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DEVELOPMENT OF STATISTICAL MODEL FOR THE EFFECT OF BUILD ORIENTATION ON THE PARAMETERS OF INTEREST OF A RAPID PROTOTYPED PART

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Abstract

The main idea behind this paper is to highlight efforts made to improve the application potential of the fused deposition modelling (FDM) process by producing the rapid prototyping parts at minimum cost. Build orientation analysis for different shaped parts is carried out. The mathematical model is formulated to estimate the requirement of model material, support material, time and percentage volumetric error for part preparation in FDM. The parts produced by the FDM rapid prototyping process are considered for build orientation analysis. The concept can be extended for parts produced with any layered manufacturing process. This is the first attempt to deal with diversified types of part geometries and formulate a mathematical model for all types of parts to determine material and time in FDM.

1. Introduction

The idea of using rapid prototyping (RP) is appreciated worldwide, owing to zero tool costs, reduced lead times, and considerable gains in terms of freedom in product design and production schedules [1]. RP is allowing designers to make prototypes faster and less expensively compared with established practices [2]. The RP parts can be built with various possible build orientations. The specific part orientation influences the prototype build time, material, and accuracy. Most of the time, RP parts are required to be built with the fastest speeds and lowest costs, provided the quality requirements are fixed at a certain level. An appropriate build orientation ensures optimum utilization of the resources and reduces the cost. Costing is one of the major areas of improvement in RP. An important problem is automatic support generation and part orientation, because part orientation influences the final prototype build time and the surface finish of critical areas [3]. Optimal part orientation can be one of the methods of solving part accuracy problems [4]. The surface quality, build time, and support structure were identified as the important parameters for the best orientations [5]. Determination of the optimal build orientation and minimizing the manufacturing cost were identified as two of the most basic problems for all laminated manufacturing processes [6]. Hada et al. [7] inferred that the earlier published work mainly focuses on selection of appropriate orientation with the stereo-lithography process. Part build time and surface accuracy are the two important factors which decide the optimum orientation [8].

Matos M.A. et al. [10] produced evidence of a significant amount of research carried out in the area of laminated manufacturing process planning and part build optimization. They presented a multi-objective optimization problem associated with the fused deposition modelling (FDM) process and suggested future research by including several additional process variables. Taufik and Jain [11] presented the development of a part-build orientation system for rapid prototyping by considering the volumetric error (VE) encountered in parts during the building process. The methodology involves a primitive volume approach, which assumes a complex part to be constructed from a combination of basic primitive volumes. The system graphically displays the VE at different orientations for any part and recommends the best orientation for the minimum VE in the whole part. A Pareto-based optimization algorithm has been reported to determine a series of best part orientations in stereo-lithography systems. The optimization was performed using the multi-objective genetic algorithm [12]. Qin et al. [13] presented a study describing genetic algorithms developed specifically for problems with multiple objectives. Their study used specialized fitness functions and introduced methods to promote solution diversity. The ability to select the optimal orientation of build-up has been reported as one of the critical factors, since it affects the part quality, build time, and part cost [14]. Nguyen and Choi [15] stated part deposition orientation as a very important factor in layered manufacturing, as it affects build time, support structure, dimensional accuracy, surface finish, and cost of the prototype. A number of layered manufacturing process-specific parameters and constraints have been reported that need to be considered while deciding the part deposition orientation. Determination of an optimal part deposition orientation has been explained as a difficult and time-consuming task. It has been observed from the literature referenced that the majority of research has focused on the optimization of one specific build goal, or several build goals with respect to only one specific variable. The main idea behind the current paper is to highlight the efforts made to improve the application potential of the FDM process by producing the RP components at minimum cost. The build orientation analyses for prismatic, curved boundary, and complex-shaped parts are carried out. The effects of build orientations on cost and other significant parameters are analysed. The mathematical model is formulated as a unique solution to estimate the total cost of part preparation in FDM. The major objective of the study is to identify the optimal part build orientation and parameters determining minimum cost of part preparation in the FDM process.

This paper is focused to study the effect of build orientation along x and y axis and layer thickness on the cost-effective parameters such as model material, support material, time requirement and error.

2. Difficulties with shape diversities of parts

Rapid prototyping processes build parts in an additive fashion, by growing slices of material from the bottom to the top of the part, directly from computer-driven data [16-18]. In particular, in all layer manufacturing processes, the part building philosophy is the same. However, the types of part geometries and features that must be dealt with during product design and development are numerous. Hence, it is extremely difficult to arrive at a single solution that will derive optimal build orientation for all types of parts. The four parts were identified which has different geometries as shows in Fig. 1a. Valve-body, Fig. 1b. Valve-seat, Fig. 1c. Silencer and Fig. 1d. Flange. The given figure shows the geometries having different build orientation having step size of 22.50.

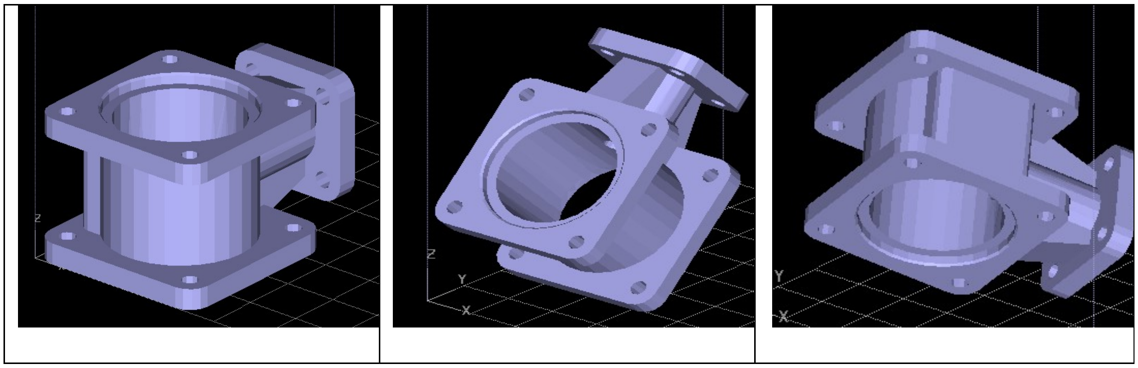


Fig 1a. Part1 (Valve-Body) with different Build Orientation

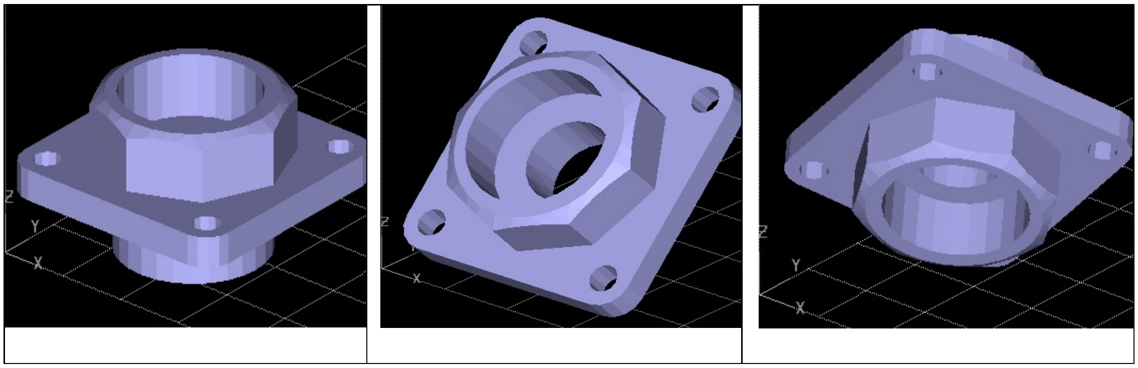


Fig 1b. Part 2 (Valve-Seat) with different Build Orientation

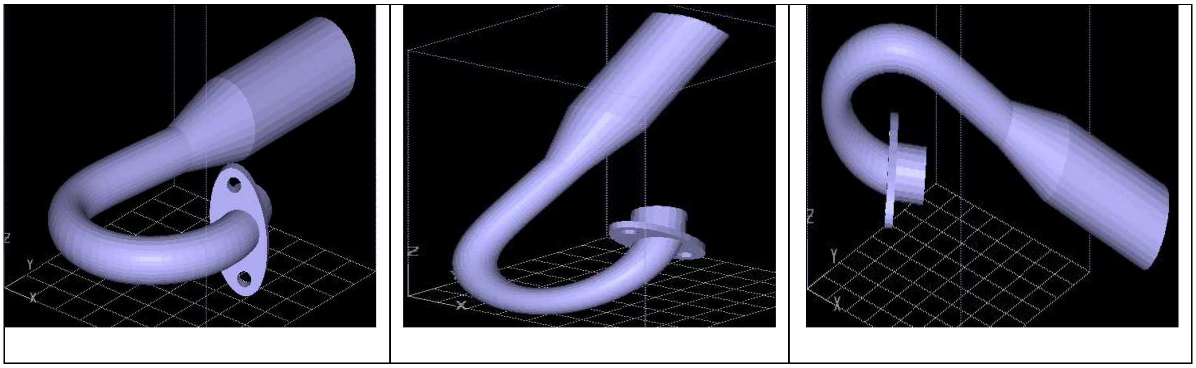


Fig 1c. Part 3 (Silenser) with different Build Orientation

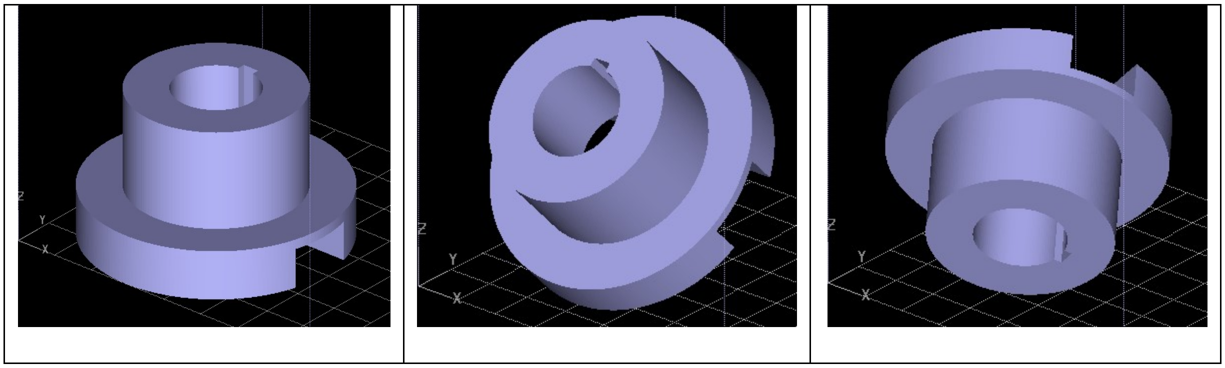


Fig 1d. Part 4 (Flange) with different Build Orientation

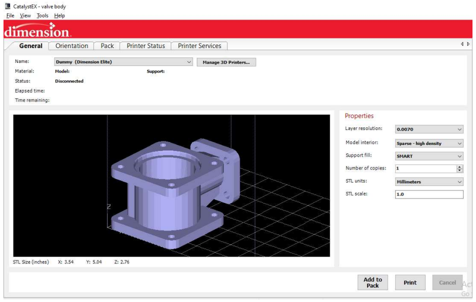
3. Study Design and Process Parameter

In the study of rapid prototyping, the study was conducted on CatalystEX 4.0 software which used to import the 3D model object and slice it and prepare a file for rapid prototyping. The input parameters consider for the operation of model are orientation of an object, model interior, support fill, and layer resolution. For the study, model interior has kept constant as Sparce i.e. High Density. And, support fill kept constant as SMART. The orientation parameter and layer resolution has changed. The study was conducted for 4 different shapes of geometry as shown in above figures. The effect of orientation of object and layer thickness/resolution was studied on required model material, support material, time for printing and percentage volumetric error. The study was carried out in accordance with the test situation, as given in Table 1, by using response surface method. The input parameter for mathematical modelling is build orientation. The build orientation is given in terms of degree as shown in below table. But, when the data is observed, the data shows sinusoidal nature. In order to fit the data in the mathematical modelling, data transformation is needed. So, data of build orientation which is in the range of 0° to 180° has transformed into radian and further transformed into abs(sin(2θ)) where θ is in radian. Considering obtain values of build orientation are used for the mathematical modelling. Therefore, the note to use equation for mathematical modeling is, instead of using direct angle in degree, use the value of abs(sin(2θ)).

$$\emptyset = abs(\sin(2\theta))$$

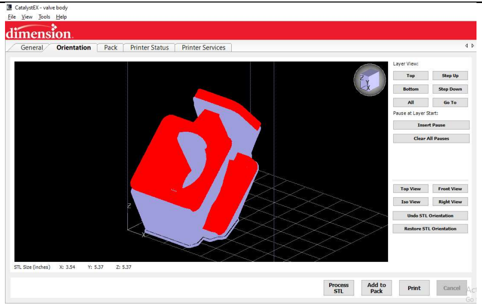
Table 1. Independent Variables with their factors

Parameters	Factor level								
	Level 1	Level 2	Level 3	Level 4	Level 5	Level 6	Level 7	Level 8	Level 9
Orientation along X axis (^{0})	0	22.5	45	67.5	90	112.5	135	157.5	180
Orientation along Y axis (^{0})	0	22.5	45	67.5	90	112.5	135	157.5	180
Layer thickness (inches)	0.007	0.01	--	--	--	--	--	--	--



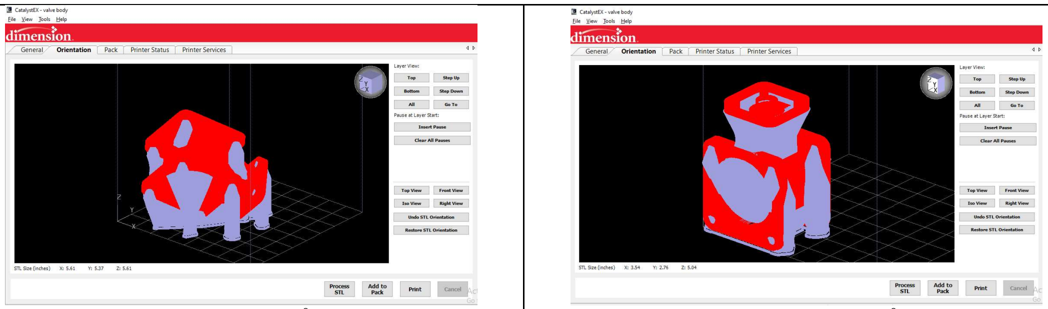
Name: Dummy (Dimension Elite)
Material: Model: Support:
Status: Disconnected
Elapsed time:
Time remaining:
Layer resolution: 0.0070
Model interior: Sparse - high density
Support fill: SMART
Number of copies: 1
STL units: Millimeters
STL scale: 1.0
STL Size (inches) X: 3.54 Y: 5.04 Z: 2.76

(a) Part Orientation at 0^0 about X- axis



STL Size (inches) X: 3.54 Y: 5.37 Z: 5.37

(b) Part Orientation at 45^0 about X- axis



STL Size (inches) X: 5.61 Y: 5.37 Z: 5.61

STL Size (inches) X: 3.54 Y: 2.76 Z: 5.04

(c) Part Orientation at 45^0 about X- axis and Y-Axis

(d) Part Orientation at 90^0 about X- axis

Fig. 2 Model and support building with different orientations: (a) part oriented at 0^0 about the X axis; (b) Part Orientation at 45^0 about X- axis; (c) Part Orientation at 45^0 about X- axis and Y-axis; (d) Part Orientation at 90^0 about X- axis

4. Methodology

For the design of experimentation, a Box Behnken design was used [13, 14]. Identified independent variables are Orientation along X axis, Orientation along Y axis and Layer resolution and dependent variables which are model material, support material, time and error used for design. In the current study Design Expert software was used. Total four model of each 162 runs were generated. For the design and execution of the tests, Response surface methodology is employed.

The statistical program "Design Expert (DX-13)" is used to pick suitable model. The response surface model (RSM) is used for the analyzing purpose. DX-13 also used to track the progress of RSM. The linear regression equations are obtaining for the response characteristics such as model material, support material, time and error. The study data are used to obtain these regression equations. These equations are also use full to examine the effect of rapid prototyping on different parameters. The analysis of variance i.e. (ANOVA) is a statistical technique for analyzing findings.

The sum of square, model summary statistics and lack of fit test were used to determine the model's performance in terms of model material, support material, time and error. The sum of squares test for the chronological model reveals, how the rising difficulty to contribute the model. This used to observe the 2FI has been suggested for model material, support material, time and error.

The "lack of fit test" evaluates the pure error with the residual error from the simulated design point of view. This shows that the suggested models in all four features have a negligible lack of fit value i.e. $p<0.05$; thus, 2FI model adequacy is validated. Additional test called "model summary statistics" indicates that proposed models are best to fit with small standard of deviation, high "Adjusted R-Squared" values, along with a small "PRESS" score.

5. Analysis of Variance

For statistical evaluation of the results, ANOVA technique is used. For the necessary response characteristics, process variables with a p-value less than 0.05 are deemed significant words. The ANOVA results for Model Material (MM), Support

Material (SM), Time for printing (Time) and percentage volumetric error have been represented respectively for all four components. The Design-Expert program has been used for statistically interpretation of the data of experimental design, which included very useful data and affirmed the use of factorial design for execution of experiments. To check the sufficiency and adequacy of models, statistical variables like model F-value, correlation coefficient (R2), lack of fit F-value, adjusted R-squared (R2Adj), predicted residual error sum of squares (PRESS), predicted R-squared (R2Pred), and adequate precision (AP) were generated by the ANOVA provision available in the Design-Expert software given by [15].

a. *Statistical interference of Model Material*

In this statistical interference of rapid prototyping model material, the model got an F-value of 259.12, 321.54,74.85,242.79 for valve-seat, valve-body, silencer and flange respectively means the model is considerable. The probability of only 0.01% of the F-value will large due to the noise occurrence. The P-values < 0.05 shows the model is considerable, and the Lack of Fit, i.e. F value of 18.93,8.80,34.07, 11.80 for valve-seat, valve-body, silencer and flange respectively means this is considerable. For the equation of model material, predicted R2 value i.e. 0.9006, 9190, 0.718, 0.8959 for valve-seat, valve-body, silencer and flange respectively is nearer to the R2 value i.e. 0.9093, 0.9256, 0.743, 0.9038 for valve-seat, valve-body, , silencer and flange respectively. Also the difference between these two values are less than 0.2 which shows model accuracy. The precision value for model material is measure from the signal to noise ratio. The preferable value of precision should be more than four and in this case it is observed as 57.0845, 67.649, 32.48, 55.007 for valve-seat, valve-body, silencer and flange respectively which shows decent signal. This model can be used to find your way through the design world.

b. *Statistical interference of Support Material*

In this statistical interference of rapid prototyping support material, the model got an F-value of 228.03, 152.25, 212.59,158.29 for valve-seat, valve-body, silencer and flange respectively means the model is considerable. The probability of only 0.01% of the F-value will large due to the noise occurrence. The P-values < 0.05 shows the model is considerable, and the Lack of Fit, i.e. F value of 16.89, 10.30, 22.51 and 34.79 for valve-seat, valve-body, silencer and flange respectively means this is considerable. For the equation of support material, predicted R2 value i.e. 0.8901, 0.8436, 0.8824, and 0.8481 for valve-seat, valve-body, silencer and flange respectively is nearer to the R2 value i.e. 0.8982, 0.8549, 0.8917 and 0.8597 for valve-seat, valve-body, silencer and flange respectively. Also the difference between these two values are less than 0.2 which shows model accuracy. The precision value for support material is measure from the signal to noise ratio. The preferable value of precision should be more than four and in this case it is observed as 50.83, 40.91, 48.64 and 40.60 for valve-seat, valve-body, silencer and flange respectively which shows decent signal. This model can be used to find your way through the design world.

c. Statistical interference of Time

In this statistical interference of rapid prototyping Time, the model got an F-value of 172.78, 238.96, 203.45 and 178.02 for valve-seat, valve-body, silencer and flange respectively means the model is considerable. The probability of only 0.01% of the F-value will large due to the noise occurrence. The P-values < 0.05 shows the model is considerable, and the Lack of Fit, i.e. F value of 31.72, 52.72, 18.75, and 19.83 for valve-seat, valve-body, silencer and flange respectively means this is considerable. For the equation of Time, predicted R2 value i.e. 0.8581, 0.8937, 0.8770, and 0.8620 for valve-seat, valve-body, silencer and flange respectively is nearer to the R2 value i.e. 0.8699, 0.9024, 0.8873, and 0.8733 for valve-seat, valve-body, , silencer and flange respectively. Also the difference between these two values are less than 0.2 which shows model accuracy. The precision value for Time is measure from the signal to noise ratio. The preferable value of precision should be more than four and in this case it is observed as 43.09, 51.70, 48.11, and 44.20 for valve-seat, valve-body, silencer and flange respectively which shows decent signal. This model can be used to find your way through the design world.

d. Statistical interference of Percentage Volumetric Error

In this statistical interference of rapid prototyping % volumetric error, the model got an F-value of 132.69, 250.73, 199.87 and 134.33 for valve-seat, valve-body, silencer and flange respectively means the model is considerable. The probability of only 0.01% of the F-value will large due to the noise occurrence. The P-values < 0.05 shows the model is considerable, and the Lack of Fit, i.e. F value of 155.66, 23.79, 25.57, and 22.02 for valve-seat, valve-body, silencer and flange respectively means this is considerable. For the equation of % volumetric error, predicted R2 value i.e. 0.8226, 0.8989, 0.8755, and 0.8239 for valve-seat, valve-body, silencer and flange respectively is nearer to the R2 value i.e. 0.8370, 0.9066, 0.8855, and 0.8387 for valve-seat, valve-body, silencer and flange respectively. Also the difference between these two values are less than 0.2 which shows model accuracy. The precision value for % volumetric error is measure from the signal to noise ratio. The preferable value of precision should be more than four and in this case it is observed as 35.89, 52.01, 46.54, and 38.39 for valve-seat, valve-body, silencer and flange respectively which shows decent signal. This model can be used to find your way through the design world.

6. Results and Discussion

The influence of various independent parameters, the Orientation along X axis (θx), Orientation along Y axis (θy), and Layer Thickness on four cost performance parameters namely MM, SM, Time, and Error will be explained by Graphs of response surfaces. To evaluate the ability of the observed outcomes, predicted and normal residual plots against actual data plots were acquired.

a. Effect of independent parameter on Model Material

With experimental data from Table 1, a regression equation for melting rate as function of four input parameters has been established.

Regression equation in terms of actual factor:

$$MM_{Valveseat} = 2.45477 + 0.4025 * \emptyset x + 0.4108 * \emptyset y + 25.606 * \mathrm{LT} + 0.076 * \emptyset x * \emptyset y + 5.833 * \emptyset x * \mathrm{LT} + 4.862 * \emptyset y * \mathrm{LT}$$
………………………………………………Eq.1a

$$MM_{Valvebody} = 4.799 + 0.187 * \emptyset x + 0.194 * \emptyset y + 50.56 * \mathrm{LT} + 0.089 * \emptyset x * \emptyset y + 3.975 * \emptyset x * \mathrm{LT} + 2.139 * \emptyset y * \mathrm{LT}$$
………………………………………………Eq.1b

$$MM_{Silencer} = 2.163 + 0.084 * \emptyset x + 0.120 * \emptyset y + 22.780 * \mathrm{LT} + 0.0055 * \emptyset x * \emptyset y + 1.806 * \emptyset x * \mathrm{LT} + 1.327 * \emptyset y * \mathrm{LT}$$
………………………………………………Eq.1c

$$MM_{Flange} = 6.950 + 1.138 * \emptyset x + 1.296 * \emptyset y + 72.411 * \mathrm{LT} + 0.241 * \emptyset x * \emptyset y + 16.672 * \emptyset x * \mathrm{LT} + 15.342 * \emptyset y * \mathrm{LT}$$
………………………………………………Eq.1d

The above response surface has been generated to investigate the impact of process factors on the rate of Model Material and is shown in Fig. 3a, 3b, 3c, and 3d.

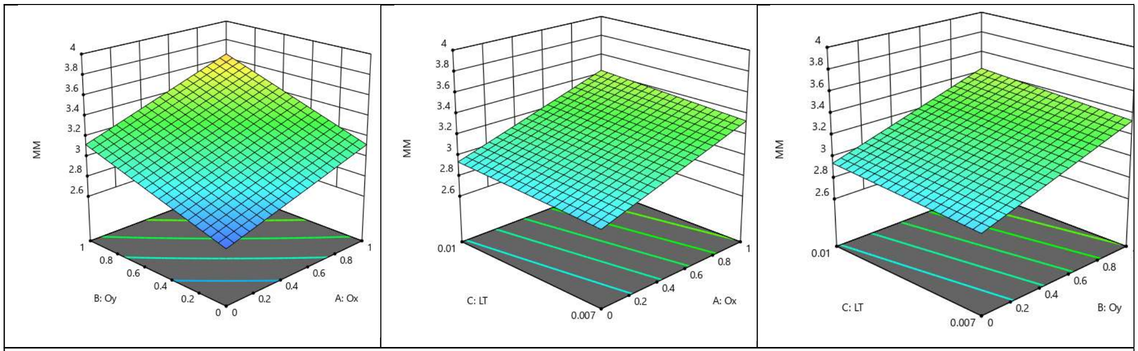


Fig.3a. Effect of Build Orientation and Layer Thickness on MM for Valve-body

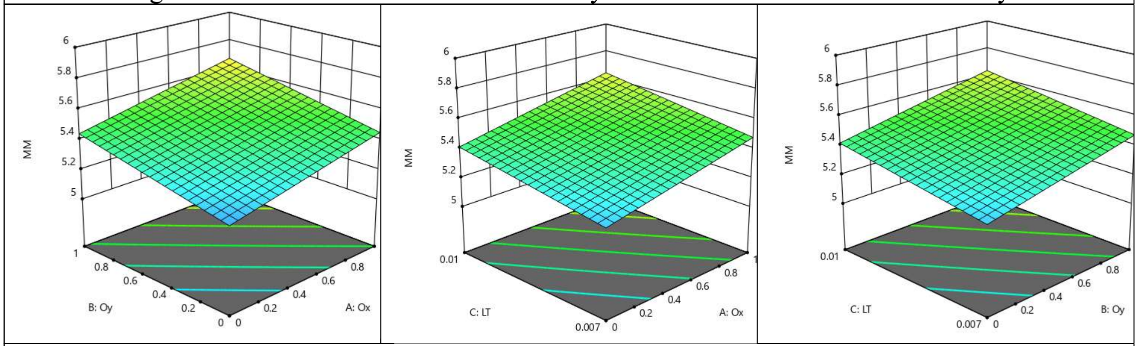


Fig.3b. Effect of Build Orientation and Layer Thickness on MM for Valve-seat

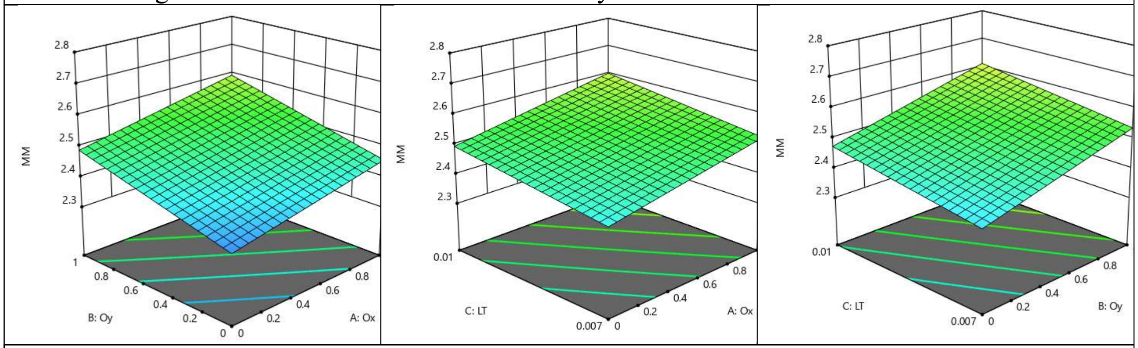


Fig.3c. Effect of Build Orientation and Layer Thickness on MM for Silence

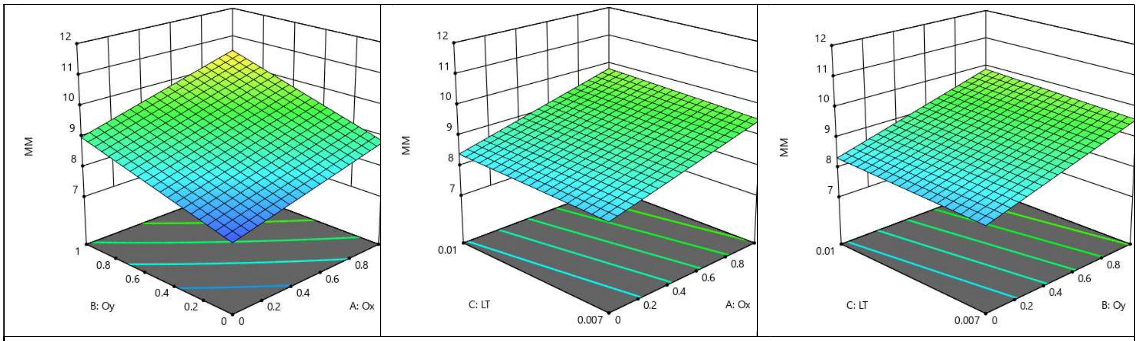


Fig.3d. Effect of Build Orientation and Layer Thickness on MM for Flange

From the above figure, it has been clearly seen the effect of build orientation on requirement of model material is very small for all the parts. The three parameters observed are orientation along X-axis, Y-axis, and Layer Thickness. Total four parts are examined under CatalystEX 4.0 software. The orientations were stated in the equation 1.a, 1.b, 1.c, and 1.d in the form of radian. As seen in figure, the build orientation i.e. orientation along X-axis increases, there is slightly changes in the model material for all parts. Similar effect can be seen for remaining parts. The effect of build orientation i.e. orientation along Y has also checked for model material. It has been observed that, though there is increment in the orientation, but model material has small changes. From the study of above graph, it can be stated that the effect of build orientation is very small or negligible. As per Layer thickness or resolution point of view, it shows minor effect on model material. From the above graph of all parts, it has observed that, as the Layer thickness increases from 0.007 to 0.01 inch, the model material requirement is slightly increasing.

b. Effect of independent parameter on Support Material

With experimental data from Table 1, a regression equation for support material as function of four input parameters has been established. Regression equation in terms of actual factor:

$$SM_{Valveseat} = 1.123 + 0.538 * \sin(2\emptyset x) + 0.521 * \sin(2\emptyset y) + 11.858 * \mathrm{LT} + 0.252 * \sin(2\emptyset x) * \sin(2\emptyset y) + 5.872 * \sin(2\emptyset x) * \mathrm{LT} + 6.493 * \sin(2\emptyset y) * \mathrm{LT}$$

……………………………………………….Eq.2a

$$SM_{Valvebody} = 2.289 + 1.383 * \sin(2\emptyset x) + 1.316 * \sin(2\emptyset y) + 20.811 * \mathrm{LT} + 0.910 * \sin(2\emptyset x) * \sin(2\emptyset y) + 17.043 * \sin(2\emptyset x) * \mathrm{LT} + 17.836 * \sin(2\emptyset y) * \mathrm{LT}$$

…………………………………………….Eq.2b

$$SM_{Silencer} = 1.043 + 0.539 * \sin(2\emptyset x) + 0.544 * \sin(2\emptyset y) + 9.753 * \mathrm{LT} + 0.318 * \sin(2\emptyset x) * \sin(2\emptyset y) + 6.36 * \sin(2\emptyset x) * \mathrm{LT} + 7.073 * \sin(2\emptyset y) * \mathrm{LT}$$

…………………………………………….Eq.2c

$$SM_{Flange} = 1.346 + 1.445 * \sin(2\emptyset x) + 1.223 * \sin(2\emptyset y) + 9.258 * \mathrm{LT} + 1.6 * \sin(2\emptyset x) * \sin(2\emptyset y) + 21.78 * \sin(2\emptyset x) * \mathrm{LT} + 20.55 * \sin(2\emptyset y) * \mathrm{LT}$$

…………………………………………….Eq.2d

The above response surface has been generated to investigate the impact of process factors on the rate of support Material and is shown in Fig. 4a, 4b, 4c & 4d.

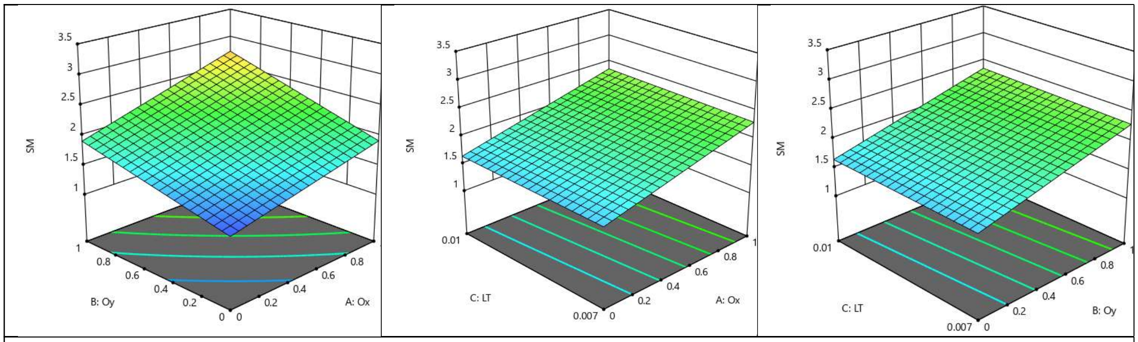


Fig.4a. Effect of Build Orientation and Layer Thickness on SM for Valve-body

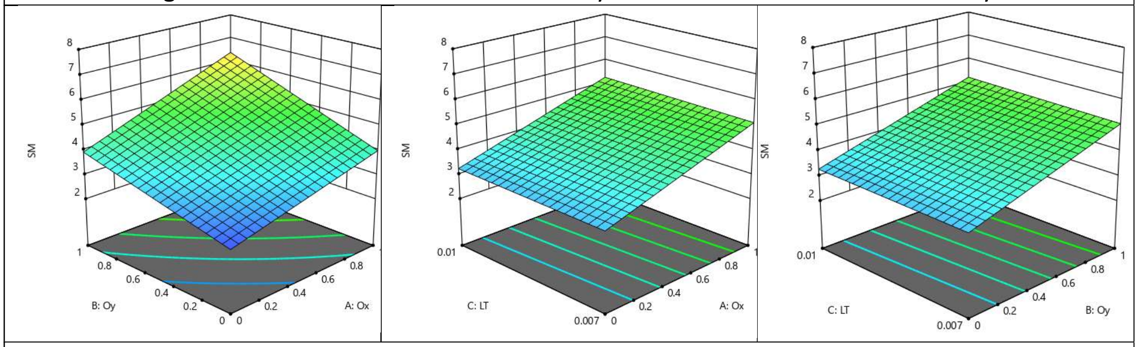


Fig.4b. Effect of Build Orientation and Layer Thickness on SM for Valve-seat

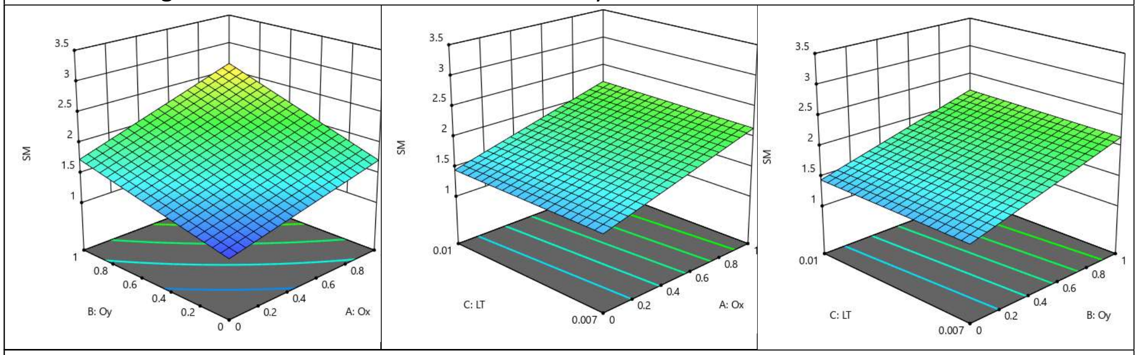


Fig.4c. Effect of Build Orientation and Layer Thickness on SM for Silencer

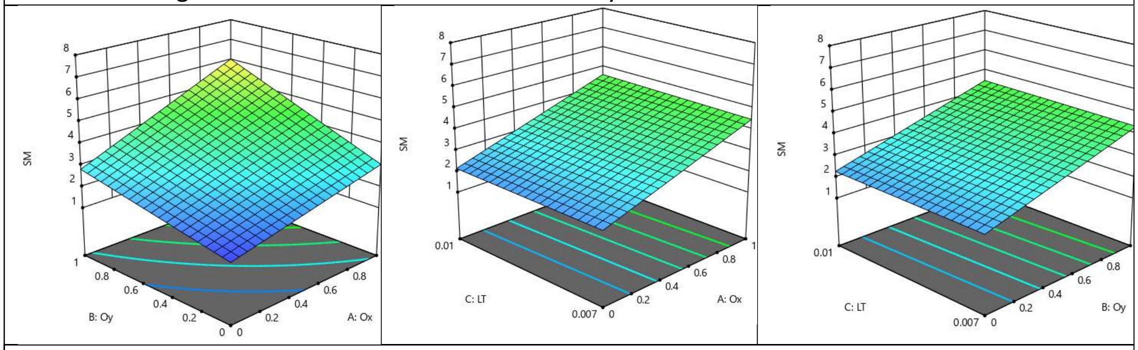


Fig.4d. Effect of Build Orientation and Layer Thickness on SM for Flange

From the above figure, it has been clearly seen the effect of build orientation on requirement of support material for all the parts. The three parameters observed are orientation along X-axis, Y-axis, and Layer Thickness. Total four parts are examined under CatalystEX 4.0 software. The orientations were stated in the equation 2.a, 2.b, 2.c, and 2.d in the form of abs(sin2θ) as given in above equation. As seen in figure, the build orientation i.e. orientation along X-axis (Øx) increases, there is also increase in the support material for all parts. The effect of build orientation i.e. orientation along Y (Øy) has also checked for support material. It has also been observed that, as increase in the orientation, support material also increases. From the study of above graph, it can be stated that build orientation has significant effect on support material. As per layer thickness or resolution point of view, it shows negligible effect on support material. From the above graph of all parts, it has observed that, as the Layer thickness increases from 0.007 to 0.01 inch, the support material requirement is negligibly increasing.

c. *Effect of independent parameter on Time*

With experimental data from Table 1, a regression equation for melting rate as function of four input parameters has been established.

Regression equation in terms of actual factor:

$$Time_{Valveseat} = 6.658 + 4.261 * \sin(2\emptyset x) + 3.702 * \sin(2\emptyset y) - 36.927 * \mathrm{LT} + 2.254 * \sin(2\emptyset x) * \sin(2\emptyset y) - 18.381 * \sin(2\emptyset x) * \mathrm{LT} - 25.695 * \sin(2\emptyset y) * \mathrm{LT} \ldots\ldots \text{Eq.3a}$$

$$Time_{Valvebody} = 20.185 + 6.946 * \sin(2\emptyset x) + 7.441 * \sin(2\emptyset y) - 115.895 * \mathrm{LT} + 2.491 * \sin(2\emptyset x) * \sin(2\emptyset y) - 18.581 * \sin(2\emptyset x) * \mathrm{LT} - 46.201 * \sin(2\emptyset y) * \mathrm{LT} \ldots\ldots \text{Eq.3b}$$

$$Time_{Silencer} = 11.728 + 3.057 * \sin(2\emptyset x) + 3.460 * \sin(2\emptyset y) - 67.73 * \mathrm{LT} + 0.887 * \sin(2\emptyset x) * \sin(2\emptyset y) - 5.18 * \sin(2\emptyset x) * \mathrm{LT} - 20.76 * \sin(2\emptyset y) * \mathrm{LT} \ldots\ldots \text{Eq.3c}$$

$$Time_{Flange} = 16.61 + 7.901 * \sin(2\emptyset x) + 7.493 * \sin(2\emptyset y) - 94.20 * \mathrm{LT} + 3.429 * \sin(2\emptyset x) * \sin(2\emptyset y) - 28.377 * \sin(2\emptyset x) * \mathrm{LT} - 48.984 * \sin(2\emptyset y) * \mathrm{LT} \ldots\ldots \text{Eq.3d}$$

The above response surface has been generated to investigate the impact of process factors on the rate of Model Material and is shown in Fig. 5a, 5b, 5c, 5d.

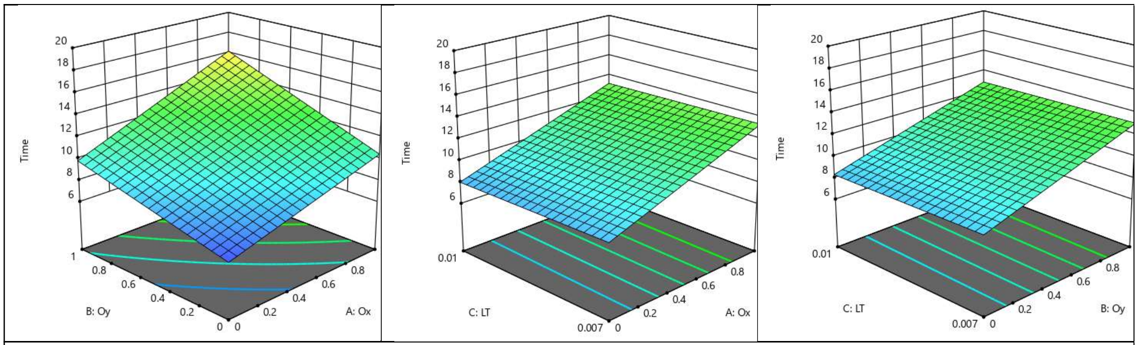


Fig.5a. Effect of Build Orientation and Layer Thickness on Time for Valve-body

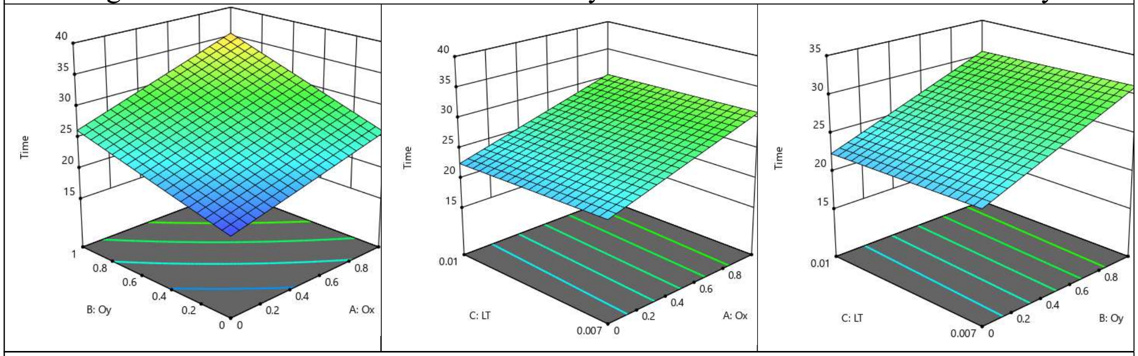


Fig.5b. Effect of Build Orientation and Layer Thickness on Time for Valve-seat

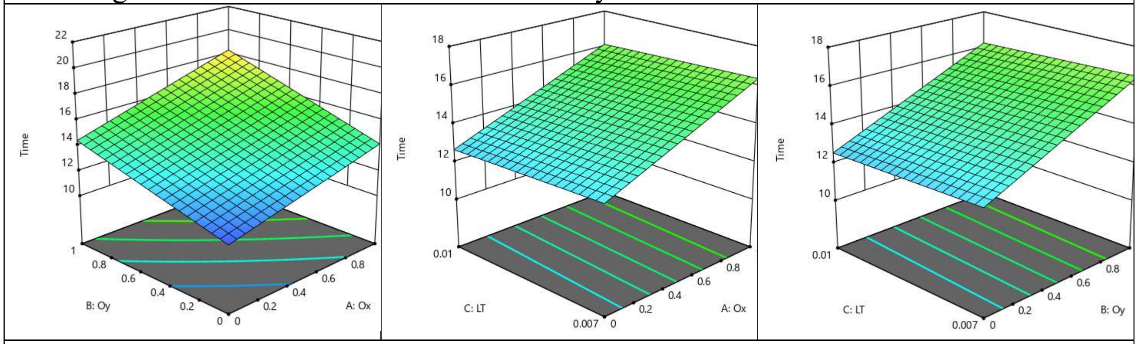


Fig.5c. Effect of Build Orientation and Layer Thickness on Time for Silencer

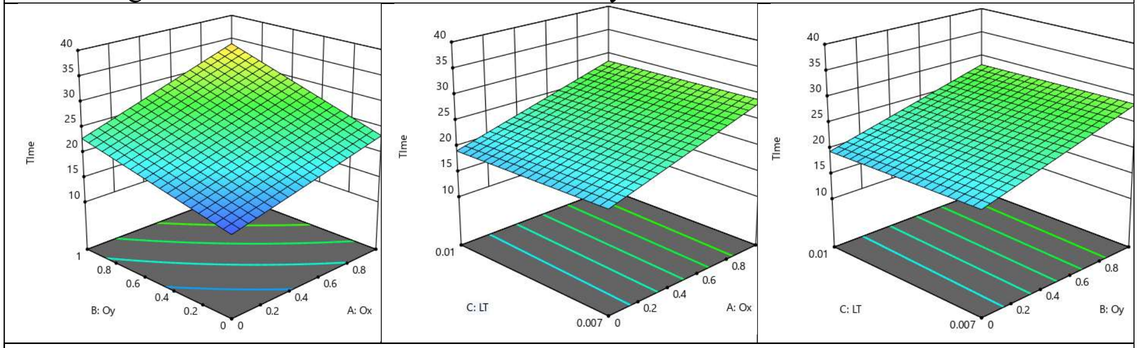


Fig.5d. Effect of Build Orientation and Layer Thickness on Time for Flange

From the above figure, it has been clearly seen the effect of build orientation on requirement of time for printing for all the parts. The three parameters observed are orientation along X-axis, Y-axis, and Layer Thickness. Total four parts are examined under CatalystEX 4.0 software. The orientations were stated in the equation 3.a, 3.b, 3.c, and 3.d in the form of abs(sin2θ) as given in above equation. As seen in figure, the build orientation i.e. orientation along X-axis (Øx) increases, there is also increase in the time for all parts. The effect of build orientation i.e. orientation along Y (Øy) has also checked for time. It has also been observed that, as increase in the orientation, time also increases. From the study of above graph, it can be stated that build orientation has significant effect on time. As per layer thickness or resolution point of view, it shows negligible effect on time. From the above graph of all parts, it has observed that, as the Layer thickness increases from 0.007 to 0.01 inch, the time requirement is negligibly increases.

d. Effect of independent parameter on Percentage Volumetric Error (Error)

With experimental data from Table 1, a regression equation for melting rate as function of four input parameters has been established.

Regression equation in terms of actual factor:

$$Error_{Valveseat} = 0.222 + 0.407 * \emptyset x + 0.396 * \emptyset y - 0.397 * \mathrm{LT} + 0.677 * \emptyset x * \emptyset y - 1.711 * \emptyset x * \mathrm{LT} - 2.267 * \emptyset y * \mathrm{LT} \ldots\ldots \text{Eq.4a}$$

$$Error_{Valvebody} = 0.903 + 0.390 * \emptyset x + 0.437 * \emptyset y - 3.119 * \mathrm{LT} + 0.185 * \emptyset x * \emptyset y - 0.548 * \emptyset x * \mathrm{LT} - 1.647 * \emptyset y * \mathrm{LT} \ldots\ldots \text{Eq.4b}$$

$$Error_{Silencer} = 4.638 + 2.002 * \emptyset x + 2.009 * \emptyset y - 16.047 * \mathrm{LT} + 0.854 * \emptyset x * \emptyset y - 2.757 * \emptyset x * \mathrm{LT} - 7.753 * \emptyset y * \mathrm{LT} \ldots\ldots \text{Eq.4c}$$

$$Error_{Flange} = 1.153 + 0.210 * \emptyset x + 0.311 * \emptyset y - 4.035 * \mathrm{LT} + 0.057 * \emptyset x * \emptyset y + 0.218 * \emptyset x * \mathrm{LT} - 1.060 * \emptyset y * \mathrm{LT} \ldots\ldots \text{Eq.4d}$$

The above response surface has been generated to investigate the impact of process factors on the rate of Model Material and is shown in Fig. 6a, 6b, 6c, 6d.

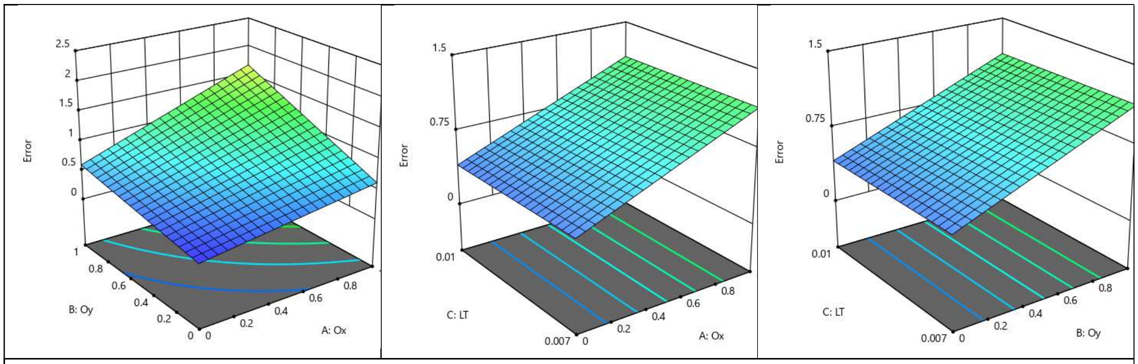


Fig.6a. Effect of Build Orientation and Layer Thickness on Error for Valve-body

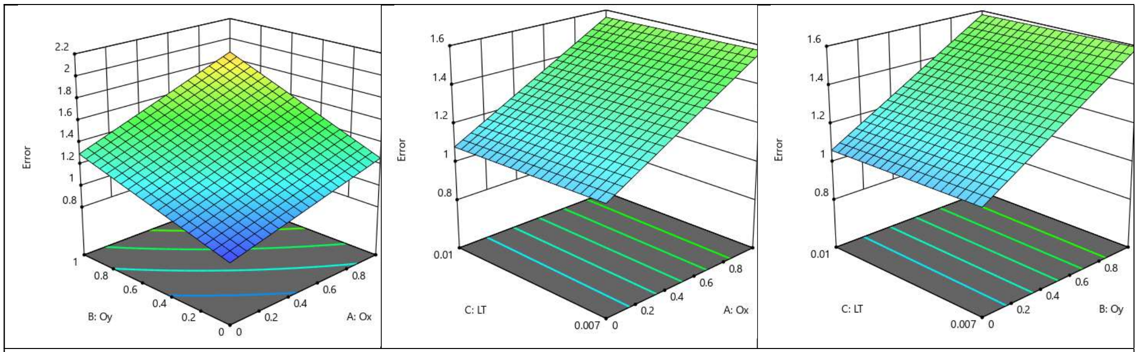


Fig. 6b. Effect of Build Orientation and Layer Thickness on Error for Valve-seat

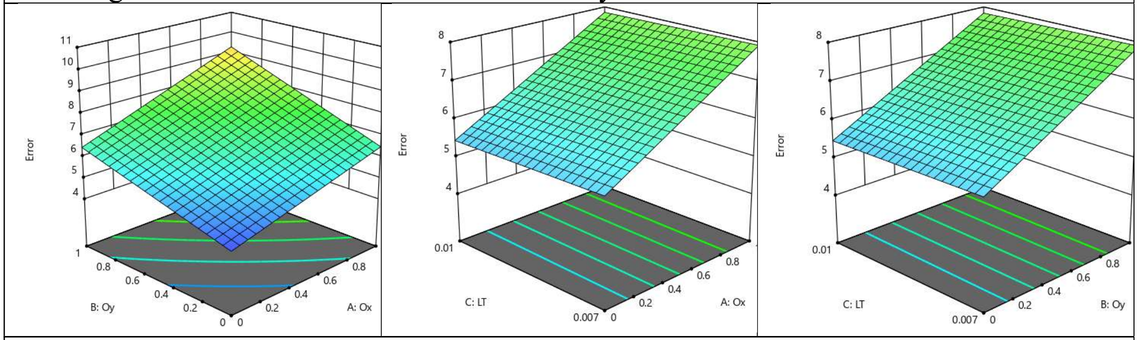


Fig. 6c. Effect of Build Orientation and Layer Thickness on Error for Silencer

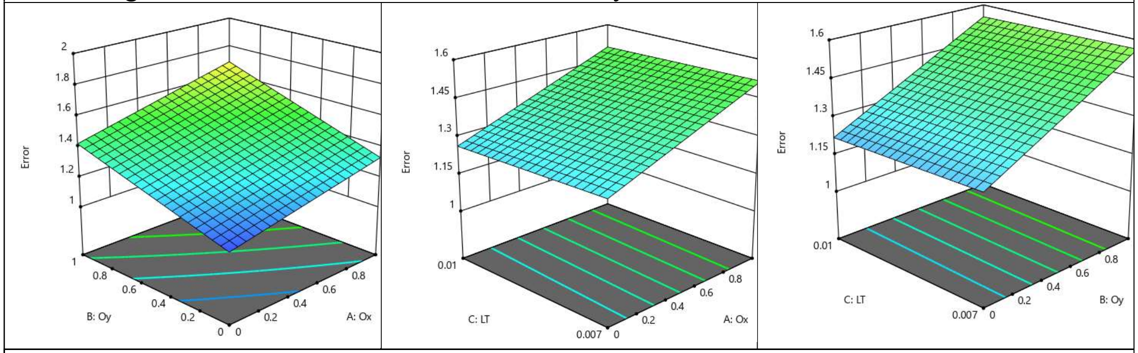


Fig. 6d. Effect of Build Orientation and Layer Thickness on Error for Flange

From the above figure, it has been clearly seen the effect of build orientation on volumetric percentage error is very small for all the parts. The three parameters observed are orientation along X-axis, Y-axis, and Layer Thickness. Total four parts are examined under CatalystEX 4.0 software. The orientations were stated in the equation 4.a, 4.b, 4.c, and 4.d in the form of radian. As seen in figure, the build orientation i.e. orientation along X-axis increases, there is slightly changes in the error for all parts. Similar effect can be seen for remaining parts. The effect of build orientation i.e. orientation along Y has also checked for error. It has been observed that, though there is increment in the orientation, but error has small changes. From the study of above graph, it can be stated that the effect of build orientation is very small or negligible. As per Layer thickness or resolution point of view, it shows minor effect on error. From the above graph of all parts, it has observed that, as the Layer thickness increases from 0.007 to 0.01 inch, the error is slightly increases.

Conclusion

A detailed study of the rapid prototyping with various parameters is carried out to understand the effect of the build orientation i.e. orientation along X axis, Orientation along Y axis and layer thickness. The studies are conducted for various combinations of the orientation along X axis and Y axis, (i.e.; 00, 22.50, 450, 67.50, 900, 112.50, 1350, 157.50, and 1800), and layer thickness (i.e.0.007 inch and 0.01inch). The testing was conducted for four different parts. The parameters were kept constant for all the specimens. The parts consider for the study are valve-seat, valve-body, silencer and flange.

In this current study the four independent parameters are used such as the orientation along X axis, Orientation along Y axis, and layer thickness and see the effect of the model material, support material, time and error. The mathematical model and ANOVA were used to establish the relation for each independent parameter for all parts. The model material requirement for the rapid prototyping is found to have negligible effect of orientation along X axis, Orientation along Y axis and layer thickness. The effect of orientation along X axis, Orientation along Y axis and layer thickness also show negligible effect on percentage volumetric error. The support material is found to have with rise in the value of $\emptyset x$ and $\emptyset y$. Due to increase in these value, the height of rapid prototyping is increases ultimately increase in the requirement support material for the support of model. It can also be concluded that, as the value of $\emptyset x$ and $\emptyset y$ which ultimately increase in the amount of use of support material, results in the increase in time requirement for the printing. Hence, the time requirement affected by the orientation along X axis, Orientation along Y axis. The layer thickness also plays role in the support material and time. The increase in the layer thickness, the requirement of model material, support material and time require will be reduced. The Regression equation in terms of the actual factor is developed for each independent parameter. By inculcating this concept of modern technologies discussed in the current study of rapid prototyping, which is worked out with the excellent result.

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