and Zb56 binder. The chosen thicknesses of the printed layers are 0.1 and 0.087mm and the binder saturation levels are 90% and 125%. On the contrary if the binder saturation was kept constant and increasing the layer thickness would decrease tensile strength and increase flexural strength. The results reveal that network structure specimens having wall thickness of 0.7 mm had high dimensional deviation of about +0.5 mm. Under the constant layer thickness the 90% saturation binder are relatively lower in strength compared to 125% saturation but are more uniform in characteristic.

12. Noriega et.al [2013] has made the use of artificial neural networks and an optimization algorithm to improve dimensional accuracy of FDM square cross section. In FDM technique a consecutive fused layer of liquid in layer by layer form makes final geometry. Due to characteristic process however it is not possible to produce good dimensional tolerance. This paper has made some attempt to overcome these drawbacks. For this purpose, a model was developed to forecast the dimensions of the manufactured parts, based on available design characteristics. Particularly, this work has used an artificial neural network combined with an optimization algorithm, to determine the optimal dimensional values for the CAD model. Further according to the algorithm provided the CAD model was revamped. The analysis of then result shows that errors in the manufacturing are reduced drastically it was 50 and 30% for external and internal dimensions respectively.

13. Gunther et.al [2014] this paper aims to calculate the scope that can achieved using three-dimensional (3D) printing technology. Initially conventional additive manufacturing was analyzed using different parameters. The aim is to coat the particulate material followed by printing it on the tilted surface, taking into considerations of the distortions, which define the design of the test parts. For the easy evaluation of the tilted parts a prototype of magnified model was presented. After the study conclusion was drawn that 3D printing principle is suitable for the tilted parts, making production without any downtime possible. The so produced parts have sufficient accuracy for foundry applications. There is a significant comparison is made between the continuous 3D printing and conventional printing, and the conclusion is drawn that the special geometry has an edge when time factor is considered. Another big advantage is appreciation of the first in first out principle, which is also compatible with the chemical and thermal curing process.

14. 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 narrow 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. The results reveal that the generated system produces continuous filament. Material degradation occurred in the heated cylinder to some extent that does not affect the tensile strength of the extrudate. All the analysis was favourable except that constant area was not achieved throughout the length of the filament, which may lead the part variation and surface finish.

15. Pilipovic et.al [2007] has done an analysis which would aid in the selection of material for the rapid prototyping. Prototyping has numerous advantages in the field of research especially when there is a hit and trial experiment is pursued or when the mammoth structure are to be built without any defect in engineering as well as in manufacturing. In this work on the stipulated standards of the 3D printing machines (ZPrinter 310 Plus) and the hybrid Polyjet technique (Objet Eden 330), the test specimen were produced. Experiments were executed based on the dimensional tolerances, surface roughness and the basic mechanical properties of the prototype. Based on the results of the experiment results of measuring the dimensions of test specimen shows that the Objet Eden 330 instrument is more accurate in quality than the Z Printer 310 Plus. Mechanical properties of Full Cure belong to best category. For Vero material, the producer stipulates that VeroBlack has the highest flexural modulus. In VeroBlue materials the producer’s guaranteed values almost match the obtained ones. The worst mechanical properties are from the test specimens made of powder. However, their properties depend on the reinforcing agent which is added to powder or binding.

16. 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. The use of this type of model is the area of interest for the researchers as it provides the ease in the changing parameters as per the demands of the situation and helps in eliminating the part to part variation and improvement in the efficiency of the product. The results reveal that the use of external resistive heat source helps in the improvement of the design.

17. Sood at el. [2011] have developed a huge effort on improving the quality of FDM parts. Several quality objectives have been considered separately, including surface roughness, mechanical strength, sliding wear, and dimensional accuracy. The thesis deals with various part quality measures such as improvement in dimensional accuracy, minimization of surface roughness, and improvement in mechanical properties measured in terms of tensile, compressive, flexural, impact strength and sliding wear. The understanding generated in this work not only explain the complex build mechanism but also present in detail the influence of processing parameters such as layer thickness, orientation, raster angle, raster width and air gap on studied responses with the help of statistically validated models, microphotographs and non-traditional optimization methods

18. Boschetto et. al [2012] presented an experimental analysis to investigate the effects of several factors on the shape profile. Based on their experiment results, a domain was defined to clarify the influence on profile shape by only two parameters: layer thickness and stratification angle the model has been validated by an experimental campaign. The specimens have been investigated by means of profilometer analysis in order to study macrogeometrical and microgeometrical aspects. Finally, a case study highlighted the reliability of the model. The direct implication of this work is the capability, in process planning, to know in advance if the FDM part dimensions will satisfy the specification and the component will fit with others. Moreover, this model can be employed to choose the suitable manufacturing strategy in order to comply with industrial constrains and scopes.

19. Bellini et al. [2005] developed a screw-driven extruder to process composite ceramic-polymer granules. They reported promising qualitative results for the influence of some processing parameters on the mesostructural quality of ceramic models. However, there still exists limited knowledge about the fabrication of this type of materials using binder jetting additive manufacturing process. There are several important factors such as saturation level, power level, drying time as well as spread speed, which would potentially affect the accuracy and strength of the printed parts before and after sintering. Therefore, in this research an extensive experimental study was performed to obtain the optimal process parameters for the dental porcelain materials fabricated via ExOne binder jetting system. The results also provide general printing guidelines for the fabrication of glass ceramic materials.

20. Braanker et al. [2010] described an analysis they carried out to choose between the different methods for processing recycled high-density polyethylene.

21. Lee et al. [1995] suggested that the dimensional inaccuracy of 3D-printed parts is a direct result of the layer-by-layer manufacturing process and the interaction between adjacent layers. The mathematical models for both the top surface and the side surface are developed to quantitatively study the surface profiles. Critical process parameters are categorized into pre-process parameters and fabrication process parameters to investigate their impacts on the surface profiles. Results from the experiments validate the feasibility and effectiveness of the proposed surface profile models and indicate that good quality top surface can be achieved by coordinating the speed of filament driving motor and the axis driving motors synchronously, and the quality of side surface can be guaranteed by adjusting the stratification angle and the layer thickness appropriately. Based on the comparison between experimental results and analytical values, several optimization approaches for process parameters and conclusions are demonstrated to enhance the surface quality.

22. Senthilkumaran et al. [2009] developed a model for shrinkage in SLS and proposed a shrinkage compensation scheme to enhance the accuracy of parts. They reported considerable improvement in the accuracy of the parts applying their compensation scheme

23. Stopp et al. [2008] offered a novel approach for 3D printer calibration and increment of parts accuracy. Their method was based on the setting of bleed compensation.

24. Suwanprateeb et al. [2009] developed a new composition of powder and binder that resulted in the fabrication of transparent models like stereolithography models. The objective of this research is to study the effects of two parameters of layer thickness and binder saturation level on mechanical strength, integrity, surface quality, and dimensional accuracy in the 3D printing process. Various specimens include tensile and flexural test specimens and individual network structure specimens are made by the 3D printing process under different layer thicknesses and binder saturation by use of ZCorp.'s ZP102 powder and Zb56 binder. Two printing layer thicknesses, 0.1 and 0.087 mm, are evaluated at 90% and 125% binder saturation levels. Experimental findings show that under the same layer thickness, increment of binder saturation level from 90% to 125% would result in an increase of tensile and flexural strengths of the specimens and decrease of dimensional accuracy and surface uniformity of specimens

25. Pilipović et al. [2009] performed an experimental research work to compare two different RP processes from part mechanical properties point of view. In this work, based on the stipulated standards of the 3D printing machines (ZPrinter 310 Plus) and the hybrid Polyjet technique (Objet Eden 330), adequate test specimens were made. Furthermore, with adequate equipment, we carried out the analysis of the dimensions, roughness of surfaces, and mechanical properties of prototype test specimens. Then, based on the data obtained by testing of properties, we provided a critical commentary regarding the data stipulated by their producers. The best mechanical properties belong to test specimens made of FullCure. For Vero material, the producer stipulates that VeroBlack has the highest flexural modulus, and still the analysis results show that it is the lowest one. In VeroBlue materials the producer's guaranteed values almost match the obtained ones. The worst mechanical properties are from the test specimens made of powder. However, their properties depend on the reinforcing agent which is added to powder or binding.

26. Pyda et al. [2004] The heat capacity of poly (lactic acid) (PLA) is reported from T¼(5 to 600) K as obtained by differential scanning calorimetry (d.s.c.) and adiabatic calorimetry. The heat capacity of solid PLA is linked to its group vibrational spectrum and the skeletal vibrations.

27. Yardimci et al. [25] Fused Deposition processes involve successive melting, extrusion and solidification of thermoplastic polymer melts. Fluid mechanics and heat transfer of neat or particle-filled polymeric melts, viscoelastic deformation and solidification of the roads that are being produced, and repetitive thermal loading of the growing part are important physical processes that control the final quality of the part. Previous computational process models investigated deposition and cooling processes for single and multiple filaments. In the current study, complimentary computational models are presented for the extrusion phase of the process. Impact of liquefier and nozzle design on thermal hardware behavior and operational stability has been quantified.

Some of the researchers work is also shown in the table below

Table.1. Showing the research of the different researcher

Name of Researchers	**Year/ PAGE NO.**	**Contribution**	**Working Material**	**Optimization Method**	**Printer type**	**Input Parameters**	**Output Parameters**
Thrimurt-Hulu et.al.	2004 748-761	Optimized part deposition orientation in fused deposition modeling	ABS	GA Genetic algorithms	_	Slice thickness, build deposition orientation	Surface finish and build time
Lee et.al.	2005	Optimized rapid prototyping parameters for production of flexible ABS object	ABS	Taguchi method,ANOVA	_	Air gap, raster angle, raster width	Elastic performance
Ang et .al.	2006	Investigates of the mechanical properties and porosity relationships in fused deposition modeling fabricated porous structure	ABS	full factorial design	_	Porosity, compressive yield strength ,compressive modulus	All input parameters

Sebastian et.al.	2008	Developed a new method for printer calibration and contour accuracy manufacturing with 3D – print technology	Plaster powder ZP130	_	_	Direction and position	_
Sun et.al.	2008	Investigated the effect of processing conditions on the bonding quality of FDM polymer filament	ABS-P400	_	Stratasy's FDM 2000	Liquefier temperature, envelope temperature, convective condition	Mesostructure, Bond strength b/w filaments
Mohammad el.al.	2010	Investigated the effect of layer thickness and binder saturation level parameter on 3D printing process	Zp102 powder & Zb56 binder	_		Layer thickness, binder saturation level	Mechanical strength, integrity, surface quality,
Nancharaiah et.al.	2010	Experimentally investigated the surface quality and dimensional accuracy of FDM components	ABS	Taguchi and ANOVA	_	Layer thickness , road width , raster angle, air gap	Surface quality and dimensional accuracy
Arivazhagen et.al.	2011	Performed Dynamic mechanical analysis of FDM rapid processed polycarbonate material	PC	Laboratory experiment	_	Build style, raster angle, raster width	Storage modulus, complex viscosity, loss modulus
Zhang et.al.	2012	Optimized process parameters for fused deposition modeling	ABS	Taguchi method	_	Wire Width compensation, extrusion velocity, filling velocity, layer thickness	Dimensional error, warpage deformation
Ismail et. al.	2013	Performed experimental investigation of FDM process for improvement of mechanical properties and production cost	ABSplus-P430	_	_	Raster angle, part orientation	Surface roughness, manufacturing time, maintenance cost
Sahu et. al.	2013	Performed a study on dimensional accuracy of fused deposition modeling	ABS	Taguchi method and Fuzzy logic	_	_	_
Villalpando et. al.	2014	Proposed an optimization	ABS	Genetic algorithm	_	Deposited layer, raster	Mechanical

		approach for components build by fused deposition modeling with parametric internal structure		approach		orientation	property, build time, material utilized
Baschetto et. al.	2014	Predicted accuracy in fused deposition modeling	ABS	_	Statasy's Dimension BS1768	Layer thickness, deposition angle	Dimension deviation
Yangyang et. al.	2015	Executed 3D printing of shape memory polymer for functional part fabrication	Shape memory polymer	ANOVA	Stratasy's	Extruder temperature, scanning speed	Part density, dimensional accuracy and Surface roughness

Conclusion

Models of liquifier dynamics were reviewed previously. Understanding liquefier behavior is critical in melt extrusion AM systems as a dynamic control is required to change the feed rate with print head velocity to maintain a constant road width and ensure that the printed bead has sufficient thermal energy to form a strong bond with the material on which it is printed. One of the first challenges in modeling liquifier behavior is the complex behavior of the melt, with viscosity having both temperature and shear rate dependence. Generally, viscosity in the liquefier has been described by a power-law model for the shear dependence in combination with an Arrhenius-type temperature dependence expression. While this approach to modeling polymer melt viscosity is common, it presents two challenges. First, there is a need for published viscosity data for commercial feed stocks. As with other polymer-processing technologies, commercial feedstock filaments are optimized for the process.

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