Investigating the thermal behavior of 3D printer extruder of Fused Deposition Modeling

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Abstract—In the present work, different optimization techniques used for 3D printing or fused deposition modeling processes are studied and after effects of various input parameters on some performance parameters of 3D printed component like surface finish have been reviewed. 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. In view of above, this paper presents a review of development done in the area of optimization of process parameter of 3D printed components

Keywords—3D Printing, Process parameters, Performance parameters, Optimization techniques, surface finish, Deposition rate

I. INTRODUCTION

Additive manufacturing technology is an advanced manufacturing technology used for fabricating parts layer by layer directly from a computer aided design (CAD) data file. The process builds objects by adding material in a layer by layer fashion to create a three-dimensional (3D) part, offering the benefit to produce any complex parts with shorter cycle time and lower cost compared to traditional manufacturing process. There are many commercial additive manufacturing systems available in the market such as fused deposition modeling (FDM), direct metal deposition (DMD), 3D printing, selective laser sintering (SLS), inkjet modeling (IJM) and stereo lithography (SLA). These systems differ in the manner of building layers and in the types of materials that can be fabricated by these processes safely. This paper presents a comprehensive review of 3D printing or FDM process parameteroptimization involving different method of optimization and identifies several research gaps where further research and development work can be directed to make this technology deliver products with higher accuracy, better quality and desired properties. FDM process conditions play an important role in improving surface roughness, dimensional accuracy, mechanical properties, material behavior and build time. Critical process parameters that affect the quality of processed part have been discussed. There has been extensive research on this topic focusing on experimental results and process optimization. Most of the researches on FDM process parameters have been directed toward optimizing process parameters to improve the surface finish, dimensional accuracy and mechanical properties.

II. VARIOUS TECHNIQUES FOR OPTIMIZATION OF 3D PRINTING OR FDM PROCESS PARAMETERS

The studies use several optimization techniques they may be classical or numerical based and have lead to evolved techniques used in modern technical scenario. After going through the literature the major optimization techniques and tools utilized by the researchers are as follows: Taguchi, S/N, ANOVA, Full factorial design, Genetic algorithm approach, DOE (design of experiment).

III. VARIOUS PROCESS AND PERFORMANCE PARAMETERS

The parameters which play important role in 3D printing or FDM are as follows: Slice thickness, build deposition orientation, Air gap, raster angle, raster width,build laydown pattern, wire-width compensation, extrusion velocity, filling velocity, Porosity, compressive yield strength, compressive modulus, Tensile strength, dimension accuracy and surface roughness, Liquefier temperature, envelope temperature, convective condition.

IV. VARIOUS 3D PRINTER USED

Various 3D printer utilized by the researchers are as follows: Stratasy's FDM 2000, Fab@home,Stratasy's FDM-3000, Statasy's Dimension BS1768, Zcorporation-Z450, Makerbot replicator-2, Prusai3.

V. EXISTING RESEARCH EFFORTS

Anitha et.al.[1] investigated the effects of some important FDM process parameters on surface roughness of ABS prototype. The Taguchi's design matrix, signal to noise ratio (S/N) and analysis of variance (ANOVA) are used in this study. Three process parameters including layer thickness, raster width and speed of deposition are considered. This study revealed that the factor having the most important influence on the surface roughness is the layer thickness compared to road width and speed. It has also revealed that there is inverse relation between layer thickness and surface roughness.

Thrimurthuluet.al. [2] used real coded genetic algorithm (GA) to develop an analytical model to predict the optimum part orientation for surface roughness. The prediction of the developed model is validated and it is in good agreement with the result published earlier. This study concluded that the developed model could be used to predict the optimum part orientation for any complex freeform surfaces. However, this developed model has the limitation that it can only predict build orientation but other critical process parameters cannot be predicted by this model.

Lee et.al. [3] performed experimental investigation on optimization of rapid prototyping parameters for production of flexible ABS object. They carried out Taguchi method and ANOVA technique optimizationsconsidering air gap, raster angle, raster width and layer thickness as parameters. The study concluded that layer thickness, raster angle and air gap are the critical factors in determining the elastic performance of the part. The optimum parameters determined and the results obtained are in a good agreement with the laboratory experiments with percentage error of 0.18%.

Ang et.al.[4] revealed that the mechanical properties and porosity of ABS manufactured parts are mostly influenced by process conditions such as air gap, raster width, build orientation, build laydown pattern and build layer. They used 25 fractional factorial design to understand the influence of each process variable. They reported that air gap has the largest effect on the porosity and mechanical properties of the scaffolds. Based on their study, multiple regression models are used to check the significant improvement of mechanical properties and porosity

Wang et.al.[5] found that tensile strength of FDM part is significantly higher when testing samples are put in the deposition orientation—Z direction. They demonstrated that the worst tensile strength is observed when testing samples are in the direction perpendicular to the layer. The developed model is verified experimentally and the predicted results agreed well with laboratory experiments. However, they obtained the three independent optimum solutions, for the minimum dimensional deviation, the minimum surface roughness, and the maximum tensile strength, respectively. If the dimensional deviation and surface roughness should be as minimum as possible, and at the same time the tensile strength should be maximized, the research effort could not provide a conclusive solution to the problem.

Sebastian et.al.[6] verified a new method for accurate part manufacturing using a 3D printer. In particular, the direction and position dependence of the printed results are to be verified within the building area. Test cubes with a defined edge length are printed and measured afterwards. The work shows the position and direction dependency of the 3D-printer manufacturing accuracy. Furthermore, a calibration procedure for bleed compensation calibration is presented. Show that the printer accuracy is as expected in terms of direction dependence. However, the position dependency has a greater influence on the result.

Sun et. al. [7] investigated the mechanisms controlling the bond formation among extruded polymer filaments in the fused deposition modeling (FDM) process. The bonding phenomenon is thermally driven and ultimately determines the integrity and mechanical properties of the resultant prototypes. Results suggest that better control of the cooling conditions may have strong repercussions on the mechanical properties and accuracy of the final part fabricated using the FDM process.

Saaidah et.al. [8] performed investigations into the process parameters of FDM Prodigy Plus (Stratasys, Inc., Eden Prairie, MN, USA)printer/machine. Various selected parameters are tested and the optimum condition is proposed. The quality of the parts produced is accessed in terms of dimensional accuracy and surface finish. The optimumparameters obtained are then applied in the fabrication of the master pattern prior to silicone rubber moulding (SRM). The dimensional accuracy and surface roughness are analyzed using coordinate measuring machine (CMM) and surface roughness tester, respectively.

Mohammad et.al. [9] studied the effects of two parameters i.e. 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.

Nancharaiah et.al.[10] studied the influences of process parameters such as layer thickness, raster width, raster angle and air gap on the surface finish of FDM processed ABS part through Taguchi method and ANOVA technique. It is seen that surface roughness could be improved by using lower value of layer thickness and air gap because it reduced the voids between layers. The weakness of this approach lies in only determining the best combination of process parameters. It cannot be used to determine the final optimum process conditions particularly in cases of multi-quality optimization.

Masood et.al.[11] experimentally investigated the effects of the FDM process parameters such as build style, raster width, and raster angle on the tensile properties of PC FDM. They concluded that the highest tensile strength could be obtained when build style is solid normal, raster width is 0.6064 mm and raster angle is 45. It is also concluded that the tensile strength of PC prototype greatly depended upon build style because the solid normal build style filled the part completely with fully dense raster tool paths.

Arivazhagan et.al[12] investigated the effects of the FDM process parameters such as build style, raster width, and raster angle on the dynamic mechanical properties of PC processed part. Frequency sweep from 10 Hz to 100 Hz is used at three different isothermal temperatures. It is concluded that solid normal build style with raster angle of 45, and the raster width of 0.454 mm led to the best dynamic properties than other build styles (double dense and sparse).

Zhang et.al. [13] established empirical relations between process parameters (wire-width compensation, extrusion velocity, filling velocity, and layer thickness) and dimensional error and deformation of FDM fabricated ABS part using Taguchi method combined with fuzzy comprehensive evaluation. They reported that the optimal process parameter values for dimensional error are: wire-width compensation 0.17 mm, extrusion velocity 20 mm/s, filling velocity 30 mm/s and layer thickness 0.15 mm.

Nannan et.al.[14] reviewed the main processes, materials and applications of the current AM technology and presents future research needs for this technology. To gain further acceptance from industry, research and development is needed in terms of designs, materials, novel processes and machines, process modeling and control, biomedical applications, and energy and sustainability applications in order to broaden the applications of AM technology and elevate it to a mainstream technology.

Ismail et.al.[15] this paper is to describe how parts manufactured by fused deposition modeling (FDM), with different part orientations and raster angles, are examined experimentally and evaluated to achieve the desired properties of the parts while shortening the manufacturing times due to maintenance costs. Results suggest that the orientation has a more significant influence than the raster angle on the surface roughness and mechanical behavior of the resulting fused deposition part.

Sahu et.al.[16] applied Taguchi method to study the main and interaction effects of process variables such as layer thickness, orientation, raster angle, raster width and air gap on part accuracy. In this study, prediction model, based on fuzzy logic and Mamdani method is developed to optimize dimensional accuracy. It is concluded that the value of average percentage error of less than 4.5% is obtained from the laboratory experiment which agreed well with the predicted response.

Villalpando et.al.[17] studied that the incorporation of reconfigurable parametric internal matrix structures based on primitive elements balance the mechanical properties, the material usage and the build time. Parametric internal structures are designed and compressive test components built and tested both experimentally. Compressive characteristics are also depicted using simulation tools.

Galantucci et.al.[18] In this paper an analytical dimensional performance evaluation and comparison is illustrated through two different 3D FDM printers: an industrial system, and an open-source one (a modified Fab@Home Model 1 printer). Using a factorial analysis design of experiment (DOE), optimum process parameters are found to improve dimensional accuracy on rectangular test specimens, minimizing changes in length, width and height. Fab@Home printer demonstrated to be a good platform, simple, flexible and inexpensive.

Boschetto et.al.[19] a geometrical model of the filament, dependent upon the deposition angle and layer thickness, has been developed in order to predict the obtainable part dimensions. The model has been validated by an experimental campaign. The specimens have been investigated by means of profileometer analysis in order to study macro geometrical and micro geometrical aspects.

Yang Yang et.al.[20] This article presents a novel method of shape memory polymer (SMP) processing for additive manufacturing, in particular, fused-deposition modeling (FDM).Critical extrusion process parameters have been experimented to determine an appropriate set of parameter values so that good-quality SMP filament could be made for FDM. The quality evaluation is performed based on part density, dimensional accuracy, and surface roughness. Lastly, samples of 3D SMP parts have been built to demonstrate potential applications of printed SMP parts.

Islam et.al.[21] performed experimental investigation into the dimensional error of the rapid prototyping additive process of powder-binder three dimensional printing. Ten replicates of a purpose-designed part are produced using a 3D printer, and measurements of the internal and external features of all surfaces are made using a general purpose coordinate measuring machine. The results reveal that the bases of all replicates (nominally flat) have a concave curvature, producing a flatness error of the primary datum.

Garrett et.al.[22] evaluated the material properties and dimensional accuracy of a MakerBot Replicator 2 desktop 3D printer. A design of experiments (DOE) test protocol is applied to determine the effect of the following variables on the material properties of 3D printed part: layer height, per cent infill and print orientation using a MakerBot Replicator 2 printer. Classical laminate plate theory is used to compare results from the DOE experiments with theoretically predicted elastic moduli for the tensile sample.

Carneiro et.al. [23] This paper addresses the potential of polypropylene (PP) as a candidate for fused deposition modeling (FDM)-based 3D printing technique. The entire filament production chain is evaluated, starting with the PP pellets, filament production by extrusion and test samples printing. Printed samples are mechanically characterized and the influence of filament orientation, layer thickness, infill degree and material is assessed. Regarding the latter, two grades of PP are evaluated: a glass-fiber reinforced and a neat,non-reinforced, one. It is concluded that there is still scope of further improvement in the performance of the printed samples, making this process competitive when compared to the conventional ones, for the production of small series of parts/components.

Dawei et.al.[24] proposed a density variable shape modeling method to meet the required strength of 3D objects. A continuous density distribution is estimated that satisfies the detected local stress distribution of 3D objects based on cross-sectional stress analysis. After that a pure mathematical 3D implicit function is utilizd to generate a porous structure with a gradational interior to represent this density distribution

Ksawery et.al.[25] This paper quantifies the basic tensile strength and elastic modulus of printed components produced with application of FDM and SLA printers. Tests have been conducted using ABS, fiberglass reinforced polyethylene terephthalate glycol (Z-Glass) and a Nobel printer photo resistive resin. The collected data show some distinctions between tensile modulus of 3-D prints and its base materials, i.e. Z-ABS prints Young modulus have mean value of 1.12 GPa and the encyclopedic value is between 1.7 up to 2.1 GPa. For other tested materials tensile modulus is appointed as 1.43 GPa for Z-Glass and 246 MPa for a Nobel printer photopolymer resin.

VI CONCLUSION

This article presents a review of research work carried out in the determination and optimization of the process parameters for 3D printing or FDM. A review of research work on various optimization techniques indicated that there are successful industrial applications of Taguchi method, RSM, GA and ANN. These are robust optimization techniques to make experimental design insensitive to uncontrollable factors such as environmental parameters to predict responses and optimize the FDM process parameter for good surface finishing and accuracy level. The literature review shows that process parameters including air gap, layer thickness, raster angle, raster width and build orientations are the critical factors and these must be studied and analyzed in future research.

REFERENCES

[1] Anitha R, Arunachalam S, RadhakrishnanP(2001) Critical parameters influencing the quality of prototypes in fused deposition modeling. J Mater Process Technology 118(1–3):385–388

[2] Thrimurthulu K, Pandey PM, Reddy NV(2004) Optimum part deposition orientation in fused deposition modeling. Int J Mach Tools Manufacturing 44(6):585–594

[3] Lee B, Abdullah J, Khan Z(2005) Optimization of rapid proto- typing parameters for production of flexible ABS object. J Mater Process Technology 169(1):54–61

[4] Ang KC, Leong KF, Chua CK(2006) Investigation of the mechanical properties and porosity relationships in fused deposition modeling-fabricated porous structures. Rapid Prototype J 12(2):100–105

[5] Wang CC, Lin TW, Hu SS(2007)"Optimizing the rapid proto- typing process by integrating the Taguchi method with the gray relational analysis". Rapid Prototype J 13(5):304–315

[6] Sebastian Stopp, Thomas Wolff, Franz Irlinger and Tim Lueth(2008) "A new method for printer calibration and contour accuracy manufacturing with 3D-print technology".Rapid Prototyping Journal 14/3 (2008) 167–172.

[7] Q. Sun, G.M. Rizvi, C.T. Bellehumeur, P. Gu, (2008),"Effect of processing conditions on the bonding quality of FDM polymer filaments", Rapid Prototyping Journal, Vol. 14 Iss 2 pp. 72 – 80

[8] NurSaaidah Abu Bakar, Mohd Rizal Alkahari, HambaliBoejang(2010)"Analysis on fused deposition modeling performance".Journal of Zhejiang University-SCIENCE A (Applied Physics & Engineering)ISSN 1673-565X (Print); ISSN 1862-1775

[9] Mohammad Vaezi&Chee Kai Chua(2010)"Effects of layer thickness and binder saturation level parameters on 3D printing process"Int J Advance Manufacturing Technology 53:275–284

[10] Nancharaiah T, Raju DR, RajuVR(2010)"An experimental investigation on surface quality and dimensional accuracy of FDM components". Int J Emerging Technology 1(2):106–111

[11]S. H. Masood, W. Rattanawong and P. Iovenitti(2000)" Part Build Orientations Based on Volumetric Error in Fused Deposition Modeling".Int J Advance Manufacturing Technology (2000) 16:162–168

[12] Arivazhagan A, Masood SH, Sbarski I (2011)"Dynamic mechanical analysis of FDM rapid prototyping processed polycarbonate material".In: Proceedings of the 69th annual technical conference of the society of plastics engineers 2011 (ANTEC 2011), vol 1. Boston, Massachusetts, United States, 1–5 May 2011, pp 950–955

[13] Zhang JW, PengAH(2012)"Process-parameter optimization for fused deposition modelling based on Taguchi method". Advance Mater Res 538:444–447

[14] []Nannan GUO, Ming C. LEU(2013)"Additive manufacturing: technology, applications and research needs " Front. Mech. Eng. 2013, 8(3): 215–243

[15] Ismail Durgun, RukiyeErtan(2014),"Experimental investigation of FDM process for improvement of mechanical properties and production cost", Rapid Prototyping Journal, Vol. 20 Iss 3 pp. 228 – 235

[16] Sahu RK, Mahapatra S, SoodAK(2013)"A study on dimensional accuracy of fused deposition modelling (FDM) processed parts using fuzzy logic". J Manufacturing Science Prod 13(3):183–19

[17] L. Villalpandoa, H. Eiliata, R. J. Urbanicb(2014)"An optimization approach for components built by fused deposition modeling with parametric internal structures"CIRP17(2014)800–805

[18] L.M. Galantuccia, I. Bodib, J. Kacanib, F. Lavecchiaa (2015)"Analysis of dimensional performance for a 3D open-source printer based on fused deposition modeling technique" CIRP 28 (2015) 82 – 87

[19]A. Boschetto& L. Bottini(2014)" Accuracy prediction in fused deposition modelling" Int J Advance Manufacturing Technology (2014) 73:913–928

[20]Yang Yang1, Yonghua Chen1,Ying Wei1 &Yingtian Li 1(2015)"3D printing of shape memory polymer for functional part fabrication "Int J Advance Manufacturing Technology DOI 10.1007/s00170-015-7843-2

[21]M. N. Islam1 & Samuel Sacks1(2015)" An experimental investigation into the dimensional error of powder-binder three-dimensional printing".Int J Advance Manufacturing Technology (2016) 82:1371–1380

[22] Garrett W. Melenka Jonathon S. Schofield Michael R. Dawson Jason P. Carey, (2015),"Evaluation of dimensional accuracy and material properties of the MakerBot 3D desktop printer".Rapid Prototyping Journal, Vol. 21 Iss 5 pp. 618 – 627

[23] O.S. Carneiroa, A.F. Silvab, R. Gomesa(2015)"Fused deposition modelling with polypropylene".Materials& Design 83 (2015) 768–776

[24] Dawei Li1, Ning Dai1,Xiaotong Jiang1, Xiaosheng Chen (2015)"Interior structural optimization based on the density-variable shape modelling of 3D printed objects"Int J Advance Manufacturing Technology DOI 10.1007/s00170-015-7704-z

[25]KsawerySzykiedansa, WojciechCredoa (2015) "Mechanical properties of FDM and SLA low-cost 3-D prints".Procedia Engineering 136: 257 – 262