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Investigation of Dynamic Mechanical Properties of Fused Deposition Modelling Process Using PC Material

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Abstract **Fused deposition modeling (FDM) has been perceived as a compelling innovation to produce 3D dimensional parts straightforwardly from a computer aided design (CAD) model show in a layer-by-layer style In spite of the fact that it has turned into an essentially imperative assembling process, however it is as yet not very much acknowledged added substance producing innovation for load carrying parts under powerful and cyclic conditions because of numerous preparing parameters influencing the part properties. The motivation behind this investigation is to portray the FDM fabricated parts by identifying how the individual and intelligent FDM process parameters will impact the execution of made items under powerful and cyclic conditions. Experiments were conducted through design of experiments design. Impact of every parameter on the storage modulus, loss modulus and tan delta were examined utilizing ANOVA system. Besides, ideal preparing parameters were resolved and approved by directing confirmation test. The outcomes demonstrated that plan show gave great quality expectations.**

Keywords—Fused deposition modelling (FDM); Dynamic Mechanical Property; PC Material

I. INTRODUCTION

Rapid Prototyping (RP) advances generally utilized by numerous manufacturing industries have permitted more prominent levels of product approval in a limited capacity to focus time and meeting clients' stringent necessities for new item improvements. fuse Deposition Modelling (FDM), an unmistakable RP innovation created by Stratasys Inc, produces models which can be utilized for early plan confirmation and testing. In bio-therapeutic designing, it is discovering applications for mass customization. In FDM process, parts are made through layer-by-layer statement of expelled material from a spout utilizing feedstock thermoplastic fiber twisted on a spool [1]. Stratasys Inc restricts the extent of material that can be utilized as a part of FDM for the most part to Polycarbonate (PC), Acrylonitrile Butadiene Styrene (ABS), Polyphenyl-Sulfone (PPSF) and ULTEM. In the Fused Deposition Machine, the head of the liquefier assumes a part of heart, which is the contribution to the accomplishment of intertwined affidavit displaying innovation. The material in the fiber frame is hauled or tied with the assistance of drive wheels which is stuck to the electric motors and after that goes into the chambers which are associated with heaters. The material at that point experiences the liquefier, which is a tube and is stored from an expulsion tip. The tip is essentially strung and botched into the warming chamber outlet. It isn't obligatory to limit the measurement of the expelled fiber to take into consideration better definite showing. The expelled plastic joins with the once in the past kept part and fixes without sitting around idly. The chamber holding the entire framework is controlled at a temperature not as much as the liquefying purpose of the material used to help the connection procedure. The part is evacuated at that point, from the chamber and does not require post allotment in FDM. Most recent multi decade's broad research has been done with restricted accomplishment on improving FDM working parameters for different quality attributes, for example, mechanical properties, surface roughness, manufacture quality and dimensional accuracy. For instance, Wang et al. [2] detailed that the mechanical execution can exceptionally influenced by part course. This examination likewise uncovered that the most noteworthy mechanical quality can be acquired when the part was fabricated with least z height. Rayegani and Onwubolu [3] have done a test on the effect of FDM working conditions on mechanical quality of assemble parts. The outcomes from this examination have demonstrated that little road width, negative air ap and zero form heading can enhance the mechanical quality essentially. Sood et al. [4] presumed that thick layers and rasters with zero raster to raster air gap enhance the mechanical qualities fundamentally. Christiyan et al [5]reported that utilizing low printing rate and low layer thickness can successfully enhance the mechanical execution of FDM assembled models. Impens and Urbanic [6] researched the impact of post- processing settings on the mechanical qualities for manufactured parts. They

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found that assemble bearing is the key factor in advancing tractable and pressure qualities for handled parts. Anitha et al. [7] broke down the impact of process parameters at first surface roughness of the parts delivered in FDM. They utilized Taguchi technique to upgrade the parameters. Novakova-Marcincinova and Novak-Marcincin [8] examined the anisotropic material properties of FDM made ABS material considering the factors like raster introduction and air hole. They likewise contrasted the material properties and other RP advances, for example, Stereolithography (SLA) and Laminated Object Manufacturing (LOM).

II. Materials and Methods

The analyses in this investigation were composed and performed utilizing Taguchi technique. This examination utilized the stipulated conditions as indicated by the exploratory outline to design the analyses. A total of 27 tests were directed at 3 levels of each info parameter. 3 level examinations include a test plan in which every parameter is researched at 3 levels. The beginning times of exploratory work and examination normally include the investigation of countless to decide the indispensable parameters imperative for the framework. 3 level test configuration is utilized as a part of these phases to discover pointless factors with the goal that consideration would then be able to be made just on the basic elements. The trial configuration utilized as a part of this examination considered the accompanying preparing parameters to explore their impact on the dynamic modulus of versatility; layer thickness (A), orientaton (B), raster angle (C), raster width (D) and air gap (E).The chose process parameters and their levels are displayed in Table 1 and they are chosen by the past investigations.

Table 1 FDM process parameters and 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

A total of 27 tests having measurement of 150 (length) mm X 20(breadth) X 4(height) mm were created by FDM Fortus 400 according to planned arrangement introduced in Table 2.Polycarbonates (PC) are a group of thermoplastic polymers containing carbonate groups in their chemical structures. Polycarbonates used in manufacturing are strong, tough materials, and some grades are optically transparent. They are easily worked, molded, and thermoformed. Because of these properties, polycarbonates find many applications. Products made from polycarbonate can contain the precursor monomer bisphenol-A(BPA). Polycarbonates received their name because they are polymers containing carbonate groups (−O−(C=O)−O−). A balance of useful features, including temperature resistance, impact resistance and optical properties, places polycarbonates sandwiched between commodity plastics and engineering plastics. Dynamic mechanical property estimations were led utilizing a DMA 2980 instrument and the most extreme stockpiling modulus, misfortune modulus, and tan delta were gotten. The capacity modulus measures the versatile vitality put away in the material amid distortion, though the misfortune modulus measures the damping disseminated as warmth, and tan delta (mechanical damping) is the proportion of the thick (misfortune) to the capacity modulus. It quantifies the vitality dispersal in a material. It speaks to how great a material can assimilate vitality [9]. The exploratory outline design as far as coded parameter with the deliberate stockpiling modulus, misfortune modulus and tan delta are displayed in Table 2.

Figure 1: FDM machine

Table 2 Experimental design matrix and associated responses results (PC)

Runs	A	B	C	D	E	Storage modulus (MPa)	Loss modulus (MPa)	Tan delta
1	1	1	1	1	1	1190.97	121.3	1.0826
2	1	2	1	2	2	1201.45	118.915	1.0883
3	1	3	1	3	3	1186.16	119.791	1.0869
4	1	1	2	2	2	738.73	83.785	0.9292
5	1	2	2	3	3	1044.68	112.038	1.0243
6	1	3	2	1	1	832.79	102.028	0.9414
7	1	1	3	3	3	1305.81	151.984	1.0427
8	1	2	3	1	1	961.47	99.827	0.9936
9	1	3	3	2	2	516.69	71.882	0.8717
10	2	1	1	2	3	922.08	98.85	0.9917
11	2	2	1	3	1	1374.38	153.878	1.0468
12	2	3	1	1	2	1268.85	142.822	0.9476
13	2	1	2	3	1	533.03	56.513	0.8602
14	2	2	2	1	2	1144.8	118.732	0.9773
15	2	3	2	2	3	1096.83	133.429	0.9464
16	2	1	3	1	2	1460.16	167.219	1.0822
17	2	2	3	2	3	716.83	71.937	0.8953
18	2	3	3	3	1	1235.29	125.38	1.0922
19	3	1	1	3	2	1289.46	127.989	1.0206
20	3	2	1	1	3	1158.61	120.014	1.0259
21	3	3	1	2	1	1052.02	119.641	1.027
22	3	1	2	1	3	941.72	99.58	0.9912
23	3	2	2	2	1	737.02	83.586	0.9171
24	3	3	2	3	2	1367.69	152.601	1.0837

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25	3	1	3	2	1	887.26	94.88	0.9613
26	3	2	3	3	2	1180.6	125.347	0.9801
27	3	3	3	1	3	829.38	83.581	0.9278

III. 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 PC are given in Tables 3-5.

Table 3 ANOVA results for storage modulus for PC

Source	DOF	SS	Variance	F-value	P-value
A	1	1238.345	2138.42	15.637	0.001
B	1	44550.345	41234.21	143.57	<0.0001
C	1	3064.535	5124.85	14.45	0.001
D	1	64254.936	4254.894	4.7	0.0037
E	1	246783	6783	3.99945	<0.0001
A*B	1	31456.564	2456.64	24.84	<0.0001
B*C	1	92645.27	32635.21	47.83	<0.0001
B*D	1	4987.56	8254.74	555.1764	<0.0001
B*E	1	5187.34	8223.64	12.8744	<0.0001
Error	17	3,865	3865		
Total	26	401522.625			

Table 4 ANOVA results for Loss modulus for PC

Source	DOF	SS	Variance	F-value	P-value
A	1	27.26	143.75	12.54.	0.001
B	1	32764.487	32764.487	1284,61	<0.0001
C	1	55	163.38	5.04	0.0045
D	1	142.37	284.65	8.12	0.0041
E	1	368.92	187.37	6.82	<0.0001
A*B	1	1377.23	15326.83	54.72	<0.0001
B*C	1	186.83	2274.93	4.93	0.004
B*D	1	233.73	1837.82	10.04	0.005
B*E	1	750.38	287.92	42.84	<0.0001
Error	17	1,754	1,754		
Total	26	35719.377			

Table 5 ANOVA results for Tan delta for PC

Source	DOF	SS	Variance	F-value	P-value
A	1	0.024748	0.02593	301.93	<0.0001
B	1	0.06927	0.07253	569.32	<0.0001
C	1	0.000011	0.000018	1.93	0.002
D	1	0.000029	0.000029	1.63	0.0023
E	1	0.00088	0.00086	31.12	<0.0001
A*B	1	0.00262	0.0028	28.61	0.001
B*C	1	0.000711	0.000699	6.83	<0.0001
B*D	1	0.039162	0.03587	261.75	<0.0001
B*E	1	0.001724	0.00189	27.52	<0.0001
Error	17	0.004	0.004		
Total	26	0.138444			

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

Layer Thickness parameter in Fig. 2 has low or no impact on Storage Modulus. Impact of Orientation on Loss Modulus Delta can be found in Fig.3. With the increase in Orientation, Loss modulus somewhat increased. Air Gap has no or low impact on reaction for lower and higher settings as per Fig.4.

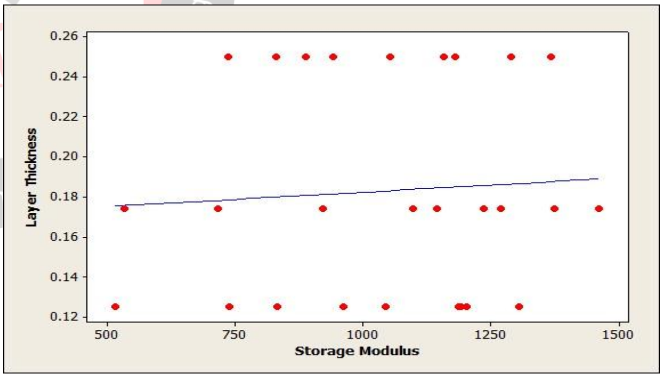

Figure 2 Fitted line plot for Storage Modulus Vs. Layer Thickness(PC)

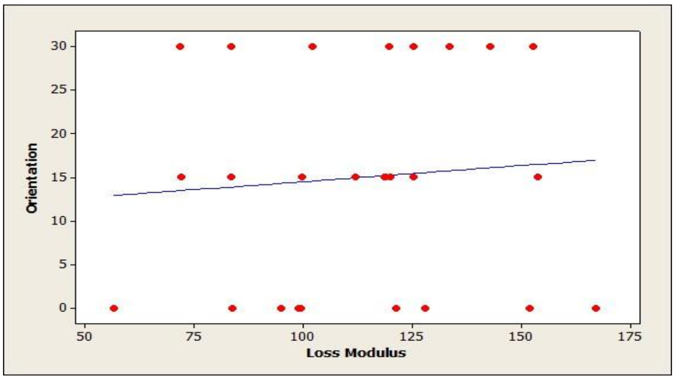

Figure 3 Fitted line plot for Loss Modulus Vs. Orientation (PC)

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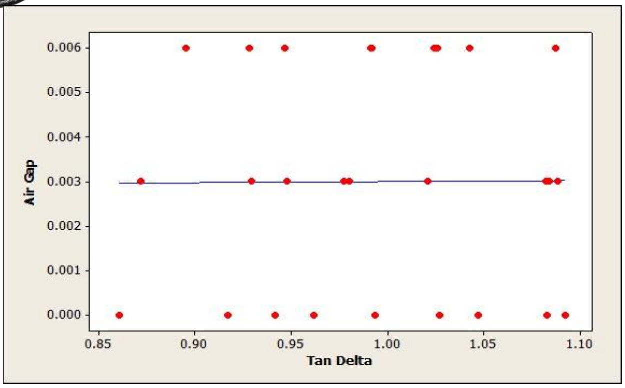
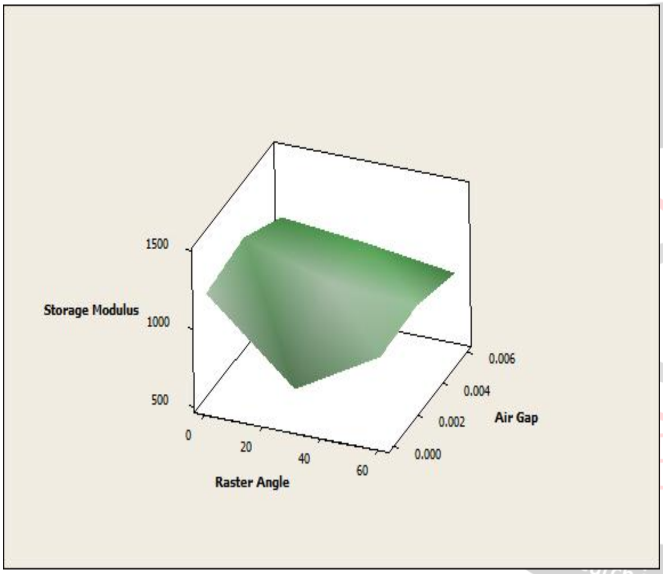
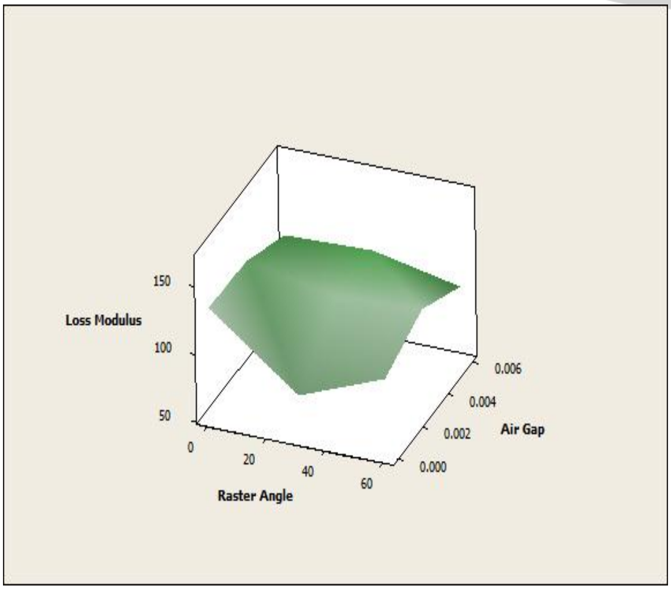


Figure 4 Fitted line plot for Tan Delta Vs. Air Gap (PC)

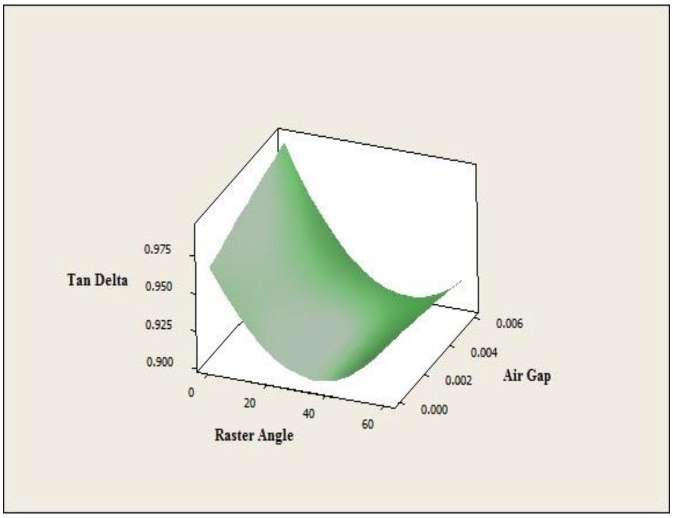
From response surface plots (Figure 5 a, b and c) it is noticed that dynamic mechanical responses first decrement and afterward increment with Raster angle increment. From response surface plots (Figure 5 a, b and c) It can be seen that dynamic mechanical responses increments with an air gap increment.



(a)



(b)



(c)

Figure 5 Response Surface plots for dynamic mechanical response (PC)

Table 6 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 6.

Table 6 Confirmation experiment of optimal parameters for PC

Mechanical property	Optimal process parameter					Predicted value	Experi. value
	A	B	C	D	E		
storage modulus	0.25	0	60	0.45	0	1531.12	1529.0
Loss modulus	0.25	0	60	0.45	0	175.21	171.11
Tan delta	0.25	0	60	0.45	0	1.2031	1.2230

An estimate outline for predicted values indicates that the highest values for dynamic mechanical responses are:

For PC material storage modulus of 1531.12 MPa, loss modulus of 175.21 MPa and tan delta of 1.2031 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.

Table 6. shows the results from the confirmation experiments with best process parameters are compared with the predicted values and the percentage deviation (error). From Table 6. 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.

IV. CONCLUSION

In this chapter, effect of layer thickness, raster width, air gap, raster angle and part 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.

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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 for PC material layer thickness of 0.25 mm, air gap of 0.0 mm, raster angle of 60°, raster width of 0.4554 mm 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 PC material storage modulus of 1529.12 MPa, loss modulus of 171.11 MPa and tan delta of 1.2230 as can be seen in Table 6.25.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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