MULTI – OBJECTIVE ANALYSIS OF PROCESS PARAMETERS: 3D PRINTING

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***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 doumble-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

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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.

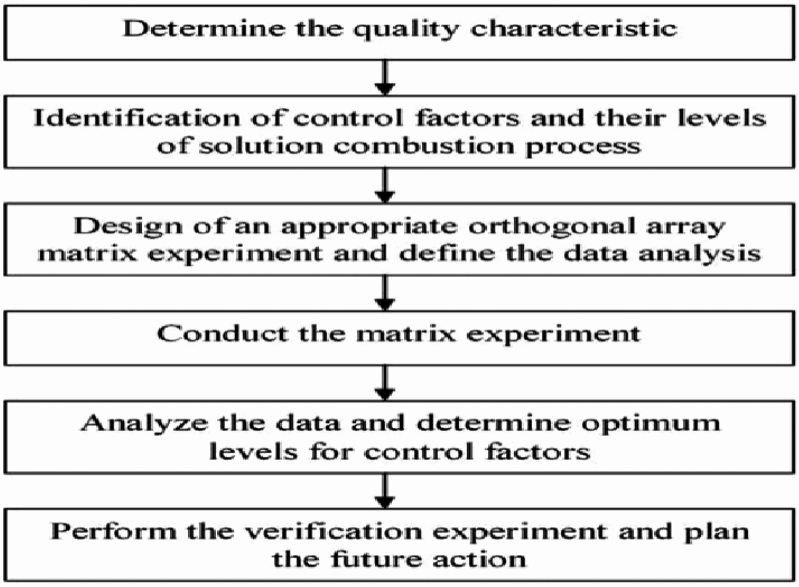
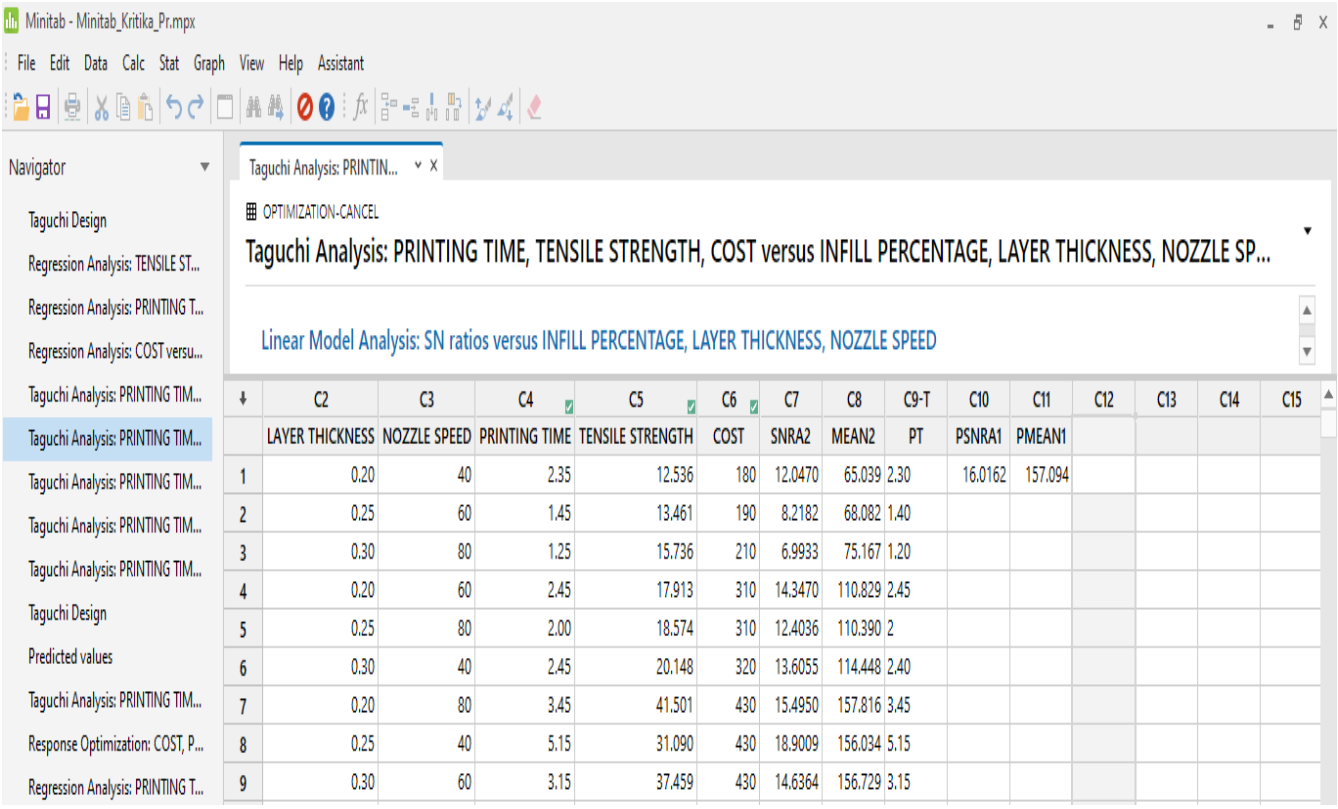


Fig. No. 1: TAGUCHI ANALYSIS

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.



	C2	C3	C4	C5	C6	C7	C8	C9-T	C10	C11	C12	C13	C14	C15
	LAYER THICKNESS	NOZZLE SPEED	PRINTING TIME	TENSILE STRENGTH	COST	SNRA2	MEAN2	PT	PSNRA1	PMEAN1				
1	0.20	40	2.35	12.536	180	12.0470	65.039	2.30	16.0162	157.094				
2	0.25	60	1.45	13.461	190	8.2182	68.082	1.40						
3	0.30	80	1.25	15.736	210	6.9933	75.167	1.20						
4	0.20	60	2.45	17.913	310	14.3470	110.829	2.45						
5	0.25	80	2.00	18.574	310	12.4036	110.390	2						
6	0.30	40	2.45	20.148	320	13.6055	114.448	2.40						
7	0.20	80	3.45	41.501	430	15.4950	157.816	3.45						
8	0.25	40	5.15	31.090	430	18.9009	156.034	5.15						
9	0.30	60	3.15	37.459	430	14.6364	156.729	3.15						

Fig. No. 2: Taguchi Analysis

Taguchi Analysis: PRINTIN...

OPTIMIZATION-CANCEL

Taguchi Analysis: PRINTING TIME, TENSILE STRENGTH, COST versus INFILL PERCENTAGE, LAYER THICKNESS, NOZZLE SP...

Linear Model Analysis: SN ratios versus INFILL PERCENTAGE, LAYER THICKNESS, NOZZLE SPEED

Estimated Model Coefficients for SN ratios

Term	Coef	SE Coef	T	P
Constant	12.9608	0.2833	45.752	0.000
INFILL P 20	-3.8746	0.4006	-9.671	0.011
INFILL P 60	0.4913	0.4006	1.226	0.345
LAYER TH 0.20	1.0022	0.4006	2.502	0.029
LAYER TH 0.25	0.2135	0.4006	0.533	0.647
NOZZLE S 40	1.8904	0.4006	4.719	0.042
NOZZLE S 60	-0.5602	0.4006	-1.398	0.297

Model Summary

S	R-Sq	R-Sq(adj)
0.8499	98.64%	94.55%

Analysis of Variance for SN ratios

Source	DF	Seq SS	Adj SS	Adj MS	F	P
INFILL PERCENTAGE	2	80.102	80.102	40.0512	55.45	0.013
LAYER THICKNESS	2	7.584	7.584	3.7921	5.25	0.010
NOZZLE SPEED	2	16.970	16.970	8.4850	11.75	0.007
Residual Error	2	1.445	1.445	0.7223		
Total	8	106.101				

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.

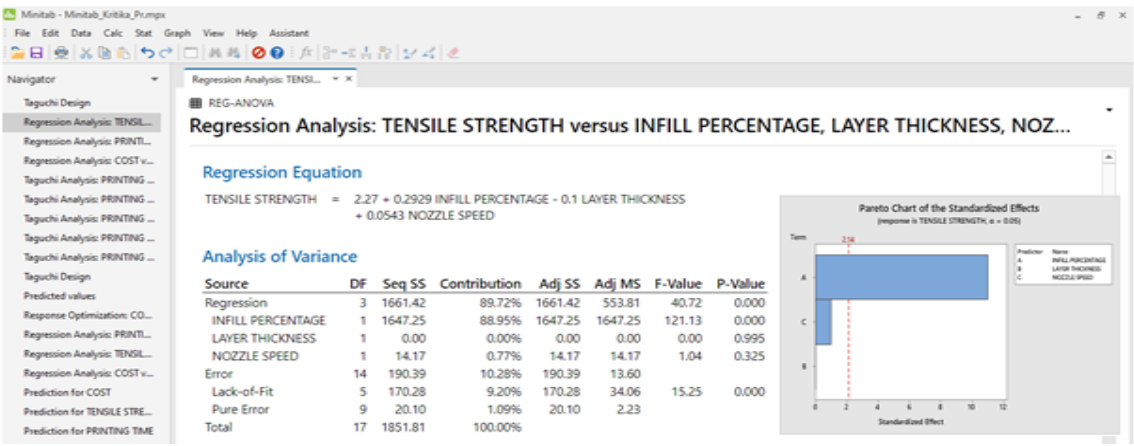


Fig No. 4**:** Regression analysis (1)

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.

Regression Analysis: PRINT...

REG-ANOVA

Regression Analysis: PRINTING TIME versus INFILL PERCENTAGE, LAYER THICKNESS, NOZZLE SPEED

Regression Equation

PRINTING TIME = 4.38 + 0.02740 INFILL PERCENTAGE + 6.62 LAYER THICKNESS - 0.02471 NOZZLE SPEED

Analysis of Variance

Source	DF	Seq SS	Contribution	Adj SS	Adj MS	F-Value	P-Value
Regression	3	18.654	75.20%	18.654	6.2180	14.15	0.000
INFILL PERCENTAGE	1	14.410	58.09%	14.410	14.4102	32.79	0.000
LAYER THICKNESS	1	1.313	5.29%	1.313	1.3134	2.99	0.106
NOZZLE SPEED	1	2.930	11.81%	2.930	2.9304	6.67	0.022
Error	14	6.153	24.80%	6.153	0.4395		
Lack-of-Fit	5	2.638	10.63%	2.638	0.5276	1.35	0.327
Pure Error	9	3.515	14.17%	3.515	0.3905		
Total	17	24.807	100.00%				

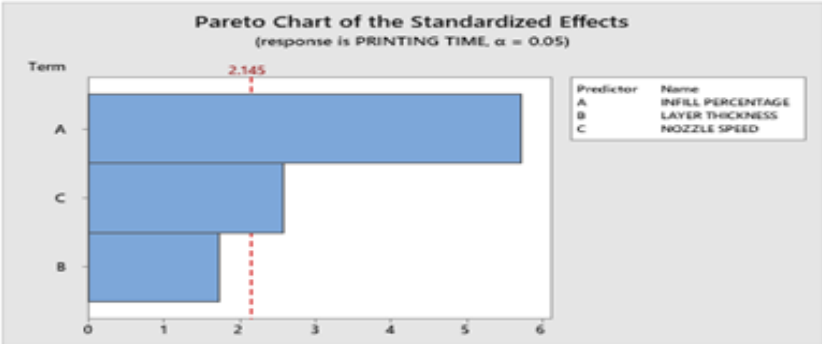


Fig No. 5**:** Regression analysis (2)

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.

Regression Analysis: COST ...

REG-ANOVA

Regression Analysis: COST versus INFILL PERCENTAGE, LAYER THICKNESS, NOZZLE SPEED

Regression Equation

COST = 91.39 + 2.9583 INFILL PERCENTAGE + 133.3 LAYER THICKNESS + 0.1667 NOZZLE SPEED

Analysis of Variance

Source	DF	Seq SS	Contribution	Adj SS	Adj MS	F-Value	P-Value
Regression	3	168700	99.76%	168700	56233	1914.97	0.000
INFILL PERCENTAGE	1	168033	99.36%	168033	168033	5722.22	0.000
LAYER THICKNESS	1	533	0.32%	533	533	18.16	0.001
NOZZLE SPEED	1	133	0.08%	133	133	4.54	0.051
Error	14	411	0.24%	411	29		
Lack-of-Fit	5	411	0.24%	411	82	*	*
Pure Error	9	0	0.00%	0	0		
Total	17	169111	100.00%				

Fig No. 6**:** Regression analysis (3)

VI. Prediction:

Prediction for COST

WORKSHEET 20

Prediction for COST

Regression Equation

COST = 91.4 + 2.9583 INFILL PERCENTAGE + 133.3 LAYER THICKNESS + 0.167 NOZZLE SPEED

Settings

Variable	Setting
INFILL PERCENTAGE	20
LAYER THICKNESS	0.2
NOZZLE SPEED	40

Prediction

Fit	SE Fit	95% CI	95% PI
183.889	5.01233	(171.004, 196.773)	(162.968, 204.809)

Settings

Variable	Setting
INFILL PERCENTAGE	60
LAYER THICKNESS	0.25
NOZZLE SPEED	60

Prediction

Fit	SE Fit	95% CI	95% PI
312.222	2.13726	(306.728, 317.716)	(294.849, 329.596)

Settings

Variable	Setting
INFILL PERCENTAGE	100
LAYER THICKNESS	0.3
NOZZLE SPEED	80

Prediction

Fit	SE Fit	95% CI	95% PI
440.556	5.01233	(427.671, 453.440)	(419.635, 461.476)

Fig. No. 7**:** Cost 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.

Prediction for TENSILE STR...

WORKSHEET 20

Prediction for TENSILE STRENGTH

Regression Equation

TENSILE STRENGTH = -1.1 + 0.2847 INFILL PERCENTAGE + 4.6 LAYER THICKNESS + 0.100 NOZZLE SPEED

TENSILE STRENGTH, COST versus INFILL PERCENTAGE, LAYER THICKNESS, NOZZLE SPEED

Variable	Setting
INFILL PERCENTAGE	20
LAYER THICKNESS	0.2
NOZZLE SPEED	40

Prediction

Fit	SE Fit	95% CI	95% PI
9.53306	3.84704	(-0.356070, 19.4222)	(-6.52380, 25.5899)

Settings

Variable	Setting
INFILL PERCENTAGE	60
LAYER THICKNESS	0.25
NOZZLE SPEED	60

Prediction

Fit	SE Fit	95% CI	95% PI
23.1576	1.64038	(18.9408, 27.3743)	(9.82306, 36.4920)

Settings

Variable	Setting
INFILL PERCENTAGE	100
LAYER THICKNESS	0.2
NOZZLE SPEED	80

Prediction

Fit	SE Fit	95% CI	95% PI
36.7821	1.07404	(20.7821, 23.3743)	(26.8929, 32.6712)

Fig. No. 8**:** Tensile Strength Prediction

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.

Prediction for PRINTING TI...

WORKSHEET 20

Prediction for PRINTING TIME

Regression Equation

PRINTING TIME = 3.75 + 0.02792 INFILL PERCENTAGE - 4.67 LAYER THICKNESS - 0.0271 NOZZLE SPEED

Settings

Variable	Setting
INFILL PERCENTAGE	20
LAYER THICKNESS	0.2
NOZZLE SPEED	40

Prediction

Fit	SE Fit	95% CI	95% PI
2.29167	0.436829	(1.16876, 3.41457)	(0.468420, 4.11491)

Settings

Variable	Setting
INFILL PERCENTAGE	60
LAYER THICKNESS	0.25
NOZZLE SPEED	60

Prediction

Fit	SE Fit	95% CI	95% PI
2.63333	0.186264	(2.15453, 3.11214)	(1.11921, 4.14746)

Settings

Variable	Setting
INFILL PERCENTAGE	100
LAYER THICKNESS	0.3
NOZZLE SPEED	80

Prediction

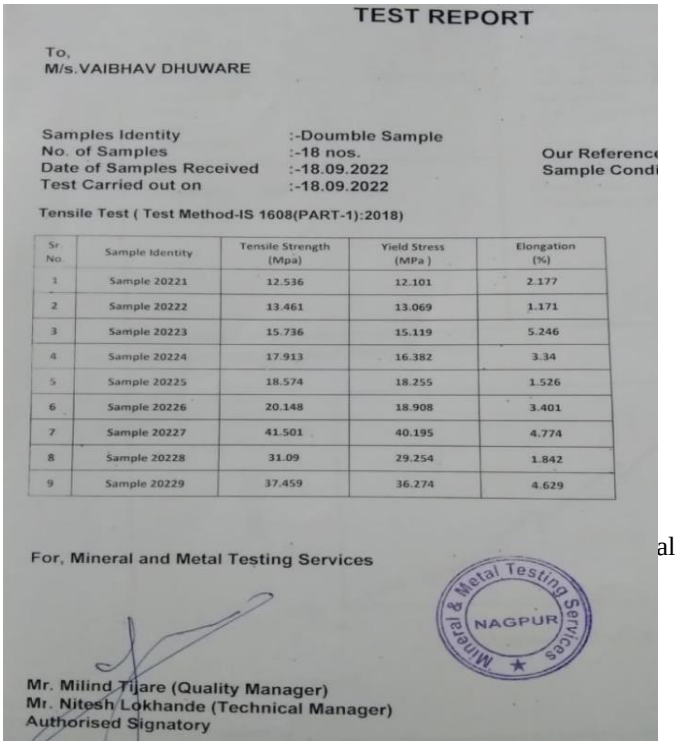
Fit	SE Fit	95% CI	95% PI
2.975	0.436829	(1.85210, 4.09790)	(1.15175, 4.79825)

Fig. No. 9**:** Printing Time Prediction

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.



TEST REPORT

To,
M/s.VAIBHAV DHUWARE

Samples Identity :-Doumble Sample
No. of Samples :-18 nos.
Date of Samples Received :-18.09.2022
Test Carried out on :-18.09.2022

Our Referenc
Sample Condi

Tensile Test (Test Method-IS 1608(PART-1):2018)

Sr. No.	Sample Identity	Tensile Strength (Mpa)	Yield Stress (MPa)	Elongation (%)
1	Sample 20221	12.536	12.101	2.177
2	Sample 20222	13.461	13.069	1.171
3	Sample 20223	15.736	15.119	5.246
4	Sample 20224	17.913	16.382	3.34
5	Sample 20225	18.574	18.255	1.526
6	Sample 20226	20.148	18.908	3.401
7	Sample 20227	41.501	40.195	4.774
8	Sample 20228	31.09	29.254	1.842
9	Sample 20229	37.459	36.274	4.629

For, Mineral and Metal Testing Services

Mineral & Metal Testing Services NAGPUR

Mr. Milind Tijare (Quality Manager)
Mr. Nitesh Lokhande (Technical Manager)
Authorised Signatory

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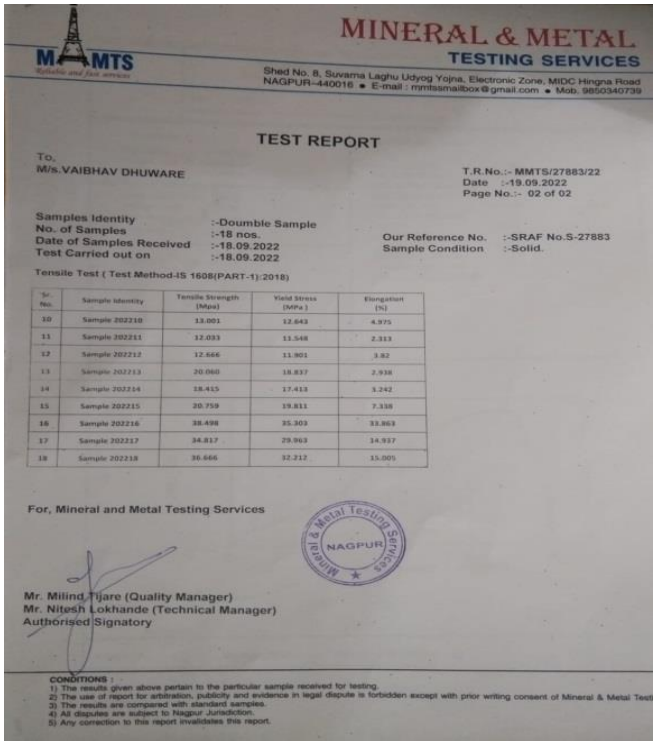

MINERAL & METAL TESTING SERVICES

MMTS

Shed No. 8, Suvarna Laghu Udyog Yojna, Electronic Zone, MIDC Hingna Road NAGPUR-440016 • E-mail : mmtsmailbox@gmail.com • Mob. 9850340739

TEST REPORT

To,
M/s.VAIBHAV DHUWARE

T.R.No.:- MMTS/27883/22
Date :-19.09.2022
Page No.:- 02 of 02

Samples Identity :-Doumble Sample
No. of Samples :-18 nos.
Date of Samples Received :-18.09.2022
Test Carried out on :-18.09.2022

Our Reference No. :-SRAF No.S-27883
Sample Condition :-Solid.

Tensile Test (Test Method-IS 1608(PART-1):2018)

Sr. No.	Sample Identity	Tensile Strength (Mpa)	Yield Stress (MPa)	Elongation (%)
10	Sample 202210	13.001	12.643	4.975
11	Sample 202211	12.033	11.548	2.313
12	Sample 202212	12.666	11.901	3.82
13	Sample 202213	20.060	18.837	2.938
14	Sample 202214	18.415	17.413	3.242
15	Sample 202215	20.759	19.811	7.338
16	Sample 202216	38.498	35.303	33.863
17	Sample 202217	34.817	29.963	14.937
18	Sample 202218	36.666	32.212	15.005

For, Mineral and Metal Testing Services

Mineral & Metal Testing Services NAGPUR

Mr. Milind Tijare (Quality Manager)
Mr. Nitesh Lokhande (Technical Manager)
Authorised Signatory

CONDITIONS :
1) The results given above pertain to the particular sample received for testing.
2) The use of report for arbitration, publicity and evidence in legal dispute is forbidden except with prior writing consent of Mineral & Metal Test
3) The results are compared with standard samples.
4) All disputes are subject to Nagpur Juradiction.
5) Any correction to this report invalidates this report.

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

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