SELECTION OF VARIOUS PROCESS PARAMETERS FOR FUSED DEPOSITION MODELING PROCESS: A COMPREHENSIVE REVIEW

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Abstract: *Rapid prototyping (RP) refers to a group of technology that can automatically construct the physical models from computer aided design (CAD) data. They make excellent visual aids for communicating ideas with co-workers or customers. In addition, prototypes can be used for design testing. Designers have always utilized prototypes; RP allows them to be made faster and less expensively. The recent development of Additive Manufacturing (AM) or Rapid prototype technologies, such as Fused Deposition Modeling (FDM), is driving it from rapid prototyping to rapid manufacturing. However, building end-user functional parts using FDM proved to be a challenging task. Fused deposition modeling (FDM) is process for developing rapid prototype objects from plastic material by laying track of semi molten plastic filament on to a platform in a layer wise manner from bottom to top. The aim of this work is to investigate the effect of various process parameters such as raster angle, road width and air gap on surface roughness and Tensile strength of fused deposition modelling built parts.*

Keywords: *Rapid prototyping, fused deposition modeling, polyethylene elastomer (PC), Tensile strength, Surface roughness*

1. INTRODUCTION

Now a day the fast growth customer demands and globalization of manufacturing industry are needed rapid manufacturing process that can satisfy the customers demand and sustain in the market place. The traditional processes need large time for manufacturing a job. So, rapid manufacturing, all non-productive times need to be eliminated. The traditional process involves time loss for making designing, manufacturing, assembly and testing. For example, in case of a foundry process, lot of time is required to prepare pattern designing, making, casting and evaluating its performance. This initially involves designing until it satisfies the product specification, which is a very slow process. In order to reduce these non-productive times to overcome the slow trend and grow up with the requirements of the next generation, the most logical answer to the future of design and manufacturing is the Additive manufacturing process also calls rapid prototyping (RP). (Arup Dey et. al. 2019)

Term rapid prototyping refers to a group of technologies that construct physical geometry models from Computer-Aided Design (CAD) data. These 3-D models are printed by "3 dimensional printers" create quickly tangible prototypes of their designs. Such models have numbers of uses. They are useful for visual aids purpose and to communicate an idea with co-workers and customers. Also, prototypes can use for testing the product design. For example, in an aerospace engineer, a model of airfoil is used to measure for lift force and drag force acting in wind tunnel. Designers have to use prototypes; Rapid prototype allows them to make faster and chip. Most prototypes process requires two to seventy hours to build, depend on the size and design of the object. These time savings allow manufacturers to bring products in market faster and cheaper. So, Rapid Prototyping technology meets the current needs of customer and industry. (Hyndhavi and Murthy 2017, Elmar Moritzer et. Al. 2019, Khaoula Abouzaid at al. 2019)

At last, more then 30 rapid prototyping machining techniques are commercially available, each have unique strengths. These techniques are also called solid free-form fabrication; computer aided manufacturing, or layer by layer manufacturing.

2. BASIC WORKING PRINCIPLES OF FDM

The basic principles of FDM are summarized in Fig. 1. The build material and support material are located on reels located at the sides of the machine. They are fed upwards through a tube into the extrusion head via drive wheels controlled by the machine. The build material is the material that will make up the final part, while the support material is sacrificial. Parts that have free hanging parts must have support structures, since the filaments cannot be deposited in mid-air. These support structures are dissolved in a solution and removed after the part is finished.

Within the extrusion head is a liquefier, which heats and melts the material to be extruded through the extrusion nozzle. This material is deposited onto the base collector, which is also heated to aid in the adhering of the build material to the plate. The temperature of the plate is below the glass transition temperature of the extruded filament, allowing for the liquefied filament to solidify upon contact.

The X-Y element of the deposition process is controlled by movement of the extrusion head in the X and Y directions. Once a single layer of the structure has been completed and successfully deposited onto the base collector plate, the build platform is lowered slightly. The process repeats, and another layer is deposited onto the previous layer, eventually generating a 3D model.

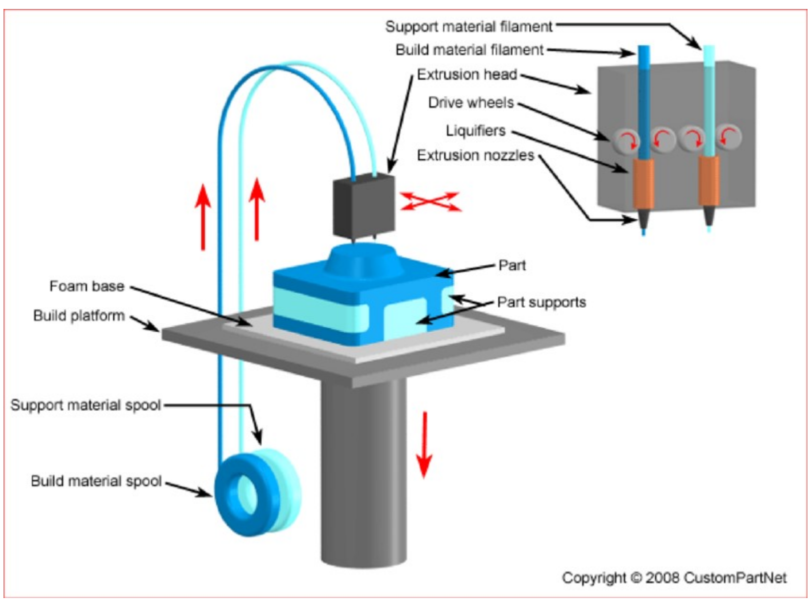

Fig. 1 Basic Working Principles of FDM

Literature review is one of the scope studies. It works as guide to run this analysis. It will give part in order to get the information about Fused Deposition Modeling and will give idea to operate the test. From the early stage of the project, various literature studies have been done. Research journals, books, printed or online conference articles were the main source in the project guides. This part will include almost operation including the test, machining properties and results. Literature review section work as reference, to give information and guide base on journal and other source in the media.

3. SIGNIFICANCE OF PARAMETERS AND TECHNIQUES

Sandeep Deswal et.al[5]., have done work for modeling and parametric optimization in FDM 3D printing process. In this work they make the part from ABS material and layer thickness, infill density, build orientation and number of contours are as significant process parameters for dimensional accuracy of build part. The hybrid statistical tools, response surface methodology, genetic algorithm, artificial neural network and genetic algorithm in MAT LAB 16.0 were used for training and optimization. From the experiment they conclude that minimum percentage variation in length = 0.06409%, width = 0.03961% and thickness = 0.85689% can be obtained by using ANN-GA compared to other method.

D.Devika et.al[6]., have done work on modeling the process parameters for PC-ABS material in FDM. In this work they find the effect of slice height, raster width, air gap, orientation and raster angle on surface roughness, dimensional accuracy and porosity. The experiment was designed by Taguchi's method and analyses were done by using ANOVA and Response surface methodology. From the experiment good dimensional accuracy and minimum surface roughness and porosity is found to be at minimum value of slice height, air gap and raster angle with maximum value of raster width and orientation angle.

Arup Dey et.al.[7], have done work on optimization of process parameters in FDM process. In this work they make the model by using PLA material with considering the layer thickness, build orientation, infill density, and extrusion temperature as process parameters to achieve higher compressive strength and lower build time. The analysis was done by using multi objective particle swarm optimization algorithm. The outcome of the optimization, among the analyzed four parameters, the extrusion temperature is insignificant for both build time and compressive strength. For build time and compressive strength, 0^{o} build orientation is preferable.

Guoying Dong et al.[8], have done work on fabrication of lattice structure by using FDM process. In this work they create two struts incline and horizontal with considering the nozzle temperature, fan speed, print speed, and layer height as process parameters for improvement of lattice structure quality. The Acrylonitrile Buta-diene Styrene (ABS) is use as basic material. The Taguchi's method use for design of experiment and analysis was done by S/N ratio analysis to find the optimum process parameters that improve the printing quality, and ANOVA provided a significance percentage of the various factors analysed. From the experiment they conclude that most significant process parameter for inclined struts is fan speed while for horizontal struts is layer height. The optimal values in inclined struts are meeting at 2550 C of nozzle temperature, 1200 mm/min of print speed, 50% of fan speed and 0.1 mm of layer height. However, in horizontal struts, the optimum is 2450 C of nozzle temperatures, 600 mm/min of print speed, 0% of fan speed and 0.2 mm of layer height. Furthermore, from the compression tests they found propose optimization method improve mechanical performance of lattice structure the optimization is based on the printing quality of lattice struts.

V. Durga Prasada Rao et. al.[9], have done work for find the effect in fused deposition modeling process parameters on tensile strength for carbon fibre PLA. In this work they have done experiment to evaluate the FDM parameters, such as layer thickness, infill pattern and print temperature on tensile strength on Carbon fibre PLA. The printing process was done in by considering three levels for each parameter and a full factorial design of experiments(3^3). The tensile test data were analyzed by conducting ANOVA and results indicate that the interactions between layer thickness in fill pattern and infill pattern-extrusion temperature have significant effect on tensile strength. From the experiment they conclude that the highest tensile strength of 26.59 MPa is obtained for a layer thickness of 0.1 mm, extrusion temperature of 2250C and cubic infill pattern.

Omar Ahmed Mohamed, et al.,[10] has done work for find the effect of process parameters on dynamic mechanical of FDM PC/ABS printed parts. In this work, they considered layer thickness, air gap, raster angle, build orientation, road width, and number of contours as input parameters and storage modules, loss module and mechanical damping as output parameters. The use ANOVA and S/N ration as analytical method. From the experiment they conclude that air gap and number of contours show a significant effect on the storage modulus and loss modulus. A gradual increase in storage modulus has been observed with the decrease in air gap and increase in the number of contours. However, an increase in layer thickness and decrease in raster angle, build orientation, and road width help to improve storage modulus and loss modulus. In the case of mechanical damping, the same trend, which is similar to storage modulus and loss modulus, was observed in terms of the effect of air gap and number of contours. However, the layer thickness, build orientation, and road width show a significant effect, where with the increase in layer thickness and road width and decrease in build orientation, mechanical damping increases. But raster angle has no effect on the mechanical damping. The optimization results revealed that the optimal process conditions to maximize the storage modulus, loss modulus, and mechanical damping simultaneously were layer thickness of 0.3302 mm, zero air gap, raster angle of 0.00, build orientation of 0.00, road width of 0.4572 mm, and 10 contours.

Saroj Kumar Padhi et. al.[11], have done work on optimization of fused deposition modeling process parameters using a fuzzy inference system couple with Taguchi's method. In this work they considered the layer thickness, raster angle, raster width, air gap and part orientation as input parameters find the effect of these parameters on the accuracy of the length, width, and thickness of acrylonitrile-butadiene styrene (ABSP 400) parts using the FDM technique. The optimum parameter settings to get minimum responses, such as the change in length, width, and thickness of the test specimen, are determined using Taguchi's parameter design. A fuzzy inference system combine with the Taguchi's method was adopted to generate a single response from three responses, to reach the sepcific target values with the overall optimum factor level settings. Further, Taguchi and artificial neural network predictive models were also presented in this study for an accuracy evaluation within the dimensions of the FDM fabricated parts, subjected to various operating conditions. From the experiment they conclude the least change in length, width, and thickness are meet at layer thickness of 0.178 mm, orientation of 00, raster angle of 00, raster width of 0.4564 mm, and air gap of 0.008 mm. Also, the orientation angle has great influence on part build quality and ANN model is best model over fuzzy inference system coupled with Taguchi philosophy model to predict the overall performance characteristic under all operating conditions.

Manu Srivastava et. al.[12], have done work on an Integrated RSM-GA based approach for multi response optimization of FDM process parameters for pyramidal ABS primitives. In this work they considered six process parameters namely raster width, raster angle, contour width, air gap, slice height and orientation to achieve four responses namely build time, model material volume, support structure volume and production cost. The Response Surface Methodology (RSM) was utilized to design and conduct experiments. The GA was use for making the prediction model. From the experiment they conclude that the lower values of contour width, raster width and higher values of raster angle, air gap, slice height and orientation result in lower time and overall cost for a FDM process.

Manu Srivastava et.al.[13], have done work on optimisation of FDM process parameters by Taguchi method for imparting customised properties to components. In this work they considered slice height, contour width, raster width and air gap as input parameters. The signal-to-noise ratios is utilised for establishing the optimal process parameters and the relative percentage contribution of factors is estimated using ANOVA. Optimal levels of process parameters were found to vary with the variation in the type of basic shape of primitive. From the experiment they found that air gap has a maximum impact over the part build volume followed by contour width and slice height. Also, the interaction effect of parameters is relatively less important.

Uzair Khaleeq uz Zaman et.al.[14], have done work on impact of fused deposition modeling (FDM) process parameters on strength of built parts using Taguchi's design of experiments. In this work they considered layer thickness, shells, infill pattern, and infill percentage as input parameters and compressive strength as output parameter. Analysis of variance (ANOVA) and signal-to-noise (S/N) ratio analysis were performed to evaluate the importance of experimental error, finding the optimal combination of process parameters for maximizing the compressive strength. From the experiment the conclude that the optimal combination included a layer thickness of 0.2 mm, number of layers on the outside of the part (shells) as 4, infill pattern of diamond, and an infill percentage of 70% as per the ANOVA and S/N ratio.

C.A. Griffiths et al.[15[, have done work on effect of build parameters on processing efficiency and material performance in fused deposition modelling. In this work they considered side of object, Infill, Number of shells and layer height as input parameter and efficiency (build time, energy consumption, part weight and scrap weight) and Performance (tensile strength and young's modulus) as output parameter. They use PLA as filament material to build part. From the experiment they conclude that for optimization of tensile properties, the infill level and number of shells are the only significant parameters and should be maximized. For optimization of efficiency outputs, the maximum layer height and lowest levels of infill and number of shells should be used. Where scrap weight minimization is incorporated into efficiency, the side of object which reduces the contact area between part and build plate should be used, in this case a side of object.

Ala'aldin Alafaghani et. al.[16], have done work on investigating the effect of fused deposition modeling processing parameters using Taguchi design of experiment method. In this work they considered infill percentage, infill pattern, layer thickness, and extrusion temperature as input parameter and PLA as workpiece material. They analyse model for dimensional accuracy. From the experiment they conclude that for better dimensional accuracy, a lower extrusion temperature, smaller layer thickness, lower infill percentage, and hexagonal infill pattern were required. On the other hand, to increase the strength of FDM parts, a higher extrusion temperature, an optimized layer thickness, a triangular infill pattern, and a higher infill percentage are required. Ductility can be improved by switching to rectilinear infill pattern and by increasing the layer thickness.

D. Seprianto et.al.[17], have done work for find the influence of internal fill pattern, polishing time and Z-axis orientation on the tensile strength of the 3D printed part. In this work the create the CAD model of object by using modelling software then it was be converted in to G code for machine operation as per desired experiment design. In this experiment they use ASTM D-638 as work piece material. From the experiment they conclude that the polishing time is most significance parameter for tensile strength and highest tensile strength will be meeting 1.824 kgf/mm2 at the value of factors line filled pattern, polishing time is 20 minutes and orientation angle is 450.

R Wilza et.al.[18], have done work for find out the effect of process parameters on dimensional accuracy of FDM part. In this research work they considered layer height, print speed, perimeter shells and polishing time as input parameters. The material use for making this part is use ASTM D995-08. The value of each parameter is very in two levels and the analysis is done by using ANOVA analysis. From the experiment they conclude that the optimum condition for dimensional accuracy is meeting at factors value, height layer 0.14 mm, print speed 51.73 mm/s, perimeter shells 3 mm and polishing time 20 minutes.

P Doungkom et.at.[19], have done works for find out the effect of printing pattern and infiltration percent over the tensile strength of fuse deposition modelling part. In this work they have taken PLA as work piece material. The printing pattern is very at three levels as Horizontal, Crosswise and vertical and the infiltration percent is very at 20%, 60% and 100%. The analysis is done by using ANOVA analysis and from the experiment they conclude that the highest yield stress is happen in Crosswise (C), Horizontal (H) and Vertical (V), respectively. In addition to it could be separated the print pattern into two groups that are Crosswise (C) with Horizontal (H) and Vertical (V). In case of Crosswise (C) with Horizontal (H) at infill between 20% and 100% may offer increasing in Yield strength by 39 % while Vertical (V) offers less yield strength as this pattern have a fracture like brittle material. The Infiltration percentages, that produced the highest yield stress is 100%, 60%, and 20%, respectively.

Juraj Beniak et.al.[20], have done works for parametric optimization in Additive manufacturing process. In this experiment they consider PLA as work piece material. In this the part is printed at 120 mm/s speed in FDM 3D printing machine and it is followed by annealing process. From the different annealing time like 0 min. 20 min. and 60 min. the different value of tensile strength, elongation and compressive strength were meeting. From the experiment they conclude that the elongation was increase between 20 min. and 60 min. with increase of tensile strength and decrease with compressive strength and part become more tough and brittle.

4. CONCLUSION

From the Literature review it has been observed that most of research work done on ABS, PC, PLA and ABS-PC material. It has been observed that above material is also tested against surface roughness, hardness, compressive strength, creep, dimensional accuracy. It has been observed that very few works are done in surface roughness and tensile strength analysis of parts fabricated through co polyester+ material (CPE+). In FDM, one of the new used materials is CPE+, which is popular because excellent chemical resistance, temperature resistance, toughness, and dimensional stability. Good interlayer adhesion (especially when using the front enclosure add-on). Good bed adhesion (especially when using the adhesion sheets). And low levels of ultrafine particles (UFPs) and volatile organic compounds (VOCs).

5. SCOPE OF WORK

- To find out the process parameters values for CPE+ material and to design the experiment by using Taguchi's method.

- To investigate the effect of process parameters on surface roughness and tensile strength of the manufactured part and to obtain the optimum process parameters by using S/N ratio analysis for maximize tensile strength and minimize surface roughness for parts manufactured using CPE+ as a work material.
- To find out the percentage contribution of each parameter by using ANOVA method and to make the prediction model by using ANN.
- To validate the experiment results with ANN model results.

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