International Journal of Scientific Research & Engineering Trends
Volume 6, Issue 5, Sept-Oct-2020, ISSN (Online): 2395-566X

Effect of Infill parameters on Time, Material Length, Weight and Price in 3d Printing

Vishal Vijay Gholkar
Production Engineer,MH,India

***Abstract*-As we know that 3D printing is new emerging technology that growing fast and lots of research carried out on this topic. This paper show that effects of three different infill patterns on printing time, length, weight of material and price in 3D printing. Standard 3D printers use 13 different types of infill patterns. We tested infill patterns of lines, zigzag and cubic with different layer thickness, speed, infill percentage to calculate length and weight printing time and price using Cura software. An orthogonal array was used for the experimental design. Optimum process parameters were determined by the gray relational grade obtained from the gray relational analysis. The results showed that the layer thickness 0.4mm, speed 80mm/sec, infill percentage 40%, and infill pattern cubic had the fastest printing time as compared to others.**

***Keywords*-3D Printing, AM, GRA**

I.INTRODUCTION

1. Additive manufacturing

The term AM encompasses many technologies including subsets like 3D Printing, Rapid Prototyping (RP), and Direct Digital Manufacturing, Layered manufacturing and additive fabrication [1].AM builds products layer-by layer additively rather than by subtracting material from a larger piece of material like cutting out a landing gear from a block of titanium that is, “subtractive” manufacturing. This seemingly small distinction adding rather than subtracting means everything. Assembly lines and supply chains can be reduced or eliminated for many products [2].

2. Classification of Additive Manufacturing Liquid based technology:

- Stereo lithography (SLA)
- Direct light processing technique
- High viscosity Jetting
- The maple process

2.1. Powder based techniques:

- Selective Laser Sintering (SLS)
- Direct Metal Laser Sintering (DMLS)
- Fused metal deposition
- Electron beam melting
- Selective laser melting
- Selective masking sintering
- Selective inhibition sintering
- Electro photography layered manufacturing

2.2. Solid based techniques:

- Fused deposition modeling
- Sheet stalking technique [3].

3. 3D Printing

3D printing also known as additive manufacturing is one of the four basic forming operations. The 3D printing process builds a three-dimensional object from a Computer Aided Design (CAD) model, by successively adding material layer by layer that’s why it is called as additive manufacturing [4]. 3D printing is also emerging as an energy efficient technology that can provide environmental efficiencies in terms of both the manufacturing process itself, utilizing up to 90-95% of standard materials, and throughout the products operating life, through lighter and stronger design. It is used in a variety of industries including jewelry, footwear, industrial design, architecture, engineering and construction, automotive, aerospace, dental and medical industries, education and consumer products [5].

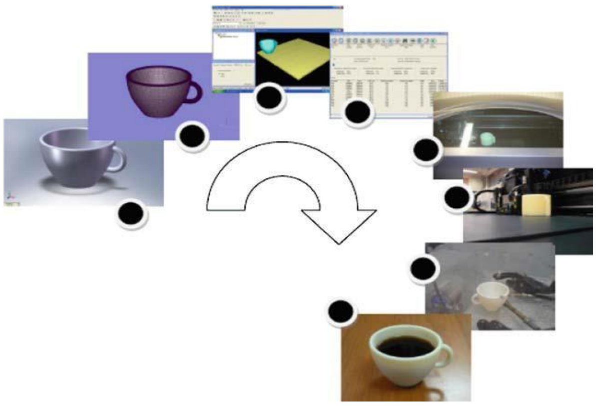


Fig 1 3D printing process [5].

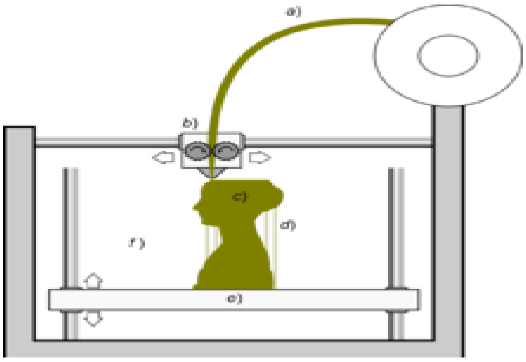
3.1. Stepwise procedure of 3D printing

We will refer to eight key steps in the process sequence:

- Conceptualization and CAD
- Conversion to STL
- Transfer and manipulation of STL file on AM machine
- Machine setup
- Build
- Part removal and cleanup
- Post-processing of part

- Application

4. Fused Deposition Modeling FDM



a – Filament
b – Nozzle
c – Object
d – Support
e – Bed

Fig 2 Fused Deposition Modeling (FDM).

Fused Deposition Modeling is one of the most widely used additive manufacturing processes for fabricating and printing plastic parts.FDM works on an "additive" principle by laying down material in layers; a plastic filament or metal wire is unwound from a coil and supplies material to produce a part. The process works by melting plastic filament that is deposited, through a heated extruder. Thickness of deposited layer onto a build platform according to the 3D data supplied to the printer [6].

5. Infill Patterns

Inside a 3D print's outer shells are called infill, and it can be adjusted with respect to density – 0% is hollow while 100% is solid pattern. In the following, we'll take a look at a variety of different infill patterns, specifically those that are available in Cura. Infill patterns can drastically affect a print's strength and flexibility in the latest version of Cura (4.5), there are 13 types of infill patterns available for use. We've grouped them according to what they're best suited for:

Table No 1 – Infill Patterns

Low strength	Lines, Zig Zag
Medium strength	Grid, Triangle, Tri-hexagon
High strength	Cubic, Octet, Cubic subdivision, Quarter cubic,Gyroid.
Flexible 3D Print	Concentric, Cross, Cross 3D.

Similar to "rectilinear" in other slicers, both patterns produce a 2D grid where only one axis is printed per layer. The difference between the two is that lines generates multiple lines per layer while zig-zag is simply one constant line (unless interrupted by the model).

5.1. Grid:

A self-explanatory 2D pattern, the main advantage of grid is print speed, as it's the least complex of the three.

5.2. Triangles:

A 2D mesh made of triangles, this pattern has an inherent advantage in strength when a load is applied perpendicular to the object's face. It also makes sense for parts with thin, rectangular components, which might otherwise have very few connections between walls.

5.3. Tri-hexagons:

This 2D pattern produces hexagons interspersed with triangles. One advantage is that hexagons are an efficient shape, making them a strong infill pattern relative to their material usage. In addition to that, hexagon infill has shorter lines to connect each side, leading to fewer issues with bowing from poor print cooling.

5.4. Cubic:

This is a 3D pattern of stacked and tilted cubes.

5.4.1. Cubic subdivision:

This variation of cubic uses less material.

Octet: Also known as tetrahedral infill, this pattern stacks pyramid shapes.

5.4.2. Quarter cubic:

This 3D pattern is like octet, but half of the pyramid shapes are shifted with respect to the other half.

5.5. Gyroid:

A particularly unique 3D pattern, which gives the impression of waves. Nevertheless, it is equally strong in multiple directions. This infill pattern would therefore be a good choice for a part that will be stressed in multiple ways.

5.6. Concentric:

This 2D pattern produces "waves" through the interior of the print, mimicking the shapes of the outer walls. This is much like how a stone thrown into water makes concentric circular ripples on the surface.

5.7. Cross:

Another 2D pattern, cross produces grids of what appear to be very fanciful crosses. The spaces between crosses and grids allow for bending and twisting.

5.7.1. Cross 3D:

This 3D pattern is similar to cross, but as the print grows, the lines move at inclines. The end result is an object with slightly more rigidity [7].

Reasons for using different infill patterns

International Journal of Scientific Research & Engineering Trends
Volume 6, Issue 5, Sept-Oct-2020, ISSN (Online): 2395-566X

- It can create any complex geometry in any form of shape and structure.
- It reduces the printing time by changing the infill pattern according to the use of the model in real face.
- It increases the strength of the model by changing the infill pattern in slicing software.
- Less use of material by changing settings. If a model is not for use in real life cycle (only used for checking dimensions or an assembly design), printing on lower density gives saving of material.
- It is most suitable for production of customized or single objects.
- All the components in assembly are fabricated simultaneously, layer-by-layer. A support material is used to fill-up the cavities [8]

6. Taguchi Method

The Full Factorial Design requires a large number of experiments to be carried out as stated above. It becomes laborious and complex, if the number of factors increase. To overcome this problem Taguchi suggested a specially designed method called the use of orthogonal array to study the entire parameter space with lesser number of experiments to be conducted. Taguchi thus, recommends the use of the loss function to measure the performance characteristics that are deviating from the desired target value. The value of this loss function is further transformed into signal-to-noise (S/N) ratio. Usually, there are three categories of the performance characteristics to analyze the S/N ratio. They are: nominal-the-best, larger-the-better, and smaller-the- better [9].

6.1. Steps Involved in Taguchi Method

The use of Taguchi's parameter design involves the following steps [9].

- Identify the main function and its side effects.
- b. Identify the noise factors, testing condition and quality characteristics.
- Identify the objective function to be optimized.
- Identify the control factors and their levels.
- Select a suitable Orthogonal Array and construct the Matrix
- Conduct the Matrix experiment.
- Examine the data; predict the optimum control factor levels and its performance.
- Conduct the verification experiment.

7. Grey Relational Analysis

In a complex multivariate system, the relationship among various factors is usually unclear. Such systems are often called as "gray" implying poor, incomplete, and uncertain information. Gray relational analysis is an impacting measurement method in gray system theory that analyzes uncertain relations between one main factor and all the other factors in a given system. When experiments are ambiguous or when the experimental method cannot be carried out exactly, gray analysis helps to compensate for the shortcomings in statistical regression [10]. For data preprocessing in the gray relational analysis process, "the lower is better" used for Length, Weight, Printing time, Price are the indication of better performance in 3D Printing process.

II. EXPERIMENT DETAILS

1. Materials, experiment conditions, and measurements

First, the performance characteristics in the 3D printing process were considered as Length, Weight of Material, Material Coast, Printing time. The experimental studies were performed on a Ultimaker S5 using Cura Software as shown in Fig. 4. The experiments were conducted under different process parameters like Layer Thickness, Speed, Infill pattern, Infill percentage etc (Table 2).

Table no 2 - Process Parameters.

Level of Process Parameters	Process Parameters			
	Layer Thickness	Speed	Infill Percentage	Infill Pattern
1	0.10	60	40	LINE
2	0.15	80	60	ZIGZAG
3	0.20	100	80	CUBIC

The study was carried out on 20mm X 20mm X 20mm work piece of PLA (Poly Lactic Acide) material as shown in Fig. 3. The material length, weight, and printing time measured using Cura Software.

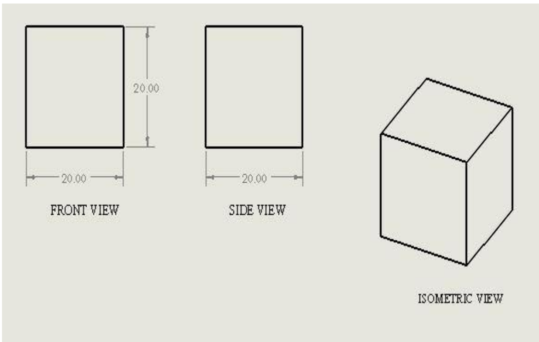


Fig 3 – PLA Part.

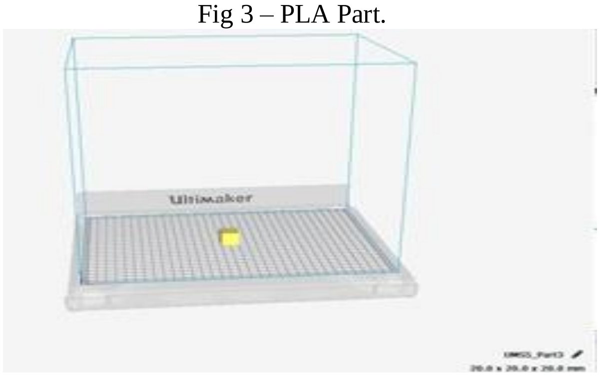


Fig 4 – Experimental Setup.

International Journal of Scientific Research & Engineering Trends
Volume 6, Issue 5, Sept-Oct-2020, ISSN (Online): 2395-566X

III. DESIGN OF EXPERIMENT

Taguchi method proposes to acquire the characteristic data by using orthogonal arrays and to analyze the performance measure from the data to decide the optimal process parameters [10]. The method uses a special design of orthogonal arrays to study the entire process parameter with small number of experiments only. In this study an L9 orthogonal array with 4 columns and 9 rows are used therefore only 9 experiments are required to study (Table 3).

Table no 3 - Experimental design using L9 orthogonal array.

Exno	Layer Thickness	Speed	Infill Percent age	Infill Pattern
1	0.1	60	40	LINE
2	0.1	80	60	ZIGZAG
3	0.1	100	80	CUBIC
4	0.15	60	60	CUBIC
5	0.15	80	80	LINE
6	0.15	100	40	ZIGZAG
7	0.20	60	80	ZIGZAG
8	0.20	80	40	CUBIC
9	0.20	100	60	LINE

After using above L9 experiments data as a inputtoCura software for slicing we got Some following data (Table 4)

Table no 4 - Measured Responses According to L9 orthogonal Array.

INPUT					OUTPUT			
Experiment no	Layer Thickness	Speed	Infill Percentage	Infill Pattern	Length in m	Weight in g	Time in min	Price in Rs
1	0.1	60	40	LINE	0.73	6	67	9.77
2	0.1	80	60	ZIGZAG	0.92	7	59	12.44
3	0.1	100	80	CUBIC	1.10	9	56	14.82
4	0.15	60	60	CUBIC	0.93	7	45	12.49
5	0.15	80	80	LINE	1.10	9	41	14.73
6	0.15	100	40	ZIGZAG	0.75	6	27	10.49
7	0.20	60	80	ZIGZAG	1.10	9	32	14.74
8	0.20	80	40	CUBIC	0.74	6	19	9.95
9	0.20	100	60	LINE	0.90	7	20	12.11

IV. METHODOLOGY

Optimization of various process parameters Using Grey Relational Analysis [11]

Step 1: Normalization of Data

The first step in grey relational analysis is normalization of data which is performed to prepare raw data for the analysis. Normalization of data in the range between zero and unity is also called as the grey relational generation .In this investigation "smaller-the-better" (1) criterion is used for normalization of Length, Weight, Printing time, Price.

$$x_i^*(k) = \frac{max x^{(0)}(k) - x^{(0)}(k)}{max x_i^{(0)}(k) - min x_i^{(0)}(k)} \quad (1)$$

Step 2: Determination of deviation sequence

The deviation sequence$\Delta 0i$ (k) is the absolute difference between the reference sequence $x*(k)$ and the comparability sequence $x*(k)$after normalization. It is determined using Eq. 2 as:

$$\Delta_{0i}(k) = |x_0^*(k) - x_i^*(k)| \quad (2)$$

Step 3: Determination of Grey Relational CoefficientGRC for all the sequences expresses the relationship between the ideal (best) and actual normalized S/N ratio. If the two sequences agree at all points, then their grey relational coefficient is 1. The grey relational coefficient $\gamma(x0(k), xi(k))$ can be expressed by Eq. 3.

$$\gamma(x_0(k), x_i(k)) = \frac{\Delta min + \zeta \Delta max}{\Delta_{0i}(k) + \zeta \Delta_{max}} \quad (3)$$

where, Δmin is the smallest value of $\Delta 0i$ (k) = $minimink|x*(k) - x*(k)|$and Δmax is the largestvalue of $\Delta 0i$ $(k) = maximaxk$ $|x*(k) - x*(k)|$,$x*(k)$ is the ideal normalized S/N ratio, $x*(k)$ is the normalized comparability sequence, and ζ is the distinguishing coefficient. The value of ζ can be adjusted with the systematic actual need and defined in the range between 0 and 1; here it is taken as 0.5.

Step 4: Determination of Grey Relational Grade

γ $(xx$ $) = 1$ $m\gamma(x$ $(k), x$ $(k))(4)$
$o, i\sum m$i=1

The overall evaluation of the multiple performancecharacteristics is based on the grey relational grade. The grey relational grade is an average sum of the grey relational coefficients which is defined as follows:

xi (k) =$i(o)i(o)(1)$

Step 5: Determination of Optimal parameters

The grey relational grade calculated for each sequence is taken as a response for the further analysis. The larger-the-better quality characteristic was used for analyzing the

International Journal of Scientific Research & Engineering Trends
Volume 6, Issue 5, Sept-Oct-2020, ISSN (Online): 2395-566X

GRG, since a larger value indicates the better performance of the process. The response table of Taguchi method was employed here to calculate the average grey relational grade for each factor level. In this, the grouping of the grey relational grades was done initially by the factor levelfor each column in the orthogonal array and then byaveraging them.

Step 6: Prediction of grey relational grade underoptimum parameters

After evaluating the optimal parameter settings, the next step is to predict and verify the improvement of quality characteristics using the optimal parametric combination. The estimated grey relational grade by using the optimal level of the machining parameters can be calculated as

$$\hat{\gamma} = \gamma_m + \sum_{i=1}^{o} (\bar{\gamma} - \gamma_m)$$

where $\gamma m$is the total mean grey relational grade, $\bar{\gamma}$ is the mean grey relational grade at the optimal level, and o is the number of the main design parameters that affect the quality characteristics. The predicted or estimated grey relational grade (optimal) is equal to the mean grey relational grade plus the summation of the difference between the overall mean greyrelational grade and the mean grey relational grade for each of the factors at optimal level.

1. Calculation

Table No 5 – Input data for Grey Relational Analysis

Length in m	**Weight in g**	**Time in min**	**Price in Rs**
0.73	6	67	9.77
0.92	7	59	12.44
1.10	9	56	14.82
0.93	7	45	12.49
1.10	9	41	14.73
0.75	6	27	10.49
1.10	9	32	14.74
0.74	6	19	9.95
0.90	7	20	12.11

Step 1: Normalization of Data

Table No 6 - Normalization of Data

Lengthin m	Weighting g	Time in min	Price in Rs
1	1	0	1
0.4865	0.6667	0.1667	0.4713
0	0	0.2292	0
0.4595	0.6667	0.4583	0.4614
0	0	0.5417	0.0178
0.9459	1	0.8333	0.8574
0	0	0.7292	0.0158
0.9730	1	1	0.9644
0.5405	0.6667	0.9792	0.5366

Step 2: Determination of deviation sequence

Table No 7 - Determination of deviation sequence.

Length in m	**Weight in g**	**Time in min**	**Price in Rs**
0.0000	0.0000	1.0000	0.0000
0.5135	0.3333	0.8333	0.5287
1.0000	1.0000	0.7708	1.0000
0.5405	0.3333	0.5417	0.5386
1.0000	1.0000	0.4583	0.9822
0.0541	0.0000	0.1667	0.1426
1.0000	1.0000	0.2708	0.9842
0.0270	0.0000	0.0000	0.0356
0.4595	0.3333	0.0208	0.4634

Step 3: Determination of Grey Relational Coefficient

Table No 8 - Determination of Grey Relational Coefficient.

Length in m	**Weight in g**	**Time in min**	**Price in Rs**
1.0000	1.0000	0.3333	1.0000
0.49333	0.6000	0.3750	0.4860
0.33333	0.3333	0.3934	0.3333
0.48052	0.6000	0.4800	0.4814
0.33333	0.3333	0.5217	0.3373
0.90244	1.0000	0.7500	0.7781
0.33333	0.3333	0.6486	0.3369
0.94872	1.0000	1.0000	0.9335
0.52113	0.6000	0.9600	0.5190

Step 4: Determination of Grey Relational Grade

Table No 9 - Determination of Grey Relational Grade.

Grade	**Rank**
0.8333	3
0.4886	6
0.3484	9
0.5105	5
0.3814	8
0.8576	2
0.4131	7
0.9705	1
0.6500	4

Step 5: Determination of Optimal parameters

International Journal of Scientific Research & Engineering Trends
Volume 6, Issue 5, Sept-Oct-2020, ISSN (Online): 2395-566X

Table No 10 - Determination of Optimal parameters.

Factors	Level 1	Level 2	Level3	MaxMin	Rank
LayerThickness	0.5568	0.5832	0.6779	0.1211	2
Speed	0.5856	0.6135	0.6187	0.0330	4
InfillPercentage	0.8871	0.5497	0.3810	0.5062	1
InfillPattern	0.6216	0.5864	0.6098	0.0351	3

Fig 5 – Main Effect plot Grey Relational Grade.

2. Result

Table No 11 - Rank

INPUT					OUTPUT				
Experiment no	Layer Thickness	Speed	Infill Percentage	Infill Pattern	Length in m	Weight in g	Time in min	Price in Rs	Rank
1	0.1	60	40	LINE	0.73	6	67	9.77	3
2	0.1	80	60	ZIGZAG	0.92	7	59	12.44	6
3	0.1	100	80	CUBIC	1.10	9	56	14.82	9
4	0.15	60	60	CUBIC	0.93	7	45	12.49	5
5	0.15	80	80	LINE	1.10	9	41	14.73	8
6	0.15	100	40	ZIGZAG	0.75	6	27	10.49	2
7	0.20	60	80	ZIGZAG	1.10	9	32	14.74	7
8	**0.20**	**80**	**40**	**CUBIC**	**0.74**	**6**	**19**	**9.95**	**1**
9	0.20	100	60	LINE	0.90	7	20	12.11	4

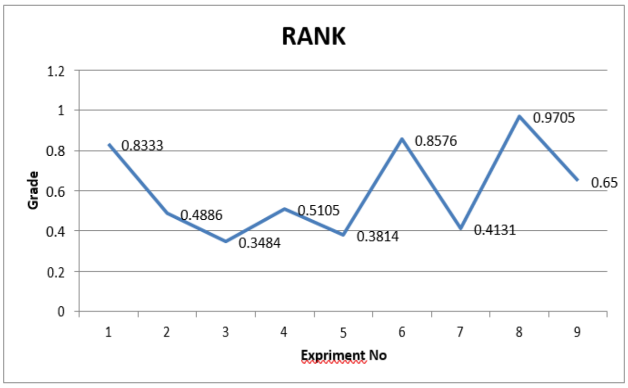


Fig 6 – Rank.

V. RESULT AND DISCUSSION

- In 3D Printing process minimum Length, Weight, Printing time, Price are an indication of better performance. For data preprocessing in the gray relational analysis process, Length, Weight, Printing time, Price were taken as the “lower is better”.

- Let the results of 9 experiments used for grey relational analysis. In the first step we normalize data using Eq. 1. All the sequences after data preprocessing using Eq. 1 are listed in (Table 6) and denoted as $x*\ (k)$ and $x*(k)$ for comparability sequences and reference sequence.
- In second step we calculate Deviation sequence using Eq. 2 are listed in (Table 7.
- In 3rd step we calculate grey relational coefficient using Eq. 3 are listed in (Table 8).
- In 4th step we calculate grey relational grade using Eq.4 are listed in (Table 9) .The grey relational grade is an average sum of the grey relational coefficients.
- In 5th step the grouping of the grey relational grades was initially done by the factor level for each column in the orthogonal array and then by averaging them. From the response table of GRG (Table 10),
- According to the performed experimental design, it is clearly observed from (Table 11) and Fig. 6 that the process parameters’ setting of combination 8 has the highest gray relational grade. Therefore, run 8 is the optimal process parameter setting for minimum Length, Weight, Printing time, Price (i.e., the best multiperformance characteristics) among the 9 runs.
- Therefore, the optimal level of the process parameters is the level with the greatest gray relational grade value. The optimal process performance for the minimum Length, Weight, Printing time, Price was obtained in layer thickness 0.2mm, speed 80mm/sec, infill percentage 40%, and infill pattern cubic combination.
- According to step 5 it is clear that third level of layer thickness (i.e. 0.20mm), third level of speed (i.e. 100), first levels infill percentage (i.e. 40%) and first level of infill pattern (i.e. line) are the optimal parameters for the high speed printing of PLA for above conditions. It can be also seen from Table 10 and Fig. 5 that GRG feed is the most significant parameter in high speed printing of PLA. After feed, the sequence of effect of process parameter in 3D printing is: cutting speed, machining condition, insert type and depth of cut.

VI. CONCLUSION

The gray relational analysis based on the Taguchi method's response table was conducted as a way of studying the optimization of 3D printing process factor level. The minimum Length, Weight, Printing time, Price was selected to be the quality targets. From the response table of the largest value of gray relational grade for the process parameters was found.In this work, the effect of infill pattern on Length, Weight, Printing time and Price have been studied. The results in the 3D printing process show that

- Infill patterns reduce the printing time, length and weight of material.
- We find that in 8 and 9 runs having same layer thickness but different speed but no difference in printing time this is because different infill patterns.
- Speed is inversely proportional to Printing time. When speed increases printing time decreases.
- Similarly Layer thickness is inversely proportional to Printing time.
- Infill percentage is directly proportional to length and weight of material. When Infill percentage is increases length and weight of material also increases.

REFERENCES

[1] https://www.additivemanufacturing.com accessed on 25/3/2020 at 6.19 PM IST.
[2] Thomas Campbell, Christopher Williams, Olga Ivanova, Banning Garrett, Could 3D Printing Change the World?Technologies, Potential, and Implications of Additive Manufacturing", Strategic Foresight report, October 2011.
[3] Rapid Manufacturing: An Industrial Revaluation For The Digital Age Edition N.
[4] https://www.wikipedia.org/wiki/3D_printing accessed on 25/3/2020 at 6.29 PM IST.
[5] Ian Gibson , David Rosen , Brent Stucker, "Additive ManufacturingTechnologies3D Printing, Rapid Prototyping, and Direct Digital Manufacturing", Second Edition.
[6] Rapid Prototyping and Engineering Applications: A Toolbox for Prototype Development.
[7] https://www.m.all3dp.com/2/cura-infill-patterns-all-you-need-to-know/accessed on29/03/2020 at 3.12PM IST.
[8] Effects of Infill Patterns on Time, Surface Roughness and Tensile Strength in 3D Printing Dhruv Maheshkumar Patel Research Assistant IGNITE – The Silver Oak Incubation Centre, Ahmedabad – 382481. Gujarat, INDIA.
[9] Application Of Taguchi Method For Optimization Of Process Parameters In Improving The Surface Roughness Of Lathe Facing Operation Srinivas Athreya1, Dr Y.D.Venkatesh2 1(Mechanical Department, Fr. C. Rodrigues Institute of Technology, University Of Mumbai, India) 2(Principal, Xavier Institute of Engineering, University Of Mumbai, India).
[10] Gray relational analysis of performance characteristics in MQL milling of 7075 Al alloy. Nihat Tosun& Hasim Pihtili.
[11] Optimization of High Pressure Coolant Assisted Turning of Inconel 718 withMulti-performance Characteristics Sunil J. Raykar, Uday A. Dabade.