MULTI–OBJECTIVE ANALYSIS OF PROCESS PARAMETERS: 3D PRINTING

1 Vaibhav F. Dhuware, 2Kritika Bhambri, 3Pankaj G. Fating, 4Samruddhi D. Madavi, 5Nilesh R. Sawarkar, 6Prof. Rohit B. Sharma

Department of Mechanical Engineering, J D College of Engineering and Management, Nagpur, India

Abstract — The experiment provides the best possible combination that can be used to develop a high-strength product that can withstand a certain amount of load, is inexpensive, and does not require excessively long manufacturing times. For output parameters tensile strength, printing time, and cost, the ideal input parameter combinations are infill percentage, layer thickness, and printing time with the L9OA's triangular and gyroid infill patterns. Minitab software and a physical test are used in the analysis. We chose the values for all of the parameters after consulting with experts in the field and reading several research papers. Ender-3 was used to print each double-shaped sample. The testing was done on a UTM machine model number UTE -60-HGFL.

Key Words—Rapid Prototyping, Infill Patterns, Printing Parameters, Taguchi Analysis, L9OA, Design of Experiment, Minitab

I. INTRODUCTION

The project titled “Multi-objective Analysis of process parameters: 3D Printing” focuses on the relationship between the effects of input parameters, namely, Layer thickness, Infill percentage and Nozzle speed on the output parameters, namely, Tensile strength, Printing time and Cost effectiveness. The process, in all followed the mentioned flow: planning about the design according to process parameters, slicing, printing using Fused Deposition Modeling, Testing and Optimization.

II. PROPOSED METHODOLOGY:

The Research Methodology includes a quantitative type of research using samples, data, their comparisons and finally, the analysis of the better obtained outcome.

In all, 2 sets of pattern, “Gyroid” and “Triangular” with 9 distinctive combinations, formed by Design of Experiment (L9OA) on Minitab, which counts to 18 total samples are printed, followed by the Tensile strength testing on the Universal Testing Machine.

After receiving the output values, analysis of the best combination prediction is done by using Taguchi method. The L9OA format was selected as it suited the levels and factors combination used in the research. The aforementioned orthogonal array uses the criteria of either 3^3 or 3^4, which indicates that it is suitable either for an application where there are 3 levels and 4 factors or with 3 levels and 3 factors.

Apparently, in the experiment we get 3 levels with 3 factors as follows:

i) Infill Percentage
ii) Nozzle Speed / Printing Speed
iii) Layer Thickness

The mentioned input factors are selected after the resources referred that they acquired direct relationship, on the most basic understanding level with the output parameters to be:

i) Tensile Strength
ii) Printing Time
iii) Cost Effectiveness

III. Design of Experiment

The term "design of experiments" (DOE) refers to a subfield of applied statistics that deals with organising, carrying out, interpreting, and evaluating controlled tests to assess the variables that influence a parameter's or combination of parameters' value. DOE is a powerful data collection and analysis tool that can be used in a variety of experimental situations. It enables the manipulation of numerous input variables to ascertain their impact on a desired outcome. DOE can identify crucial interactions that may be missed when experimenting with one component at a time by altering several inputs at the same time. It is possible to investigate every potential combination (full factorial) or just a subset of them (fractional factorial).

IV. Taguchi Analysis
The Taguchi method of quality control is an engineering strategy that places an emphasis on the contributions of product design and development, as well as research and development (R&D), to lowering the incidence of flaws and failures in manufactured items.

Fig. No. 1: TAGUCHI ANALYSIS

Genichi Taguchi, a Japanese engineer and statistician, invented this strategy, which believes design to be more essential than the manufacturing process in quality control and attempts to remove deviations in production before they arise.

Fig. No. 2: Taguchi Analysis
Fig. No. 3: Taguchi-SNR

In the above stated image, Fig:2, we can observe that only two models qualify for possessing a comparatively better SNR, according to the conventional assessing parameters of Signal to Noise Ratio, are model no. 7 and 8 for both triangular and gyroid infill patterns (model 20227 and 20228 for triangular and 202216 and 202217 for gyroid, according to testing specimen’s chronology). The two carry a Signal to Noise Ratio of 15.5dB and 18.9dB respectively.

However, model number 9, i.e. 20229 for triangular patterned specimen and 202218 for gyroidal specimen, is nearly equal to 15dB, according to the considerations, will still provide an unreliable connection.

On the other hand, Fig 3 indicates that the Standard Residual Error, same as Sum of squares (Seq SS) of the ANOVA analysis of SN ratios turns out to be small i.e. 1.4 (smaller the standard residual error, the better the model fits the data) with the R-sq value of 98.64% (the assumed value of appropriate R-sq value is over 90%).

The smaller the residual standard error, the better a regression model fits a dataset. Contrarily, the higher the residual standard error, the worse a regression model fits a dataset.

A regression model that has a small residual standard error will have data points that are closely packed around the fitted regression line.

V. Regression analysis:

a) Tensile Strength VS Input parameters

Infill percentage is a 89% contributor in building tensile strength with 0.77% of contribution from nozzle speed and 0% contribution from layer thickness.
b) Printing Time VS Input parameters
Infill percentage and nozzle speed have within limits P-values i.e. 0.000 and 0.022 with 58.09% and 11.81% of contributions respectively. On the other hand, layer thickness holds 0.106 as P-value and 5.29% of contribution to response printing time.

Fig No. 5: Regression analysis (2)

c) Cost VS Input parameters
Besides direct effectiveness, infill percent has maximum contribution to the response followed by layer thickness and nozzle speed, in chronology.

Fig No. 6: Regression analysis (3)
VI. Prediction:

The standard error of the fit is used to measure the precision of the estimate of the mean response. The smaller the standard error, the more precise the predicted mean response. Henceforth, according to the predictions, lowest SE Fit is obtained in the case with Infill percentage as 60%, Layer thickness as 0.25mm and Nozzle speed as 60mm/sec.

According to the predictions, lowest SE Fit is obtained in the case with Infill percentage as 100%, Layer thickness as 0.2 mm and Nozzle speed as 80mm/sec.
According to the predictions, lowest SE Fit is obtained in the case with Infill percentage as 60%, Layer thickness as 0.25mm and Nozzle speed as 60mm/sec.

VII. UTM based Test

In the physical test, model no. 20227 from triangular pattern was observed to withstand the highest amount of load i.e. 5.6kN and possessed a Tensile strength: 41.501 MPa, Infill percent: 100 %, Nozzle speed: 80 mm/s, Layer height: 0.2mm. The highest tensile strength of 38.498 MPa in gyroid pattern, was observed in model no. 202216 which had a load withstanding capacity of 5.17kN with the similar technical specifications as triangular’s. Despite having same values of input parameters, the most important parameter that would define the designed model’s life i.e. the tensile strength, varies.
VIII. Conclusion

The experiment provides best possible combination that can be used to develop a high in strength product that can sustain certain amount of load, is nominal in cost and does not take excessively longer durations to be manufactured. In reference to the objective of this analysis, a pattern that fulfills the requirements at its best, was to be found out. Deducing conclusions from Signal to Noise ratios analysis, Predictions based on Regression analysis and results from Universal Testing Machine, the TRIANGULAR PATTERN having following specifications is considered to be the most stable pattern to produce low-duty products used in an industry.

Specifications :-
1. Infill % = 100%
2. Layer Thickness = 0.2mm
3. Nozzle Speed = 80mm/s
4. Tensile Strength = 41.501MPa
5. Yield Stress = 40.195 MPa
6. Elongation = 4.774 %
7. Printing Time = 3 hours 40 min
8. Cost = Rs.350

Besides the observation, a product with requirement of tensile strength within 38.5 MPa of range and similar other specifications as that of model 20227, can utilize Gyroid pattern based objects too.

IX. Scope for Future Work

On the basis of industrial needs; small, light-duty products can be produced based on Tensile Strength, Cost effectiveness and lesser yet worthy printing time can be further studied and hence, aesthetically pleasing and environment friendly manufacturing can take place. In this study, the material used was PLA (Poly-lactic Acid) which can be changed as per changes in further technical needs

REFERENCES

[4] Effect of Temperature on the Mechanical Properties of 3-D Printed PLA tensile Specimens by Manuscript by Emerald Technology
[8] A Complete Review on 3d Printing and Different Process Parameters on which it’s Performance Depends by Santosh Kumar Patel, Dinesh Kumar Soni
[10] A comprehensive review of 3D printing and their process parameters by Ankur Thakur, Prof. N.V. Saxena
[14] Effect of Infill Parameters on Tensile Mechanical Behavior in Desktop 3D Printing by Miguel Fernandez-Vicente, Wilson Calle, Santiago Ferrandiz, Andres Conejero
[15] Study on optimization of 3D printing parameters by Junhui Wu
[16] Relationship between FDM 3D Printing Parameters Study: Parameter Optimization for Lower Defects by Patrich Ferretti, Christian Leon-Cardenas , Gian Maria Santi
[17] Effect of infill parameters on mechanical properties in additive manufacturing by Juan Ivorra-Martinez, Luis Quiles-Carrillo, Diego Lascano, Santiago Ferrandiz and Teodomiro Boronat

[18] Effect of layer thickness, deposition angle, and infill on maximum flexural force in FDM-built specimens by Ognjan Lužanin, Dejan Movrin, Miroslav Plančak