EFFECT ON PROCESS PARAMETER OF FDM MACHINE USING MADM METHOD

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ABSTRACT

There are several different methods of 3D printing, but the most widely used is a process known as Fused Deposition Modeling (FDM). FDM printers use a thermoplastic filament, which is heated to its melting point and then extruded, layer by layer, to create a three dimensional object .Fused deposition modeling (FDM) is a fast growing rapid prototyping (RP) technology due to its ability to build functional parts having complex geometrical shapes in reasonable build time. The dimensional accuracy, surface roughness, mechanical strength and above all functionality of built parts are dependent on many process variables and their settings. Rapid Prototyping (RP) technology has been advanced to fabricate initial prototypes from various materials. Stratasys Fused Deposition Modeling (FDM)is one of the typical RP processes that provide functional prototypes of PLA, ABS, nylon, wax etc plastic material. Rapid prototyping technologies for easy production of prototypes, parts and tools are new methods which are developing unbelievably quickly. Successful product development means developing a product of high quality, at lowest cost, in the shortest time, in at a reasonable price. The development of the part and its introduction to market is time consumption process. But 'time is Money' and therefore could be said that money saving is greatest when time to market is minimalized utmost. Experimentation was planned as per taguchi's L9 orthogonal array .In this techniques are using such as, multi objective optimization on the basis of ratio analysis(MOORA),Analytical hierachy process(AHP) method for optimization of fused deposition modeling(FDM)

Keyword : - *Fused Depostion Modeling(FDM), Layer Thickness, Orientation , Infill, Preferance selection Method (PSI).*

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1. INTRODUCTION

1.1 History of Rapid Prototyping

In 1987 the manufacturing industry was introduce to an emerging new technology called rapid prototype (RP) at the AUTOFACT shown in Detroit. At that time it was referred to as stereo-lithography and the prototype was produced by curing photosensitive polymers with an ultraviolet laser. After that, several further forms of rapid prototyping technology have been introducing the marketplace. Rapid prototyping is a useful technology in which a model uses CAD is taken as input and then layer by layer construction a solid part similar to the model be able to. It helps to use for study in development of different components of a system. It has minimum production risks and it is a time saving process in case of complex design. In the behind sixties Herbert Voelcker, an engineering professor thinking about computer controlled automatic machine tool. He was trying to discover a technique to control the automatic machine tools using a program in the computer. Carl Deckard proposed the layer based manufacturing method in 1987. His thoughts of structure a model layer through layer. He used a laser beam to fuse the metal power to form a solid model, creation only one layer at a moment. That methodis developed into Selective Laser Sintering. Voelcker helpful finding, inventive thoughts and research has specified to new approaches to the rapid prototyping manufacturing. The rapid prototyping technique has developed and revolutionize. Though there are many people who have done significant work in the field of the RP, Charles Hull's model of apparatus for manufacture of three dimensional objects by Stereo lithography has been predictable the most. He is known as the father of Rapid Prototyping.

Today a design in any CAD software can be prototype without much hard work and it has made manufacturing not only simple and quick but also charges effectual.

1.2 Fused Deposition Modeling (FDM)

Fused deposition modeling, which is often referred to by its initials FDM, is a type of additive fabrication or (sometimes called rapid prototyping/rapid manufacturing (RP or RM)) technology commonly used within engineering design. Scott Crump was develop the FDM technology in the late 1980s and was commercialized in 1990. The FDM technology is marketed commercially by Stratasys. FDM works on an "additive" principle by laying down material in layers. A plastic filament or wire is unwound from a material spool (coil) and supplies material to the extrusion nozzle and which can turn on and off the flow.

The nozzle is heated to melt the material and can be moved in both horizontal and vertical directions by a numerically controlled mechanism, directly controlled by a CAM software package. The part or object is produced by extruding small beads of thermoplastic such as ABS, PLA, PC, NAYLON material to form layers as the material hardens immediately after extrusion from the nozzle.

A "water-soluble" material like High impact polystyrene (HIPS) can be used for supports material while manufacturing is in progress. HIPS support material is quickly dissolved with specialized mechanical agitation equipment utilizing a precisely heated sodium hydroxide solution.

1.2.1 FDM Process

The FDM process itself consists of building the model layers by depositing a thin filament of melted plastic via a precisely calibrated orifice mounted on a computer controlled XY movement. The width of the deposited plastic line is fine, so the mass of the model is builtup in many successive passes. The model is created on a base which is also computer controlled to index downward one layer thickness as each layer is completed. Each successive layer fuses to the preceding layer as the thermoplastic material is dispensed in a hot, semi-liquid state, then cools down and solidifies. The resolution and precision of the FDM process varies with the machine and the type of material employed. The finest that can be had currently is a layer thickness of about 0.125mm, but typical layer thickness is twice that. Line width of each pass is twice the layer thickness. Precision is around +/- 0.1mm for smaller parts. The materials that can be employed are all thermoplastics, a number of other plastics are also available.To allow hollow sections and overhanging parts, the process automatically generates supports. These can either be special "break-away" style supports of the same material as the model, or in some cases, supports of another material. Newest technology allows the support material to be "water soluble", allowing relatively easy removal (never the lesser quiring a heated ultrasonic tank, a mild chemical solution and some time). It is also possible to create structures with a solid skin and a honeycomb interior, resulting in a lighter part with less material use.

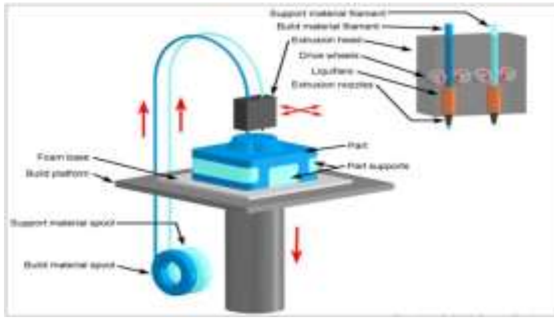


Figure 1.8: Fused Deposition Modeling (FDM)

2. LITERATURE REVIEW

Vinod G. Surange, Punit V Ghara et al. **[1]** have to develop a low cost 3D Printer by using materials which are easily available and cost effective. We have been successful in reducing the cost to a considerable extent i.e about 10-15 %. The parts made in 3D design software are successfully imported in the printing software and the product obtained has the same dimension given during the design stage of the product i.e an accuracy close to 100%.We were able to successfully fabricate the 3D printer according to its virtual design proposed at reduced cost.
Miguel Fernandez-Vicente, Wilson Calle,2 Santiago Ferrandiz, and Andres Conejero et al. [2] to investigate the significant effects of infill density and pattern on mechanical properties of the desktop FFF 3Dprinting process have been experimentally studied. Practical findings in the 3D printing process showed that, The combination of rectilinear pattern in a 100% infill shows the highest tensile strength, with a value of 36.4Mpa, a difference of less than 1% from that of raw ABS material, Under the same density, the honeycomb pattern shows a better tensile strength, although the difference between the different patterns is less than 5%. This discrepancy could be attributed to small variations of amount of plastic deposited for each pattern, The deposition trajectories and consequently the inter layer bonding zones are very different between honeycomb and rectilinear patterns. This could be a reason to explain the elastic modulus difference .However, more research on this topic needs to be under taken before this association could be more clearly understood, The change in the infill density determines mainly the tensile strength, and the stiffness, especially between20% and 50%.C The mechanical behavior between the different so structure similar, and the dispersion between the samples is below 10%.C The relationship between infill density and tensile strength can be fitted in a squared-X model. Further studies are needed to understand the crystal volume fraction of the samples as previous studies developed on PLA, as it was observed, a strong relationship between this characteristic and the tensile strength.37The scarcity of studies in literature about the influence of me so structure, as well as other factors, such as environment ,reveal a need for further research into the mechanical behavior of the 3D printed pieces.
Nectarios Vidakis,Achilles et al. [3] has performed tensile strength of parts build with FDM was measured. Parts were tested in tension and results were compared to the nominal ABS filament strength. The aim of this work was to determine the actual mechanical strength of 3d printed parts, and provide this valuable information to designers .The machines employed automate the 3d printing of parts, providing an easy-to-set-up process, but without an ability to adjust build parameters, such as the layers fill pattern, which does affect the strength of the build parts. The parameters that can be selected in the machines used were chosen from a wide range and results verified the anisotropic behaviour of the build parts. This observation identifies the build direction as a critical parameter for the determination of the mechanical properties of the finished parts.As expected, the tensile strength of the 3d printed specimens is lower than the nominal filament strength for both materials. The ABS results were closer to the nominal values, while the ABS plus showed larger deviation from the nominal filament tensile strength. In order to accurately design load bearing parts with the 3d printing process, these differences between the maximum tensile strength for the 3d printed specimens and the nominal filament material should be taken into account.
NAJIM A. Saad, Ahmed Sabah et al. [4] have studied the light weight structure of (ABS/PLA) consist of honey comb core with skin layers as sandwich structure, the design includes design of the core with increasing the infill parentage of (10%, 30%, 50%, 70%, 90% and 100%) by increasing of hexagonal pores volume to test tensile strength, also includes the different between the heat and adhesive joining to prepare the sandwich structure panels for stiffness test. The samples are prepared by 3D Printing technique, type fused deposition modeling. FDM and the (3D desktop printer) type of printing machine is used to conduct this work. Different mechanical and physical

properties (tensile strength, stiffness, specific strength, etc.) are tested. The results show improvement of, specific strength. Tensile strength and modulus with increasing of pore size (hexagonal) reduction for tensile test samples, heat joining gives lower stiffness than adhesive joining of flexural strength test.

Garrett W Melenka, Jonathon S. Schofield, Michael R. Dawson, Jason P. Carey et al. [5] the common process parameters and understand the impact on the mechanical properties of specimens in PLA. The second order response surface model was used to derive the required relationship among process parameters and the tensile strength. The analysis of the experimental results made it possible to understand the impact of control factors on the mechanical properties of specimens produced using the Rep – Rap method. With regard to UTS values, it is possible to observe a decrease in strength as the infill orientation approaches 90° degrees and an increase as the perimeters increase. An initial increase is evident as the layer thickness approaches 0.18 mm. Beyond this value, a reduction in strength values occurs. An interesting effect is related to the layer thickness ,since the strain value reaches its maximum at 0.15 mm and decreases as it approaches 0.2 mm. Considering the combined effects, further correlations were observed between UTS and when results were grouped with the infill orientation and the number of perimeters. The reliability of the statistical model was validated by comparing the predicted maximum UTS value with that established experimentally for a given parameter set. The lack of data in literature and the high variability in experimental results, as well as the effects of other factors, such as micro and macro-geometrical variability, humidity and temperature suggest that further investigations are needed in order to improve the knowledge about the mechanical behaviour of printed components using PLA. The experimental results can be translated into practical suggestions for the settings of process parameters with a view to improve the performance of 3D printers in relation to mechanical properties. The methodology utilised in this study can be applied for future analyses on other low cost 3D printers.

Todd Letcher et al. [6] has parformed PLA filament and PLA printed specimen mechanical properties were tested. For tensile testing, it was determined that the the 45° raster orientation specimens were the strongest. In fatigue testing, the 90° specimens were clearly the least resistant to fatigue loadings. The fatigue lives for the 45° specimens and 0° specimens were very similar and should be investigated further. However, the 45° specimens did have the highest fatigue endurance limit. The filament testing (at higher strain rates where creep wasn't a factor) showed similar results to the printed specimen results. This may help to determine whether failed print jobs can be recycled into new filament to be printed again. Microscope evaluations helped to determine gap sizes left in the specimens from the printing process.

Tymrak et al [7] have studied quantifies the basic tensile strength and elastic modulus of printed components using realistic environmental conditions for standard users of a selection of open-source 3-D printers. They found that the average tensile strength of Rep Rap printed parts is 28.5 MPa for ABS and 56.6 MPa for PLA with average elastic modules of 1807 MPa for ABS and 3368 MPa for PLA. Results indicate that the 3D printed components from RepRaps are comparable in tensile strength and elastic modulus to the parts printed on commercial 3-D printing systems. There for PLA is the higher flexible compare ABS material.

Rayegani et al. [8] investigated found that both process parameters affect tensile strength. Shown that a negative air gap and smaller raster widths also improve tensile strength. The zero part orientation maximum tensile strength is obtained and increased raster angle also improves tensile strength. The optimum parameter formaximum tensile strength is part orientation is zero, raster angle 50°, raster width 0.2034and negative air gap −0.0025.

Raut et al. [9] objective of the present study was to investigate the effect of the built up orientation on the mechanical properties and total cost of the FDM parts. It can be concluded that the experimental investigation that built orientation has significant affect on the flexural and tensile and total cost of the parts. Based on these results they concluded that minimal cost of part and optimal tensile strength gives in FDM about y axis at 0% built up orientation. Good flexural strength and medium cost gives about x axis0% built up orientation.

Patel et al. [10] has performed the experiment to access the influence of three FDM parameters on the mechanical strength of FDM fabricated poly carbonate test specimen .They applied signal-to-noise ratio and ANOVA in order to find out which parameter is affected the most to output response. After the experimental work and ANOVA analysis they have find out that the layer thickness and orientation angle are highly significant to the mechanical strength of test specimen whereas raster width has a little importance as compare to other two parameters. Finally they have built the regression model in order to predict the result of mechanical strength. Results are comparing with regression result and both are relatively same which lead to be model successfully applied.

3. EXPERIMENTAL SETUP

3.1 Introduction of FDM Machine

The experiments are designed and carry out in the ALL IN 3D in Ghandhinger, which is placed. The tensile strength, tensile module, surface roughness, compressive strength and compressive module are predicted to the primary goal of the dissertation work. Varying machining parameters carried out the work in FDM replicator 2 using PLA material. One of the current challenges faced by FDM users is the quality of parts produced, which is allied with the accurate application of the specified performance. In this study, As measure of part quality in accordance to industrial requirements considered tensile strength, tensile module, compressive strength, compressive module and surface roughness. To achieve this, the present chapter describes the materials used for FDM part fabrication and presents the 3-D CAD model of the part, which was fabricated by the FDM machine.

3.2 Polylactic Acid (PLA) Materials

The material used for test specimen fabrication is PLA.

PLA (POLYLACTIC ACID) is derived from biological resources, which makes PLA plastic biodegradable. Objects printed with PLA filament are strong and will generally have a glossier look and feel. PLA has high maximum printing speeds, low layer heights, and sharp printed corners. Polylactic acid (PLA) is a rigid thermoplastic polymer that can be semi crystalline or totally amorphous, depending on the stereo purity of the polymer backbone. Polylactic acid (2-hydroxy prop ionic acid) is the natural and most common form of the acid, but polylactic acid can also be produced by micro organisms or through racemization and this “impurity” acts much like co monomers in other polymers such as polyethylene terephthalate (PET) or polyethylene (PE).

3.3 Support Material

Generally, HIPS (high impact polystyrene) is used for FDM machine, which is use Forgive better support when FDM component is generated. It gives support and after Completed the slicing, it is manually removed from FDM generated component.

3.4 Design of Experiment

3.4.1 Parameters Levels

As shown in (Table 3.4) three parameters visualizing layer thickness (micron), orientation (degree), and infill (%) were considered as input parameters and based on literature survey and studying the range available in, numbers of levels and their values are shown in Table 3.4. Therefore, this experiment is a three factor 3 level taguchi method of design of experiment.

Table 3.4: Parameters Levels and Values

Factors	Unit	Level		
Layer thickness(A)	[micron]	100	200	300
Orientation(B)	[°]	0	45	90
Infill (C)	[%]	100	90	80

So that, in this Design of Experiments and These all three factors and their unique factor level combinations (3 layer thickness X 3 orientation X 3 Infill) i.e. 9 experiment reading X 1 material= 9 and X 2 design= 18 parts for one material. Here, we used Minitab 16 software for the design of experiment by taguchi method.

Table 3.6: L9 Orthogonal Array

No of Part	Later thickness (micron)	Orientation (degree)	Infill (%)
1.	100	0	100
2.	100	45	90
3.	100	90	80
4.	200	0	90
5.	200	45	80
6.	200	90	100
7.	300	0	80
8.	300	45	100
9.	300	90	90

3.5 Measurement

Machines are used for measurement of INSTRON 5965 UTS Machine and INSTRON 5982 UTS Machine.

4. Optimization Technique

4.1.1 Multi Criteria Decision Making Method

Multiple Criterion Decision Making (MCDM) is to refer to making decisions in the Presence of multiple, usually conflicting criteria. It is depending on whether the problem is a selection problem or a design problem, the problems of MCDM can be broadly classified as into two categories:

1) Multiple Attribute decision making (MADM)

2) Multiple Objective Decisions Making (MODM)

Step 1: Present study total 9 experiments (Alternatives A1 Up to A9) are considered using Taguchi concept and the response process parameters of the FDM such as tensile strength, tensile module, compressive strength, compressive module, and surface roughnessare as shown in Table 4.14 as decision matrix.

Table 4.14: Decision Matrix Table

Alternative	Tensile Strength (N/mm^2)	Tensile module (N/mm^2)	Surface Roughness (µm)	Compressive Strength (N/mm^2)	compressive module (N/mm^2)
A_1	50.099	2350.692	3.828	58.43	1730.928
A_2	54.088	2950.732	4.134	31.211	690.823
A_3	56.158	3549.016	3.431	40.68	1517.469
A_4	40.708	2199.673	5.297	57.529	1801.422
A_5	55.27	3022.378	3.667	36.655	1187.744
A_6	37.494	3078.977	3.004	55.371	1930.566
A_7	52.791	1931.512	3.443	55.212	1450.56
A_8	48.504	2904.425	3.645	48.721	1151.595
A_9	50.135	3041.066	3.530	53.732	1900.292

4.2 Preference Selection Index (PSI) Method

Preference selection index method was developed by Maniya and Bhatt (2010) for the solve problem of multi-criteria decision-making (MCDM) problems. In this method, it is not assign a relative importance between attributes. There is no requirement of computing the weights of attributes involved in decision-making problems in Preference selection index method. This method is useful when there is a conflict in deciding the relative importance attributes (Maniya and Bhatt, 2010).

The steps involved in the PSI method are as follows:

Step 1: Define the problem: Determine the objective and identify the pertinent attributes and alternatives involved in the decision-making problem under consideration.

Step 2: Formulate the Decision Matrix: This step involves construction of a matrix based on all the information available that describes the problem attributes. Each row of decision matrix is allocated to one alternative, and each column to one attribute. Therefore, an element X_{ij} of the decision matrix X gives value of the j^{th} attribute in original real values; that is a non-normalized form and units for the ith alternative. Thus, if the number of alternatives is M and the number of attributes is N, then the decision matrix as an N · M matrix can be represented a

Step 3: Normalizing the Data Using: In the multi-attribute decision, making methods it is required to make the attribute value dimensionless. For this purpose, the attribute values are transformed into 0 and 1. This process of transforming is known as normalization, which is done because of the type of the attribute.

If the attribute is beneficial type, then larger values are desired, which can be normalized as:

$$N_{ij} = \frac{x_{ij}}{x_j^{max}} \qquad \text{……... (1)}$$

If the attribute is non-beneficial type, then smaller values are desired, which can be normalized as:

$$N_{ij} = \frac{x_j^{min}}{x_{ij}} \qquad \text{………. (}$$

Table 4.12: Normalize Decision Matrix

Alternative	**Tensile Strength (N/mm²)**	**Tensile Module (N/mm²)**	**Surface Roughness (μm)**	**Compressive Strength (N/mm²)**	**compressive module (N/mm²)**
A_1	0.8812	0.6491	1.0000	0.8569	0.7108
A_2	0.9538	0.8232	0.5293	0.3016	0.6614
A_3	1.0000	1.0000	0.6836	0.7469	0.9400
A_4	0.7143	0.6017	0.9834	0.8988	0.4668
A_5	0.9742	0.8472	0.6164	0.5746	0.7496
A_6	0.9244	0.8660	0.9436	1.0000	1.0000
A_7	0.6553	0.5208	0.9426	0.7152	0.8211
A_8	0.8544	0.8101	0.8275	0.5368	0.7861
A_9	0.8814	0.8603	0.9036	0.9512	0.8118

Where If is the attribute measure (i = 1, 2. . . N and j =1, 2. . . M).

Step 4: Calculate the Mean Value of the Normalized Data: In this step, mean value of the normalized data of every attribute is computed by the following equation:

$$= \frac{1}{n} \sum_{i=1}^{n} N_{ij} \qquad \text{………. (3)}$$

Step 5: Calculate the Preference Variation Value: In this step, a preference variation value between the values of every attribute is computed using the following equation:

$$\emptyset_j = \sum_{i-1}^{n}[N_{ij} -]^2 \qquad \text{………. (4)}$$

Step 6: Determine the Deviation in Preference Value: In this step, deviation in the preference value is computed for every attribute using the following equation:

$$\Omega_j = [1 - \emptyset_j] \qquad \text{………. (5)}$$

Step 7: Compute the Overall Preference Value: In this step of PSI method, overall preference value is determined for every attribute using the following equation:

$$\omega_j = \frac{\Omega_j}{\sum_{j=1}^{m}\Omega_j} \qquad \text{……….. (6)}$$

Moreover, the total overall preference value of all the attributes should be one i.e. $\sum_{j=1}^{m}\Omega_j$

Step 8: Compute the Preference Selection Index: Now, the preference selection index is calculated for each alternative using the following equation:

$$\theta_i = \sum_{j=1}^{m} N_{ij} \times \omega_j \qquad \text{………… (7)}$$

Step 9: Select the Appropriate Alternative for the Given Application: At last, each alternative is ranked according to descending or ascending order to facilitate the managerial interpretation of the results. The alternative having the highest preference selection index will be ranked first and so on.

Table 4.13: Preference Selection Index

Alternative	θ_i	**Rank**
A_1	0.8163	4
A_2	0.6823	9
A_3	0.8867	2
A_4	0.7199	8
A_5	0.7692	6
A_6	0.9432	1
A_7	0.7272	7
A_8	0.7771	5
A_9	0.8774	3

- COMPARISION WITH MOORA AND TOPSISI METHOD

4. RESULT AND DISCUSSION

It is observed that in comparison to MADM methods like MOORA, TOPSIS and PSI method. PSI method is simple to calculate and easy and small mathematical calculation. MOORA, TOPSIS and PSI method ranking results show that A6-A3-A9 alternative is the best three ranking among the A9 alternatives of FDM process parameters.

Table 5.1: Results of MOORA, TOPSIS, & PSI

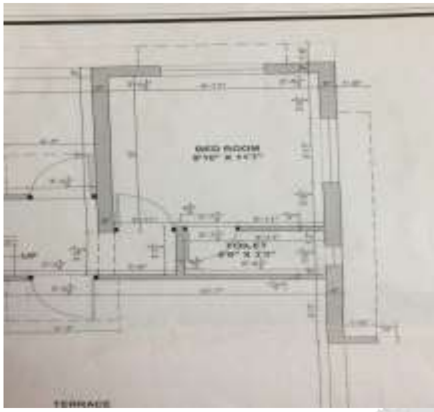
Alternative	MOORA RANK	TOPSIS RANK	PSI RANK
A_1	4	6	4
A_2	7	7	9
A_3	2	2	2
A_4	8	8	8
A_5	5	4	6
A_6	1	1	1
A_7	9	9	7
A_8	6	5	5
A_9	3	3	3

Application

FDM is moving in several directions at this time and all indications are that it will continue to expand in many areas in the future. List of application below:

- Mechanical application, Investment casting**,** Injection modeling**,** Medical application**,** Custom parts replacement **,**Medical application:
- For building fully functional prototype

MAKING 3 D HOUSE MODEL



2D MODEL 3D MODEL

5. CONCUSION AND FUTURE SCOPE

In the present study on the experiments were conducted under various process parameters such as Layer thickness, Orientation, Infill in FDM machining. Tensile strength, tensile module, compressive strength, compressive module and surface roughness are responded parameter of the PLA material using FDM process. PSI method is highly stable for selection process parameter problems. There is other scope for taking other parameters like: Bed temperature, Nozzle Diameter, Raster angle, etc.Other output parameters can be measured, by FDM process like Circularity, porosity, cylidrisity. Different Multiple Criteria Decision Making (MCDM) optimization Techniques can be applied like ARAS, PROMETHEE, WPE, and VIKOR. Etc for optimization of process parameters of the Fused Deposition Modeling.

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