Investigation of Dynamic Mechanical Properties Of Fused Deposition Modeling Process Using ABS Material

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***Abstract*—**Fused deposition modelling (FDM) is a standout amongst the most broadly utilized layered assembling innovation in different industries because of its capacity to make complex parts at the least cost. Be that as it may, with regards to the mechanical properties, the advantage of FDM isn't ideal for each application. This is because of the way that the mechanical properties of the manufactured parts by FDM firmly identified with the process parameters in which the material is being prepared, thus the most effective method to hint at change them is meriting study. Numerous researchers have inspected the impact of differing parameters on the qualities of FDM made models. FDM made parts are constantly subjected to static and dynamic loading conditions in an extensive variety of businesses. In any case, previous looks into just centered around the mechanical properties under static loading conditions, yet none of them gave an efficient report on the impact of FDM creation parameters on the mechanical execution. This examination explores the impact of assembling parameters on dynamic mechanical performance of the handled parts by FDM. The outcomes demonstrate that dynamic mechanical performance of the fabricated parts is extraordinarily impacted by handling conditions.

Keywords- Acrylonitrile butadiene styrene, Dynamic Mechanical Property, Fused deposition modeling (FDM)

1. Introduction

The importance on reducing of merchandise progress time has insightful influence on generating process and outputted in the origin of a latest generation of production equipment which use CAD (computer aided design) model without interference of human and any other equipments manufacture part layer by layer deposition standard[29]. The method of such additive fragment generation processes is known as “Rapid Prototyping”. The “Rapid Prototyping” (RP) technology allows faster plus hardness less evolution from idea invention in the type of processor imaginings to the assembly of material models. However, “Rapid Prototyping” is a economical, stretchy and rapid way to make test parts related to production, material accessibility has traditionally limited the technology for its widely spread applications. Fused Deposition modelling (FDM) is a ground-breaking added substance fabricating innovation that produces complex geometrical parts from an extensive variety of thermoplastics straightforwardly from computer aided design (CAD) model. The success of FDM has mostly been accredited to its simplicity, accuracy, and affordability, which has allowed the general public to become familiar with additive manufacturing. Fused Deposition Modelling will enable parts of any geometry to be constructed in different parts, through the consecutive deposition of molten material. Thermoplastics are the ideal filament material, although a massive range of materials, including metals, ceramics, mixtures are also well-suited with the FDM process. Present Fused Deposition Modelling systems can manufacture parts with the ingredients like polycarbonate (PC), Polyphenol-sulfone and Acrylonitrile butadiene styrene (ABS). Throughout the layer by layer production process, the FDM material also regards physical and thermal changes to cartel their mechanical properties. In the Fused Deposition Machine, the head of the liquefier plays a role of heart, which is the input to the achievement of fused deposition modelling technology. The material in the filament form is dragged or strapped with the help of drive wheels which is glued to the electric motors and then goes into the chambers which are connected with heaters. The material then goes through the liquefier, which is a tube and is deposited from an extrusion tip. The tip is mainly threaded and screwed up into the heating chamber outlet. It is not compulsory to minimize the diameter of the extruded filament to allow for better detailed displaying. The extruded plastic joins with the formerly deposited part and tightens without wasting time. The chamber holding the complete system is controlled at a temperature less than the melting point of the material used to aid the attachment process. The part is removed then, from the chamber and does not need post dispensation in FDM. Schematic diagram of FDM is shown in figure 1. The authors officially distributed a survey paper that abridges the exploration gaps and restrictions in FDM process [2]. Various examinations have focused on advancing procedure parameters for processed parts under static mechanical properties. Anithaet. al. [8] has utilized Taguchi technique for evaluation of impact of layer thickness, raster width and deposition speed on Fused Deposition Modelling handled parts.

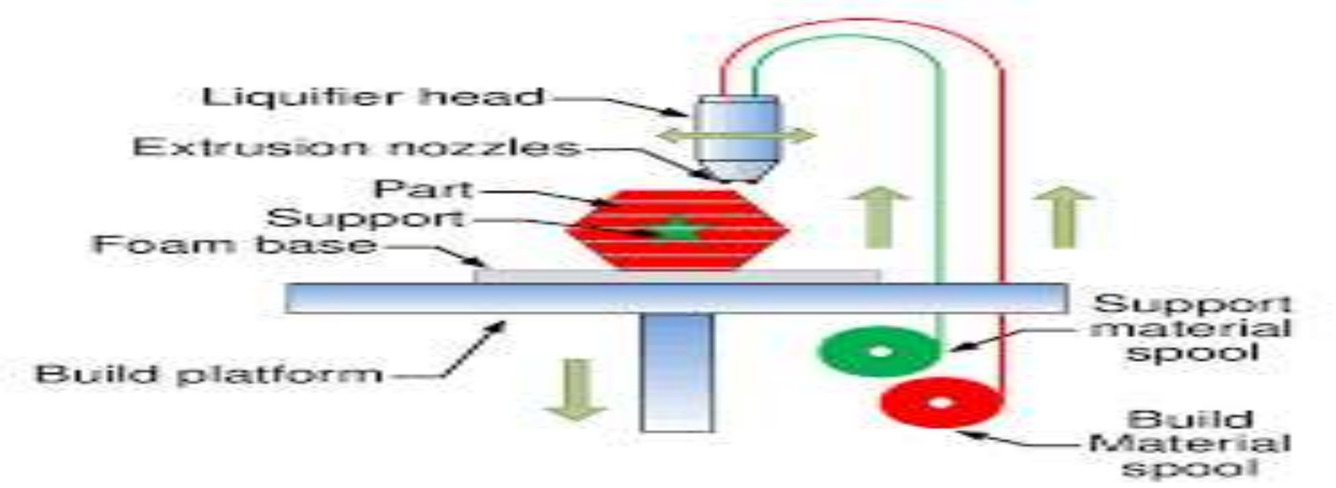


Figure.1 Schematic of FDM

The layer thickness has greater affection on quality of parts as compared to any other parameter. Mahapatraet. al. [20] revealed the impact of critical process parameters, for example, layer thickness, orientation, raster angle, raster width, and air gap utilizing a Taguchi plan L27 orthogonal array. The reactions considered in this investigation are mechanical properties of FDM created parts. Kim and Oh [9] studied different RP process based on tensile strength, impact strength and compressive strength, dimensional accuracy, hardness, surface roughness heat resistance, manufacturing speed, cost of material and geometry. Lee et al.,[18] did a trial utilizing the Taguchi strategy to locate the ideal procedure parameters of FDM that was utilized to deliver Acrylonitrile butadiene styrene (ABS) models. An analysis of variance (ANOVA), mean impact, signal to noise (S/N) ratio and an orthogonal array were used to consider the technique parameters required to achieve more prominent adaptability execution in models. It was discovered that layer thickness, raster angle and air gap altogether influence the versatility execution of ABS models Pennington et al., [23] examined different variables of process of FDM and effect of these variables on part quality and accuracy. Ziemian and Crawn, [43] considered a some of the parameters and disregarding different parameters to enhance the precision of FDM parts. Khan et al. [18] studied the effect of the layer thickness, raster angle and air gap on the performance of the FDM process with ABS prototype. Es Said et al. [22] have been studied effect of raster angle on properties like tensile strength, bending strength and impact strength of ABS part using FDM process. Their observations conclude that when polymer molecules are aligning along direction of flow that effect the strength.

2. Material and method

A total of 27 samples were manufactured for various blends of process parameters. All examples were manufactured utilizing STRATASY FORTUS 400mcFDM machine. Designed test samples using Nx CAD software, preparation of prototype of test specimens of ABS having 150 X 20 X 4 mm (L X B X H) are built by using 3D printing FDM machine. Dynamic mechanical property measurements were conducted using a DMA 2980 instrument and the storage modulus, loss modulus, and tan delta were obtained. Acrylonitrile butadiene styrene is a thermoplastic polymer finish by polymerizing styrene and acrylonitrile in the participation of polybutadiene [17]. The degrees can wander from 12% to 38% of acrylonitrile, 7% to 37% of butadiene and 41% to 65% of styrene. The outcome is a long hawser of polybutadiene confounded with shorter chains of poly (styrene-co-acrylonitrile). The nitrile bunches from closest chains, being polar, advance each other and difficulty the chains together, making ABS harder and stronger than polystyrene. The styrene gives the plastic a gleaming, impermeable surface. The polybutadiene, an extreme substance, gives sturdiness even at low temperatures. For the larger part of entries, ABS can be utilized between −18 °C and 78 °C as its machine-driven properties change with temperature. Its substance technique can be given as $(C_8H_8)_x \cdot (C_4H_6)_y \cdot (C_3H_3N)_z$. Its glass changeover temperature is around 105 °C[2,25].

2.1 Selection Of Parameters And Their Taguchi Experimental Design

Table 1 Factors with their levels

Factor	Control factors (level)		
	Low level	Medium level	High level
Layer thickness (mm)	0.125	0.174	0.25

Orientation (degree)	0	15	30
Raster angle (degree)	0	30	60
Raster width (mm)	0.4054	0.4554	0.5054
Air gap (mm)	0	0.003	0.006

243 tests are required to study about 5 factors with 3 levels if standard DOE is utilized however indistinguishable factually pertinent outcomes can be accomplished if Taguchi strategy is use with set number of investigations. In Taguchi configuration, scope of symmetrical exhibit is a vital issue for acquiring persuading conclusions [10, 18].In this investigation, 5 factors each at 3 level and interface of orientation with the various elements are viewed as, the total degree of freedom is 26. L27 orthogonal array is used in this case.

2.2 Working Range

Runs	A	B	C	D	E	Storage modulus (MPa)	Loss modulus (MPa)	Tan delta
1	1	1	1	1	1	448.38	55.532	0.774
2	1	2	1	2	2	935.2	101.147	0.9755
3	1	3	1	3	3	957.81	104.422	0.9815
4	1	1	2	2	2	538.67	48.642	0.8142
5	1	2	2	3	3	728.97	81.672	0.8711
6	1	3	2	1	1	969.2	107.193	0.9866
7	1	1	3	3	3	1293.31	148.166	0.9352
8	1	2	3	1	1	429.01	45.479	0.7547
9	1	3	3	2	2	1398.8	166.976	1.0653
10	2	1	1	2	3	1343.34	154.668	0.9529
11	2	2	1	3	1	504.28	46.629	0.7901
12	2	3	1	1	2	1221.78	137.351	1.0786
13	2	1	2	3	1	980.52	103.4	1.0548
14	2	2	2	1	2	468.52	49.239	0.7679
15	2	3	2	2	3	1326.49	141.575	0.9722
16	2	1	3	1	2	769.27	84.548	0.8978
17	2	2	3	2	3	1262.92	133.947	0.9631
18	2	3	3	3	1	1301	168.036	0.9785
19	3	1	1	3	2	1175.57	128.323	0.9759
20	3	2	1	1	3	1014.48	108.908	0.9393
21	3	3	1	2	1	1311.37	168.492	0.978
22	3	1	2	1	3	1190.28	126.425	1.0675
23	3	2	2	2	1	1096.43	117.091	0.9513
24	3	3	2	3	2	1420.33	156.39	1.0783
25	3	1	3	2	1	1251.55	151.805	1.0104
26	3	2	3	3	2	561.56	59.178	0.8265
27	3	3	3	1	3	1171.79	126.243	1.0229

The selection of the parameters and their levels is most significant stage in the DOE. Five parameters namely[2-7,12,14-15,17,20-21,25-27,30,33], A:layer thickness, B:orientation, C:raster angle, D:raster width and E:air gap are recognized as noteworthy factors based on early trials and in-depth literature review. The factor levels are chosen as per the allowable least and most extreme settings suggested by the hardware producer, experience, and genuine mechanical applications. The working conditions and theirs levels are shown in Table 1.

The exploratory examination because of noteworthy process parameters, for example, A:layer thickness, B:part introduction, C:raster point, D:air hole and E:raster width. Taguchi's parameter configuration, being a simple and practical technique, is embraced to perceive result of process parameters of FDM assembled parts with slightest experimental runs.

2.3 Statistical Design

The optimal design matrix presented in Table 2 contained a total of 27 trials. Minitab were used to analyze all statistical data collected from experimentation. Experimental results are presented in Table 3.

Table 2.L27 orthogonal array

Exp. No	Factors				
	A	B	C	D	E
1	1	1	1	1	1
2	1	1	1	1	2
3	1	1	1	1	3
4	1	2	2	2	1
5	1	2	2	2	2
6	1	2	2	2	3
7	1	3	3	3	1
8	1	3	3	3	2
9	1	3	3	3	3
10	2	1	1	3	1
11	2	1	1	3	2
12	2	1	1	3	3
13	2	2	2	1	1
14	2	2	2	1	2
15	2	2	2	1	3
16	2	3	3	3	1
17	2	3	3	3	2
18	2	3	3	3	3
19	3	1	3	2	1
20	3	1	3	2	2
21	3	1	3	2	3
22	3	2	1	3	1
23	3	2	1	3	2
24	3	2	1	3	3
25	3	3	2	1	1
26	3	3	2	1	2
27	3	3	2	1	3

Table 3.Experimental design matrix and associated responses results (ABS)

3. RESULTS AND DISCUSSION

Analysis of the experimental results was done with the aid of Minitab software. The final interaction model of storage modulus, loss modulus and tan delta for ABS are articulated as:

Storage modulus (MPa) = -599663 + 247478*A + 221206*B + 70668.2*C + 127606* D + 187700* E (1)

Loss modulus (MPa) = 5.75456 + 15.757 *A + 15.2872* B + 4.38367* C + 0.62767 D +9.0205* E (2)

Tan delta= -0.253194 + 0.0365454* A + 0.0362891* B +0.000687148 *C + 0.0079004* D + 0.0196222*E (3)

Analysis of variance (ANOVA) technique was used to test the importance of regression models and their respective variables ANOVA results for storage modulus, loss modulus and tan delta for ABS and PC are given in Tables 4-6.

Table 4 ANOVA results for storage modulus for ABS

Source	DOF	SS	Variance	F-value	P-value
A	1	1108.482	1108.482	13.937	0.001

B	1	34550.837	34550.84	1336.82	<0.0001
C	1	2764.835	2764.835	12.44	0.001
D	1	64514.618	64514.62	2.9	0.005
E	1	234245	234245	3.958	<0.0001
A*B	1	5.947	5.947	23.026	<0.0001
B*C	1	1347.418	1347.418	46.873	<0.0001
B*D	1	2321.936	2321.936	554.736	<0.0001
B*E	1	22341.529	22341.529	11.947	<0.0001
Error	17	342310.235	3904.387		
Total	26	363200.602			

Table 5 ANOVA results for Loss modulus for ABS

Source	DOF	SS	Variance	F-value	P-value
A	1	25.2	25.2	11.36	0.002
B	1	32764.487	32764.49	1145.37	<0.0001
C	1	53	53	4.47	0.0041
D	1	142.37	142.37	7.8	0.003
E	1	368.92	368.92	5.93	<0.0001
A*B	1	1377.23	1377.23	53.15	<0.0001
B*C	1	186.83	186.83	4.49	0.004
B*D	1	233.73	233.73	9.25	0.004
B*E	1	750.38	750.38	40.63	<0.0001
Error	17	1,754	1,754		
Total	26	35715.317			

Table 6 ANOVA results for Tan delta for ABS

Source	DOF	SS	Variance	F-value	P-value
A	1	0.023763	0.02482	299.72	<0.0001
B	1	0.062462	0.068273	564.82	<0.0001
C	1	0.00001	0.000012	1.83	0.00227
D	1	0.000023	0.000024	1.16	0.00284
E	1	0.000788	0.00081	29.54	<0.0001
A*B	1	0.00213	0.0027	26.93	0.0022
B*C	1	0.000643	0.000643	5.92	<0.0001
B*D	1	0.034512	0.03514	259.35	<0.0001
B*E	1	0.001524	0.00174	26.81	<0.0001
Error	17	0.0042	0.0042		
Total	26	0.125212			

Fitted line plot by regression analysis is used to examine the relationship between the response and predictor variable.

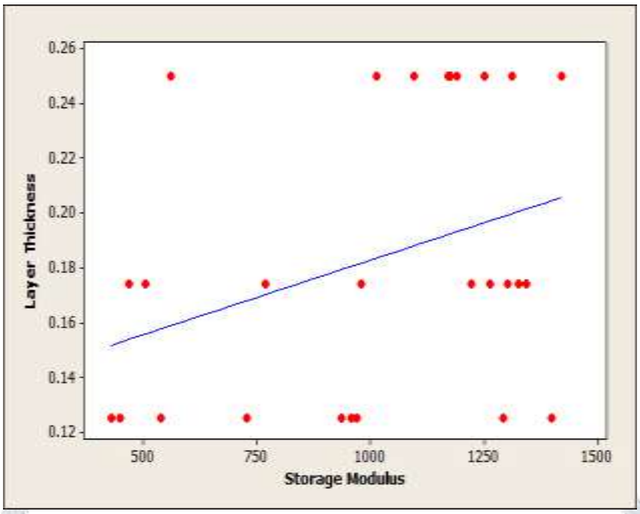


Figure.2 Fitted line plot for Storage Modulus Vs. Layer Thickness(ABS)

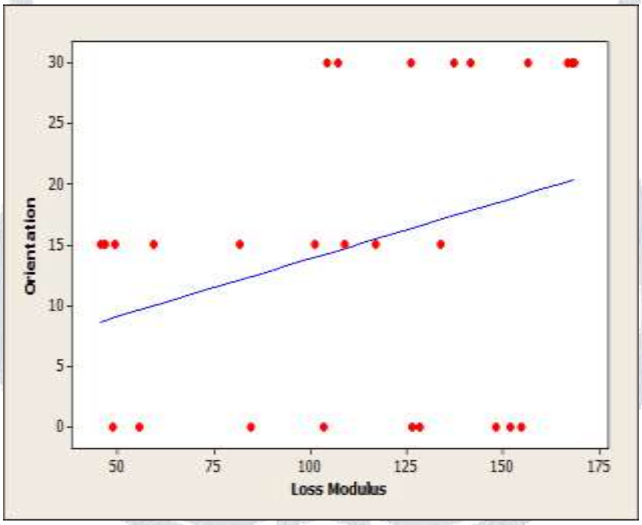


Figure. 3 Fitted line plot for Loss Modulus Vs. Orientation (ABS)

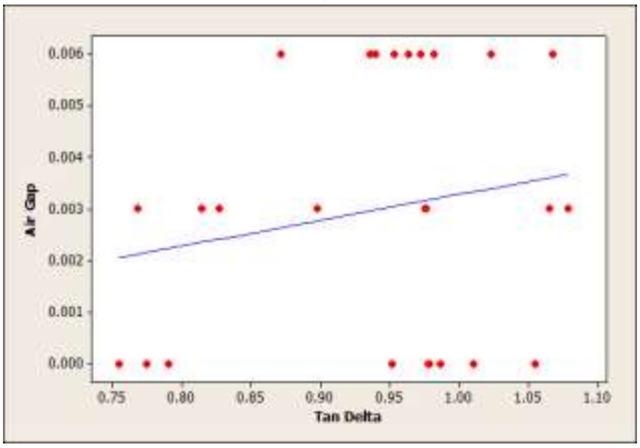
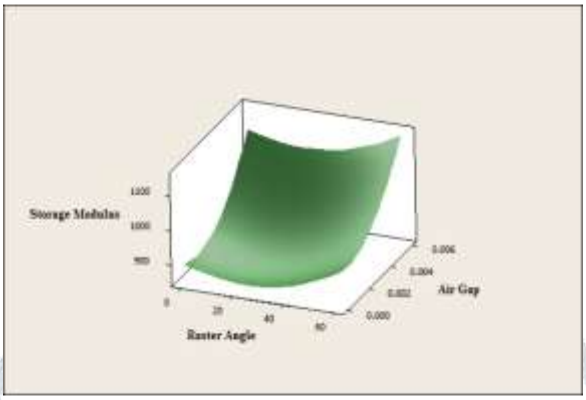


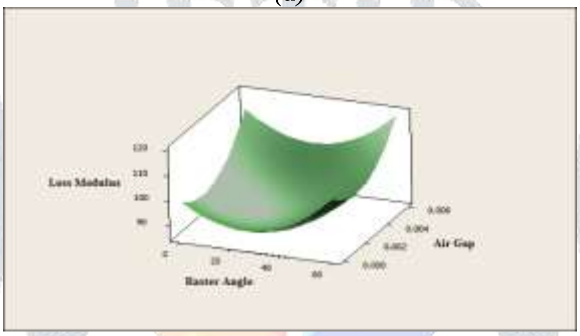
Figure.4 Fitted line plot for Tan Delta Vs. Air Gap (ABS)

Using the figure 1, it can be assessed that the layer thickness influences the Storage modulus because of the slanted fitted line. Likewise it can be seen that layer thickness at low level achieved the lower Storage modulus. Figure 2 shows the incline fitted line for Orientation parameter. It can in like manner be seen that it impacts the Loss modulus. It exhibits that the perfect setting is at low level. This suggests the low level achieved bring down Loss Modulus. Figure 3 demonstrates the incline fitted line for air gap parameter which demonstrates that airgap parameter influences the response variable. Additionally it indicates ideal setting for air gap at low level where it has achieved brings down response value in contrast with high level.

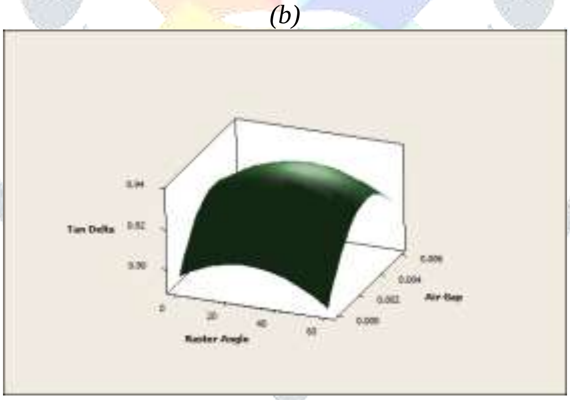
Figure 4 (a, b and c) demonstrates the response surface plots created by regression equations for the influence of interaction between the procedure parameters on all reactions.



(a)



(b)



(c)

Figure.5 Response Surface plots for dynamic mechanical response (ABS)

The highest value of dynamic mechanical responses will be at least Raster Angle. But for high estimation of Raster Angle, increment in dynamic mechanical response is generally little. Dynamic mechanical responses are increasing as for Air Gap

Table 7 shows the results from the experiments using best promising process parameters are compared with the predicted values and the percentage deviation (error) and there is very small variation among the actual observed values and predicted values which can be seen in Table 7.

Mechanical property	Optimal process parameter					Predicted value	Experi. value	Deviation
	A	B	C	D	E			
Storage modulus	0.25	0	60	0.4554	0	1463.25	1460.37	-0.02
Loss modulus	0.25	0	60	0.4554	0	172.35	168	-0.025

Tan delta	0.2 5	0	60	0.455 4	0	1.094	1.1129	1.72

Table 7 Confirmation experiment of optimal parameters for ABS

Table 7 shows the results from the confirmation experiments with best process parameters are compared with the predicted values and the percentage deviation (error). From Table 7, it can be observed that the difference between the actual observed values and predicted values is very small. Obviously, this confirms an outstanding conclusion of this study.

4. CONCLUSION

Effect of layer thickness, raster width, air gap, raster angle and build orientation each at three levels is studied. Taguchi's design of experiment is used to discover the best possible factor levels and important factors and interactions. It is found that shrinkage is main along the length, diameter of hole and width of test part where as thickness is always more than the required value. Taguchi method is adopted to decide the best factor level setting which will assure all the four performance characteristics simultaneously.

The result of Taguchi method shows that layer thickness of 0.25mm, air gap of 0.0mm , raster angle of 0°, raster width of 0.4554mm and part orientation of 0° are optimal factor settings for reaching better all performance characteristics concurrently. Results from ANOVA have also exposed that overall, out of the five process variables studied, air gap, slice thickness are found to have an enormous influence on maximizing dynamic mechanical properties followed by the build orientation and raster width, while the raster angle has least influence on these properties.

The optimization results showed that the maximum value of mechanical responses obtained from optimization process was:

For ABS material storage modulus of 1460.37 MPa, loss modulus of 168 MPa and tan delta of 1.1129 as can be seen in Table 6.24.Optimal parameters to maximize the mechanical properties are: 0.25 mm for layer thickness, 0 for air gap, 60° for raster angle, 0° for build orientation, 0.4554 mm for raster width.

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