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Mono and multi-response optimization of 3D printer parameters to attain improved hardness and surface roughness

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Abstract. 3D printing refers to process used to create a 3D object in which the material is joined or solidified with materials being added together. 3D printing Prototyping and tooling to direct part manufacturing in industrial sectors such as architectural, medical, dental, aerospace, automotive, furniture and jewellery are the potential applications of the additive manufacturing. This study describes certain aspects that must be controlled in and around an entry-level rapid prototyping 3-dimensional technology platform to investigate printing quality and optimization of the process. PLA (Poly Lactic Acid) material is to be used for making components. Printing speed, Layer thickness and Fill density are selected as 3D printing process parameters whereas component hardness and surface roughness are selected as responses. L9 layout is too followed for experimentation. Taguchi method is to be employed for the optimisation. Result of the study shows that, the longer thickness and printing speed are most influential parameters in developing surface roughness and component hardness respectively.

1. Introduction:

3D printing is a process of making physical object from a three dimensional digital model, typically by laying down many successive thin layers of material. It brings digital object into a physical form by a adding layer by layer of a material.3D printing is also known as additive manufacturing, refers to processes used to create a 3-dimensional object in which material is joined or solidified under computer control to create an object with materials being added together. Stereolithography, fused deposition modeling is the most common types that are used for 3D printing. Taguchi methods are statistical method is also called robust design method developed by Genichi Taguchi to improve the quality of manufactured goods, and also applied to engineering sectors. Yang [1] attempted to optimize the lemon juice gel based 3D printed food material to attain better rheological and mechanical properties. Nozzle height, nozzle diameter, extrusion rate and nozzle movement speed are sleeted as 3D printing process parameter. Analysis of the 3D printed component showed that good resolution, unwrinkled surface texture, lesser point defects and compressed deformation free surfaces. Lavi and Toyserkani [2] proposed a hybrid approach that coupled with material jetting and extrusion processes to make a 3 D printed silicone component. They employed statistical optimization to improve the 3D printing resolution and improve the surface quality of 3D printed features. It is clear from the analysis speed of jetting print head and velocity of the extrusion print head plays a decisive role to improve the responses. Lanaro et al [3] developed a complex chocolate object by 3D printing technique. The fineness of the extruded chocolate is assessed by achieving the span large detachment without collapsing. It is seen from the results the speed of moving nozzle, rate of extrusion rates and rate of cooling offer noteworthy influence on fineness of the extruded chocolate. The results show that the addition of pure cork and cork waste can be processed with polymers such as HDPE, having adequate physical and mechanical properties. Brites et al.,[4] developed a cork waste reinforced HDPE by 3D printing technique. Physical and mechanical properties of the material is investigated under different volume fraction of cork waste. Analysis of various properties shows that 3D printing parameters and cork waste content yields considerable improvement in mechanical properties. Manti had et al [5] designed a 3D printed chocolate with various different support structures including cross support, parallel support and without support. Fineness of the chocolate is assessed by completeness of the dimensions, weight and physical properties of the component. Result shows that, the breaking strength of the 3D printed chocolate improved by providing support structure. 3D printed chocolate made with cross support has superior breaking strength than other support structures. For the further contribution, an effort has been made to optimize of printing speed, layer thickness and fill density to accomplish the improved component hardness and surface roughness of gear component which is made by PLA.

2. Experimental work:

A spur gear with 65mm outer diameter, 52mm inner diameter and 6mm thickness was designed by using Solid works software. Designed model converted into dot STL file and then it was converted to G code. Developed G code was imported to into a computer controlled 3D Printer. During the process the PLA material heated up to 185^{0}C and the molten PLA forms the object. L_9 experimental layout is generated by Minitab 18 software. Printing speed, layer thickness and fill density is preferred as process parameter whereas hardness and surface roughness of the 3D printed component is considered as responses. The specification of the 3D printer used for the experimental work is exhibited in the Table 1. Surface roughness and hardness of the 3D printed component for different levels of the *3D* printer parameter is exposed in Table 2. The photographic view of 3D printed component is illustrated in Figure 1.

Table 1 Specification of 3D printer*:*

S No	Parameters	Properties
1	Build Volume	Up to 25X21X21 cm
2	Layer Height	0.05-0.35 mm
3	Printing surface	Heated Printed Bed
4	No of Extruders	02
5	Supported materials	Nylon and Polycarbonate

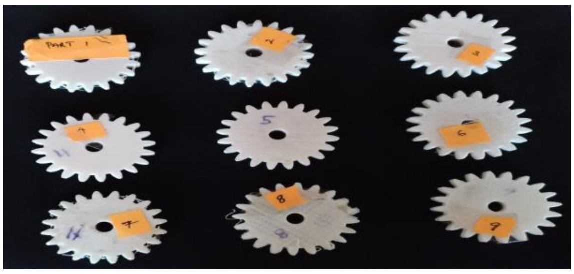

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Figure 1. 3D printed component

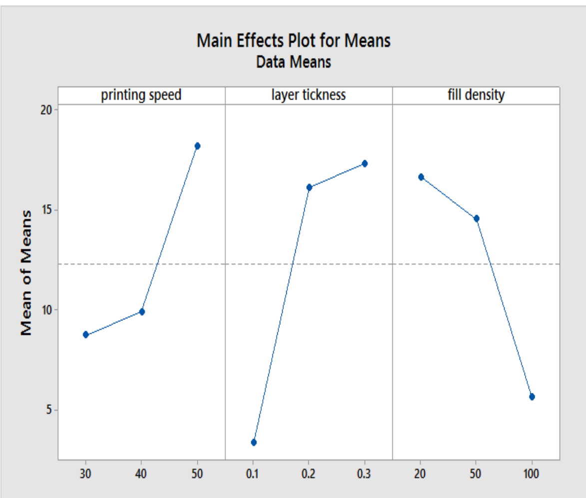
Table 2 L9 experimental layout

Component Number	Speed (mm/sec)	Layer thickness (mm) (%)	Fill Density	Surface roughness	Hardness
1	30	0.1	20	2.04	37.64
2	30	0.2	50	17.19	46.94
3	30	0.3	100	6.99	34.65
4	40	0.1	50	3.14	46.96
5	40	0.2	100	4.96	44.36
6	40	0.3	20	21.62	34.16
7	50	0.1	100	4.93	37.16
8	50	0.2	20	26.30	30.81

3. Analysis of results

3.1 Mono response optimization

Response graph for surface roughness and hardness are generated by Minitab software 18 and presented in Figure 2 and 3. From the Figure 2, it is clearly understood that the printing speed 30mm/sec to 40mm/sec the surface roughness increases, again the printing speed is 40mm/sec to 50mm/sec the surface roughness is drastically increased. The layer thickness 0.1mm to 0.2mm the surface roughness is drastically increased, again increase the layer thickness 0.2mm to 0.3mm the surface roughness is increased. If the fill density increase 20% to 50% the surface roughness decreases, again increase the fill density 50% to 100% the surface roughness drastically decreases. Among the above results, the minimum surface roughness occurs in 30mm/sec of printing speed, 0.1mm of layer thickness 20% of fill density.



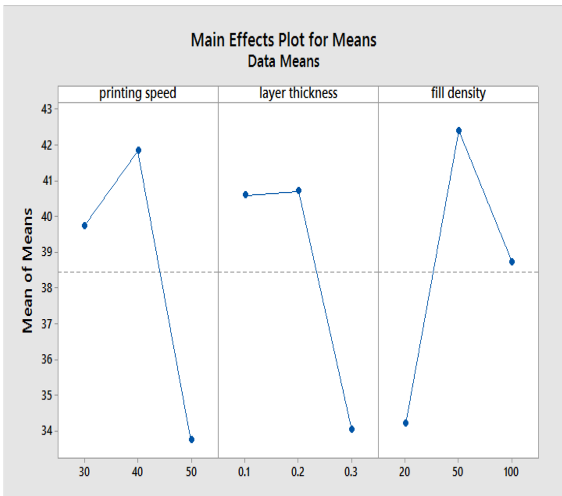


Figure 2 Response graph for surface roughness *Figure 3 Response graph for hardness*

From the Figure 3, it is clearly seen that by increasing the printing speed 30mm/sec to 40mm/sec the hardness value is increased, again increasing printing speed from 40mm/sec to 50mm/sec the hardness value is drastically decreased. If increase the layer thickness from 0.1mm to 0.2mm the hardness value is slight increases, again the increasing the layer thickness 0.2mm to 0.3mm the hardness value is drastically decreased. If increase the fill density is increased to 20% to 50% the hardness value is drastically increased if again increase the fill density from 50% to 100% the hardness value is decreased. Among the above result, the maximum hardness occurs 40mm/sec of printing speed, 0.1 mm layer thickness 50% of fill density.

Analysis of the variance for the surface roughness and hardness is performed and presented in Table 3 and 4. The Table 3 clearly brings out that layer thickness has the strongest influence on the surface roughness than the fill density and printing speed. The percentage of contribution of the layer thickness was recorded as 47.62.Further, the percentage contribution of the fill density and printing speed are recorded as 27.27 and 21.14 respectively. Table 4 illustrates that printing speed is a most influential parameter on the hardness of the component and the percentage of contribution was estimated about 35.18. The percentage of contribution of fill density and layer thickness was estimated as 33.73 and 29.18 correspondingly.

Table 3 ANOVA for surface roughness:

S No	Source	DF	Adj SS	Adj MS	% of Contribution
1	Printing Speed	2	159.63	79.82	21.14
2	Layer thickness	2	359.5	179.75	47.62
3	Fill density	2	205.87	102.93	27.27
4	Error	2	29.88	14.94	3.95
5	Total	8	754.88		100

Table 4 ANOVA for hardness:

S No	Source	DF	Adj SS	Adj MS	% of Contribution
1	Printing Speed	2	105.399	52.7	35.18143
2	Layer thickness	2	87.449	43.724	29.18985
3	Fill density	2	101.054	50.527	33.7311
4	Error	2	5.685	2.842	1.897612
5	Total	8	299.587		100

3.2 Multi-response optimization

Desirability function analysis is deployed to renovate the multi-response distinctiveness into single-response distinctiveness. Therefore, optimization of the intricate natured multi-response characteristics can be transformed into optimization of a solo response characteristic called as composite desirability. The single response optimization is aimed minimize the surface roughness and maximize the component hardness. The current work deals the estimation of composite desirability for surface roughness and hardness. Step by step procedure followed to compute the composite desirability is discussed by Sait et al [6]. Composite desirability value for each trail is estimated and tabulated in Table 5. Response graph for the composite desirability values is generated by Minitab software illustrated in Figure 4.

Table 5 Composite desirability for the L9 layout

S No	Printing Speed (mm/sec)	Layer thickness (mm)	Fill Density (%)	Surface Roughness (μm)	Hardness	Individual desirability for surface roughness	Individual desirability for hardness	Composite desirability	Rank
1	30	0.1	20	2.04	37.64	1	0.42	0.650	3
2	30	0.2	50	17.19	46.94	0.37	0.99	0.6126	4
3	30	0.3	100	6.99	34.65	0.79	0.23	0.435	6
4	40	0.1	50	3.14	46.96	0.953	1	0.977	1
5	40	0.2	100	4.96	44.36	0.87	0.83	0.859	2
6	40	0.3	20	21.62	34.16	0.19	0.02	0.064	8
7	50	0.1	100	4.93	37.16	0.8866	0.394	0.588	5
8	50	0.2	20	26.30	30.81	0	0	0	9
9	50	0.3	50	23.37	33.29	0.12	0.15	0.136	7

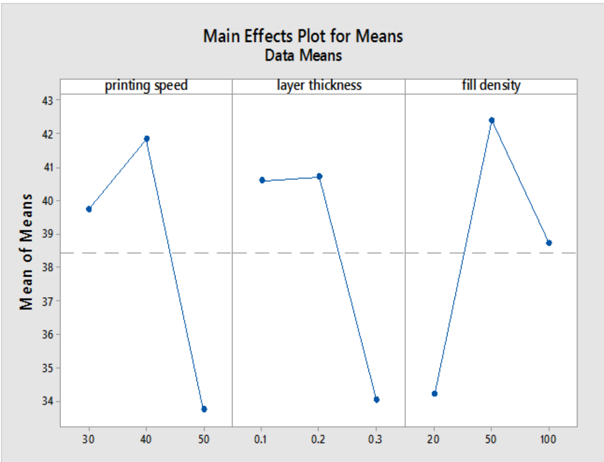


Figure 4 Response graph for composite desirability

From the Figure 4, it is clearly implicit that the increase in printing speed from 30mm/sec to 40mm/sec the desirability is increased, the further increase in printing speed from 40mm/sec to 50mm/sec the desirability drastically decreases. By increasing the layer thickness from 0.1mm to 0.2 mm the desirability value decreases, whereas the increase in layer thickness from 0.2mm to 0.3mm the desirability drastically decreases. By increasing the fill density from 20% to 50% the desirability radically increases while increasing the fill density from 50% to 100% the desirability increases. Among the 9 components, the component produced by the 4th trail has the highest value of composite desirability. Hence, the optimum parameters to attain the improved surface roughness and hardness are at 40mm/sec printing speed, 0.1mm layer thickness, and 50 % fill density. Analysis of variance also performed for the composite desirability value and tabulated in Table 6. Layer thickness has the strongest influence on the composite desirability than other parameters. The percentage contribution for the Layer thickness and fill density and printing speed is estimated as 42.84, 27.53 and 27.1 respectively.

Table 6 ANOVA for composite desirability

S No	Source	DF	Adj SS	Adj MS	% of Contribution
1	Printing Speed	2	0.26348	0.13174	27.10086
2	Layer thickness	2	0.41654	0.20827	42.84421
3	Fill density	2	0.26773	0.13386	27.53698
4	Error	2	0.02449	0.01224	2.517949
5	Total	8	0.97223		100

4 Conclusion

Optimization of printing speed, layer thickness and fill density to achieve the improved component hardness and surface roughness of gear component was carried out and the following conclusions are drawn. The minimum surface roughness of the component was achieved at 30mm/sec printing speed, 0.1mm of layer thickness and 20% of fill density. The maximum hardness was attained 40mm/sec printing speed, 0.1mm of layer thickness and 50% of fill density. Maximum composite desirability accomplished at 40mm/sec printing speed, 0.1mm layer thickness and 50% of fill density. Layer thickness is significant parameters for surface roughness of the component; fill density is the most influential parameter for hardness and layer thickness also most considerable for composite desirability. Less than 5 % error in all analysis variance estimation reflects the statistical significance of the experimental value.

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