Study of Fused Deposition Modeling Process Parameters for Polycarbonate/Acrylonitrile Butadiene Styrene Blend Material using Taguchi Method

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Abstract - *Fused Deposition Modeling (FDM) is a type of Three Dimensional (3D) printing process and it is based on layered manufacturing technology. Dimensional accuracy and mechanical properties are the main considerations of FDM parts and selection proper process parameters is very important to improve quality of parts. Aim of this research was to study the effect of FDM process parameters on* Polycarbonate/ Acrylonitrile Butadiene Styrene (*PC/ABS) blend filament using Taguchi method for L8 Orthogonal Array. In this study, Extrusion temperature, Bed temperature, layer thickness, raster width and printing speed these five process parameters were selected to improve part dimensional accuracy, surface finish of the parts .In this experimentation parts were manufactured without support structure to study dimensional accuracy of parts without support for overhang structure. Coordinate Measuring Machine (CMM) and surface roughness tester was used to measure dimensional accuracy and surface roughness, respectively of FDM parts.*

Key Words: FDM, PC/ABS blend material, Taguchi method, surface roughness, Flatness.

1. INTRODUCTION

Rapid Prototyping (RP) is a type of Additive Manufacturing (AM) technology, these are introduced in the late of 1980's. RP is used to manufacture physical solid objects directly from Computer Aided Design (CAD) model in a layer by layer procedure. These layered manufacturing process is known as AM process [1]. Manufacturing of part with Geometric Dimension and Tolerance (GD & T) is helpful to interchangeability of parts and with desired mechanical properties are more important for part functionality. So objective of every company is to manufacture quality of part with less manufacturing time, cost and minimum material consumption. For these type of application RP processes are more suitable. RP processes have large number of techniques but these have main four types, these are Stereolithography (SLA), Selective Laser Sintering (SLS), Laminated Object Manufacturing (LOM) and Fused Deposition Modeling (FDM) are the main types of RP process now they also called as Three Dimensional (3D) Printing processes [2].

1.1 Fused Deposition Modeling (FDM)

Nowdays, FDM is second most widely used and most popular Three Dimensional (3D) printing technique after SLA. FDM was introduced in the start of 1990's for prototyping by S. Scoot crump and he was a co-founder of Stratasys Inc. [1, 2]. Working principle of FDM is shown in figure. 1 this involves heating of thermoplastic material filament at a close to the its fusion point and extruded from number of extruder or single extruder in layer by layer process on X-Y horizontal plane.

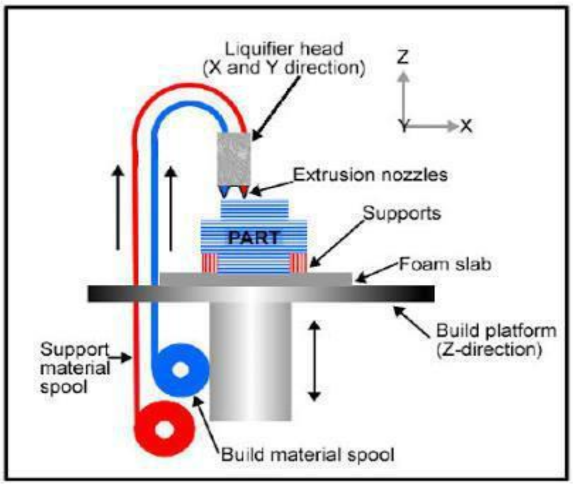

Fig -1: Working Principle of FDM [1]

This process have main three steps first is pre-processing, it include creation of CAD model and conversion of this file into .STL (Standard Triangulation Language) file format. Second step is build processing, in this .STL file sliced into number of horizontal cross section according required layer thickness and setting of other parameters will be done. Then this file is saved into G-codes. G-codes are used to give instruction to the printer by using SD card or by directly from the computer. Actual physical part is fabricated in this step. Third step is post-processing, in this part is removed from table, removal of support structure, cleaning and finishing of part is done [1]. FDM machine uses only thermoplastic material to print part and this selected according functionality of part. Such as

Acrylonitrile Butadiene Styrene (ABS), Polycarbonate (PC), Polylactic Acid (PLA), Polyamide (PA), Polystyrene (PS), ABS plus, ABSi, PC-ISO, Polycarbonate/Acrylonitrile Butadiene Styrene (PC/ABS) blend, Nylon, ABS M30, ABS P400, Wood etc. filament used in FDM [1,2, 3].

1.2 Literature survey

Quality of part is depends upon setting of process parameters and FDM have problems related to dimensional accuracy, surface finish, shrinkage of parts and mechanical properties. So optimal setting of FDM parameters is the main objective of any work. O. A. Mohamed et al [2] researched on PC-ABS blend material part to maintain flexural strength of part with minimum part build time and material consumption using Q-optimal response surface methodology. For this work researcher used five controlling parameters at level 6 such as layer thickness, air gap, raster angle, build orientation, road width and number of contours. After experimentation, it was found that part build time decreased by increase in layer thickness, air gap and the number of contours. Dynamic flexural strength of parts was improved by an increasing number of contours with zero air gaps and decrease in layer thickness but effects on to increase material consumption. In another work with same parameters and material [2] O. A. Mohamed et al [4] studied effect of FDM process parameters on creep displacement of parts. For this work they conducted total 13 experiments to study creep test, in that result showed creep displacement of part decreased at lower slice height, air gap and raster fill angle, bead width and with the slightly increase in part print direction and number of shells. O. A. Mohamed et al [5] in this research work, optimization was done to study effect of FDM process processes parameters [2] on Dynamic mechanical properties of PC-ABS blend material parts using I-optimal response surface methodology with L60 OA. In this optimization process result showed that, layer thickness at 0.3302, air gap 0mm, part orientation 5.568°, road width 0.470mm and number of contour 10 parameters are important to improve dynamic mechanical performance while raster angle has minimum effects. P. J. Nunez et al [3] aim of this research was to determine optimal process parameters for ABS Plus-P430 thermoplastic material. In this work researcher used two levels of layer thickness (0.178 mm, 0.254mm) and two levels of density (Solid, Low) to study their effects on dimensional accuracy, flatness and surface roughness of the parts with 4 parts for each test. They concluded that layer thickness 0.254mm and solid density was more significant to increase dimensional accuracy. And the lower layer thickness 0.178mm with solid density was more significant for increase surface finish and flatness of parts. Mercedes Perez et al [6] performed experiments on PLA material in two stage to study effect of layer thickness, printing speed, temperature, wall thickness and printing path. From results they concluded, lower layer height (0.15mm) and wall thickness (0.50 mm) were more significant. S. Vinodh and Priyanka Shinde [7] performed experiments to improve surface finish of ABS plus material with minimum manufacturing time. Multi-objective Decision Making (MCDM) method was used to optimize process parameters such as layer thickness, build pattern and infill pattern with two levels and performed 8 experiments. In result it was found that layer thickness 0.3302mm, build pattern solid and infill pattern smart was the optimum values. Nitish Kumar et al [10] studied experimental investigation on SLS parts using Taguchi method with L9 OA and ANOVA method. In that they studied relation of laser power, temperature and part orientation for dimensional accuracy and micro-hardness of DuraForm PA (Polyamide) as powder material. Result of this research shows that Temperature was more effective to influence micro-hardness of SLS parts. A. Hasan and W. Y. Jwu [11] form their research work it was found that impact strength, tensile strength and young's modulus increase as increase in amount of PC in PC/ABS blend.

Above literature survey is related to study relation of FDM process parameters and quality characteristics of part with its surface finish, dimensional accuracy and mechanical properties for different material. From survey it is found that PC/ABS blend material is mostly used for industrial application such as automotive, electronics and telecommunication industries. PC/ABS blend is a blend of PC and ABS, in that PC gives high impact strength, young's modulus and high toughness to the part. Also in ABS, Acrylonitrile gives wear and chemical resistance properties. Butadiene increase toughness of part due to rubbery constituent and Styrene give high processability and glossiness to the parts. So this blend combination increase part mechanical strength and used for portable application like phone case of flashlight, cover of monitor, printer remotes, keyboard, console of cars, small gears etc.[8]. From literature survey it is found that there is need to study combination effect of layer thickness (A), raster width (B), extrusion temperature (C), bed temperature (D) and printing speed (E) on dimensional accuracy and surface finish of the part and this is the objective of this research [2, 4, 5, 8, 12]. Obtained results from this work will used in next work to study effect of same parameters with increased levels on mechanical properties of the parts.

2. EXPERIMENTAL METHOD AND PROCEDURE

In this experimentation LulzBot TAZ 6 printer was used with PC/ABS Blend thermoplastic material as experimentation material. In this experimentation CAD model was created in CATIA V5 software also Design of Experiment and analysis was done using Taguchi method in Minitab 17 software. In this experimentation total 8 parts were manufacture to study effect of five parameters such as extrusion temperature, bed temperature, printing speed, layer thickness and raster width at two levels on surface finish, build time and flatness of the part and FDM of the part was done using Ultimaker Cura softwrae. Fixed parameters such as raster pattern rectilinear (+45/-45°), infill 80%, part orientation kept as horizontal and bed adhesion brim was used because this material have problem in adhesion of part to the bed, according previous experiments. Sketch of workpiece is shown in figure. 2 it contains overhangs structure so this part printed without support structure to measure flatness of top surface without support structure and this helped to save manufacturing time, material consumption of the part.

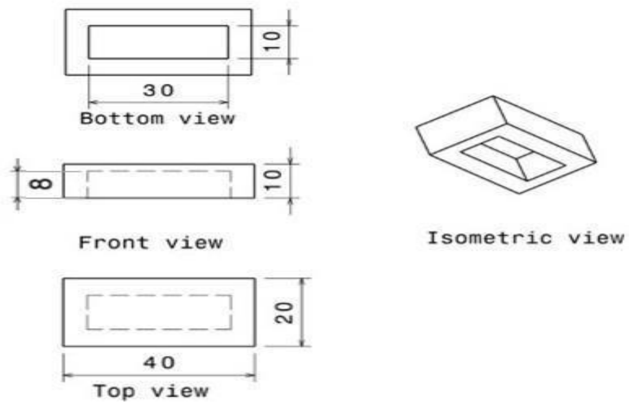

Fig -2. Sketch of required workpiece

2.1 Workpiece material details

Properties of PC/ABS Blend thermoplastic material [9] is given in following Table 1, Table 2 and Table 3. Diameter of Filament was 1.75mm selected according nozzle diameter (0.4mm) of FDM.

Table -1: Mechanical properties of PC/ABS material

MECHANICAL PROPERTIES	TEST METHOD	METRIC
Tensile Strength	ASTM D638	41 MPa
Tensile Elongation	ASTM D638	6%
Flexural Strength	ASTM D790	68 MPa
Flexural Modulus	ASTM D790	1,900 MPa
IZOD Impact	ASTM D256	196 J/m

Table -2: Thermal properties of PC/ABS material

THERMAL PROPERTIES	TEST METHOD	METRIC
Vicant Softening Temperature	ASTM D1525	112°C
Glass Transition Temperature (Tg)	DMA (SSYS)	125°C

Table -3: Other information of PC/ABS material

OTHER	TEST METHOD	VALUE
Density	ASTM D792	1.1 g/cm3
Rockwell Hardness	ASTM D785	R110

2.2 Experimental Apparatus

In this experimentation main apparatus is FDM printer, LulzBot TAZ 6 printer was used for this experimentation to fabricate parts from PC/ABS blend thermoplastic material. Setup of FDM machine is shown in following figure. 3.

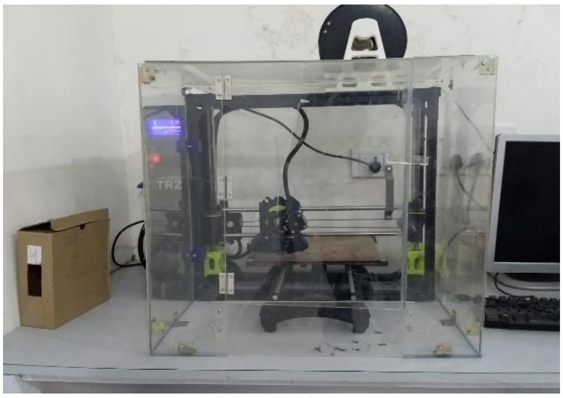

Fig -3: FDM machine setup

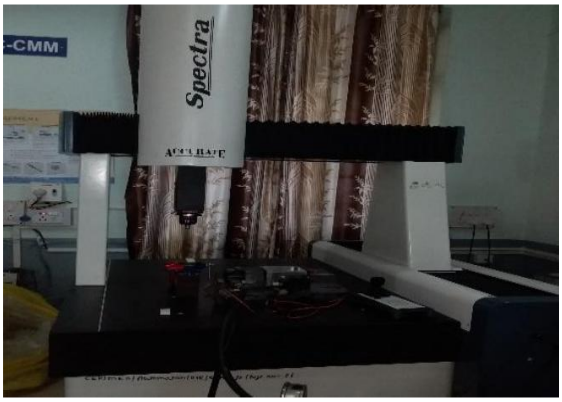

Fig -4: Co-Ordinate Measuring Machine (CMM)

After FDM, for checking of Flatness of parts were done on CNC Spectra Accurate Co-ordinate Measuring Machine 5.6.4. shown in above figure. 4. Total 8 points were measured on top surface of the part for flatness error measurement. And surface roughness of parts were measured by Mitutoyo Surface Roughness Tester (SJ210). For surface roughness average (Ra value) of 6 reading was taken on each part, on top surface 4 reading (X-axis 2 reading, Y-axis 2 reading) and 2 reading on side surface (Z-axis). Manufacturing time of parts was taken from Ultimaker Cura software.

2.3 Taguchi quality engineering method

In this experimentation Taguchi method was used for D.O.E and analysis. Experimental factors and their levels were selected according previous literature review and experimentation. From that five parameters selected at two levels of each parameters and L8 OA was selected for this experimentation in MINITAB 17 software. In order to check quality of part surface roughness, build time and Flatness were measured. Then this result converted into signal to noise ratio(S/N ratio) as a quality characteristics using Taguchi method. It is ratio of control factors and noise factor and shows how our design is close to optimum performance of product or process. S/N ratio have three quality characteristics; Nominal is Best (NB), Smaller-the-Better (SB) and Higher-the-Better (HB) and these selected according to response. In this work Smaller-the-Better (SB) quality characteristics was selected for surface roughness, build time and flatness error [10]

Following table. 4. shows Description of Experimental control parameters and table. 5. shows L8 Experimental Design.

Table-4: Description of Experimental Control parameters

Levels	Input Parameters				
	A (mm)	B (mm)	C (°C)	D (°C)	E (mm/s)
1	0.2	0.41	265	95	25
2	0.3	0.55	280	110	40

Table -5: L8 Experimental Design

Levels	Input Parameters				
	A (mm)	B (mm)	C (°C)	D (°C)	E (mm/s)
1	0.2	0.41	265	95	25
2	0.2	0.55	265	110	40
3	0.2	0.55	280	95	25
4	0.2	0.41	280	110	40
5	0.3	0.55	280	95	40
6	0.3	0.41	280	110	25
7	0.3	0.41	265	95	40
8	0.3	0.55	265	110	25

Fig -5: FDM parts for surface roughness and Flatness error measurement

3. RESULTS OF EXPERIMENTATIONS

FDM parts of PC/ABS blend material is shown in figure. 5. Following table. 6 shows measured values of build time, surface roughness and flatness error of this experimentation. Then values of S/N ratio analyzed in software and shown in table. 7.

Table -6: Experimentation results using Taguchi's method

Exp. No.	Output parameters		
	Build time (min)	Surface Roughness (μm)	Flatness (mm)
1	65	6.3093	0.01
2	34	6.2511	0.0176
3	53	6.7926	0.0038
4	43	6.8686	0.0320
5	24	10.548	0.0274
6	45	10.485	0.0525
7	29	10.051	0.2058
8	36	11.1705	0.0169

Table -7: Signal to noise ratio (S/N) ratio value

Exp. No.	Output parameters		
	Build time (min)	Surface Roughness (μm)	Flatness (mm)
1	-36.2583	-15.9996	40.0000
2	-30.6296	-15.9191	35.0897
3	-34.4855	-16.6407	48.4043
4	-32.6694	-16.7374	29.8970
5	-27.6042	-20.4634	31.2450
6	-33.0643	-20.4114	25.5968
7	-29.2480	-20.0442	13.7311
8	-31.1261	-20.9615	35.4423

3.1 Effects of process parameters on Build time

Quality characteristics for build time is smaller the better selected to analyze effect of process parameters on build time.

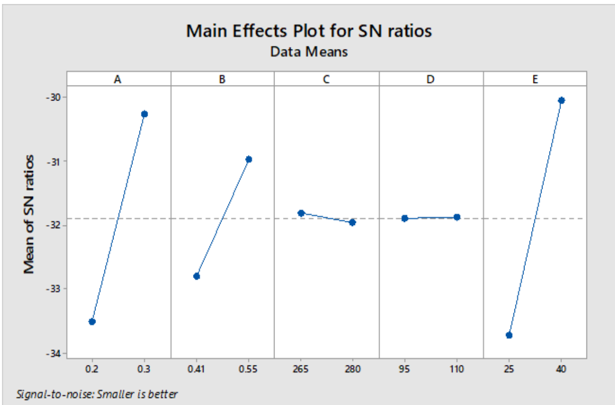

Chart -1: Main effect plot for S/N ratio of Build time

Above chart. 1 shows that combination of layer thickness (0.3mm), raster width (0.55 mm), printing speed (40 mm/s), bed temperature (110°C) and extrusion temperature (265°C) was more effective to decrease build time.
From table. 6 it shows, experiment number 5 have optimum condition with minimum build time 24 min and worse result for part 1 it required more time to print 65 min. Following response table. 8 shows printing speed was more effective to reduce build time by giving rank.

Table -8: Response Table for S/N Ratios of Build time

Level	A	B	C	D	E
1	-33.51	-32.81	-31.82	-31.90	-33.73
2	-30.26	-30.96	-31.96	-31.87	-30.04
Delta	3.25	1.85	0.14	0.03	3.70
rank	2	3	4	5	1

3.2 Effects of process parameters on surface roughness

To analyze S/N ratio, values of surface roughness taken as smaller the better quality characteristics.

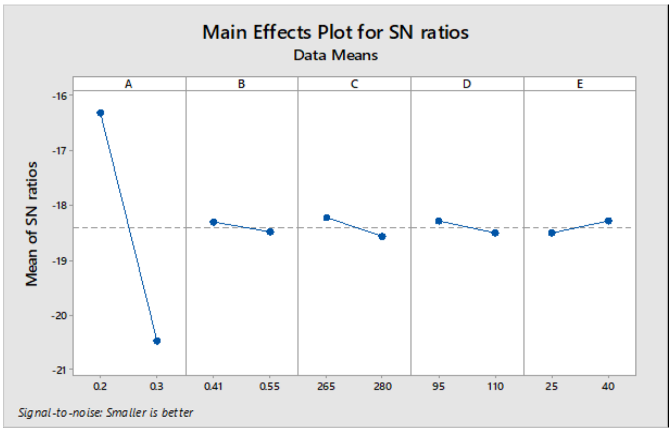

Chart -2: Main effect plot for S/N ratio of surface roughness

Above Chart. 2 shows the graph of effect of different levels of process parameters on surface roughness values obtained from experimentation result. Arithmetic average height (Ra) value was selected for measure surface roughness values with sampling length of 0.5mm. From above graph it shows, combination of layer thickness 0.2 mm, raster width 0.41mm, extrusion temperature 265°C and bed temperature 95°C and printing sped 40 mm/s was most effective to reduce surface roughness of the part. From following table. 9 it shows that layer thickness was more effective to change surface roughness. Best surface finish obtained for experiment number 2 was 6.2511 µm and worse result for experiment number 8 was 11.1705 µm.

Table-9. Response Table for S/N Ratios of Surface roughness

Level	A	B	C	D	E
1	-16.32	-18.30	-18.23	-18.29	-18.50
2	-20.47	-18.50	-18.56	-18.51	-18.29
Delta	4.15	0.2	0.33	0.22	0.21
Rank	1	5	2	3	4

3.3 Effects of process parameters on Flatness error

To analyze S/N ratio for flatness error smaller the better quality characteristics selected for flatness error. Flatness error values ranged from Lower value0.0038 mm to higher 0.2058 mm. Optimum combination of parameters for less flatness error was obtained at lower setting of layer thickness (0.2mm), extrusion temperature (95) and printing speed (25mm/s)and higher value of raster width (0.55mm) and extrusion temperature (280°C) showed by following chart. 3 Minimum value of flatness error was obtained for experiment number 3 with 0.0038mm error.

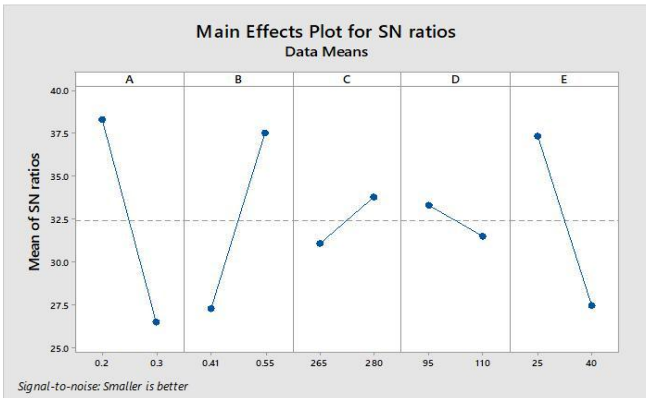

Chart -3: Main effect plot for S/N ratio of flatness (mm)

Following table. 10 shows important process parameters to obtain flat parts in the form of rank. This table showed that layer thickness was more important to obtain flat surface of the parts.

Table -10: Response Table for S/N Ratios of Flatness

Level	A	B	C	D	E
1	38.35	27.31	31.07	33.35	37.36
2	26.50	37.55	33.79	31.51	27.49
Delta	11.84	10.24	2.72	1.84	9.87
rank	1	2	4	5	3

4. CONCLUSION

This research analyzed surface finish, build time and flatness error obtained in FDM process for PC/ABS blend material. Following conclusions are made from experimental results.

- Build time of parts increase as decrease in layer thickness, raster width and printing speed. This occurred due to when layer thickness reduces it increase number of layers and number of passes of nozzle to create parts. And increase in printing speed it increase fused filament deposition rate so build time of part reduces as increase in printing speed. Increase in raster width it reduces number of raster in single layer so number of passes of nozzle reduced and part build time decreased.
- Flatness of part increase when layer thickness, printing speed and bed temperature is reduced, with higher value of raster width and extrusion temperature. In this work part printed without support so combination of lower layer thickness 0.2mm, printing speed 25mm/s and bed temperature 95°C, higher raster width 0.55mm and extrusion temperature 280°C gives proper bonding of layers and optimum setting of temperatures which reduced chances of falling layers where support was not present.
- Layer thickness was more important parameters to change surface roughness of FDM part. Surface roughness increases as increase in layer thickness because it increase stair steps effect on surface of part. To maintain same height of rasters in every layer, both extrusion temperature and bed temperature are play important role.
- In next work levels of parameters will be increased, ANOVA method will used to find out significance of parameter and multi-objection optimization method also used to find out one optimal setting which gives best result of build time, surface roughness and flatness error. Also this work extended in to study effect of process parameters on mechanical properties.

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