PAPER • OPEN ACCESS

Optimization of hybrid manufacturing process parameters by using FDM in CNC machine

To cite this article: Anuja Kale *et al* 2018 *IOP Conf. Ser.: Mater. Sci. Eng.* **402** 012088

View the article online for updates and enhancements.

IOP | ebooks™

Bringing you innovative digital publishing with leading voices to create your essential collection of books in STEM research.

Start exploring the collection - download the first chapter of every title for free.

Optimization of hybrid manufacturing process parameters by using FDM in CNC machine

Anuja Kale*, Abburi Lakshman kumar, M Murali Krishna Kumar, Dr M Prakasah

Department of Mechanical Engineering, SRM Institute of Science and Technology, Kattankulathur-603203, India.

* Corresponding author: lakshman1988jan@gmail.com

Abstract. The major methods used for manufacturing new components in industries, are Subtractive and Additive Manufacturing (AM). Subtractive method is generally more accurate and precise, but it is intricate to reduce material wastage in subtractive manufacturing. In contrast, Additive Manufacturing can produce an object with convoluted features and allows the material to be used more proficiently. A filament extrusion base process which integrates Computer Numerical Control (CNC), Material Science and Computer Aided Design system inAdditive Manufacturing is Fused Deposition Method (FDM) technique.The FDM extrusion Process produces objective parts without geometrical restrictions. However, due to the irregular shrinkage, residual stress and Stair Case effect in AM product their accuracy is usually indecisive. Combining Subtractive Processes and Additive within a single workstation, In CNC machine attachment of FDM Extruder is designed to strap up the relative merits of each process and this hybridization facilitates to overcome the limitation of each individual process. These techniques present opportunities to improve utilization of material, part complexity, and quality management in functional components. In this paper, CNC Machine is used as a workstation to hybrid both processes. By working on specified controllable parameters like layer thickness, raster angle, depth of cut for optimization of whole process using parameters significance on the process for achieving the objective of the paper is the minimization of material waste and good surface finish. The technique used for the design of experiment and optimization of parameters is Taguchi Method with significance to S/N ratio. The proposed hybrid manufacturing process is achieving the less material wastage compare to the machining product.

Keywords. Additive Manufacturing (AM), Fused Deposition Modeling (FDM), Subtractive Manufacturing, Surface roughness.

1. Introduction

Rapid Prototyping (RP) created a way, to manufacture substantial part directly from blueprint with the flexibility of complex geometry with effective material usage and reduction in build time. RP modern strategies provide flexibility of sharing design and usage of different material according to desired properties [1]. Nowadays this technology is not only used for prototyping, but improvements evaluated in the quality of the output from RP is much closer to the final product. For this reason, ASTM International Technical Committee adopted the new term as Additive Manufacturing as all the part fabricated from this technology is by material addition approach. A number of steps are involved in RP to form physical part from virtual CAD data. It should start from fully describing external and internal geometry for that CAD modeling of the part is carried. Then this CAD format file is converted to STL file format. Conversion to STL format is done to communicate CAD data to acceptable format to RP system. Next to this STL transferred and STL file manipulation is done such as size correction, positioning and build orientation. Then machine setup is done which involves build parameters likes material constraints, layer thickness, timings etc. After that automated build starts only assistance requires at this stage for power or software glitches and material shortage check. As build completed removal is done from a machine with the safety of heat and moving parts. Finally fabricated part is post processed to clean up for surface finishing, removal of support material and to make part ready to use [2]. The RP processes are categorized solid base, a liquid base, powder base as per type of raw material used. There are a number of different solid base RP processes one of them is Fused Deposition Modeling (FDM).In FDM process solid thermoplastic filament is fused and then fused material is extruded through a nozzle. Layer by layer deposition in accordance with 3D CAD model will come up with final required product [3].

In RP parts can be fabricated with complicated geometry but accuracy and precision are uncertain because of shrinkage and the internal stresses. The staircase effect due to the roundness of nozzle extruded material leads to poor surface quality of parts, as indicated by Pandey et al. (2003) [4]. To overcome these problems and achieve better results considerable work has to be done towards finishing of the product. This motivated hybridization of the additive system with CNC machine, which is used for subtractive processing. Manufactured parts from CNC machining are generally accurate and precise, but material wastage is not controllable. So by hybridizing both systems at one workstation, we can control accuracy with effective material usage. Anitha et al. (2001) indicated layer thickness is a most significant factor for surface roughness. As layer thickness reduced surface roughness reduces but the reduction in layer thickness leads to increase in build time [5]. So hybrid RP system provides the facility of shorter build time with high accuracy at a single workstation. The roundness of nozzle creates surface roughness problem in FDM, shrinkage during solidification causes dimensional inaccuracy and staircase effect. But considering shrinkage ratio and building component oversize also disturb precision of part to be manufactured. To solve this problem we considerably work on accuracy and surface roughness in FDM. Were we considered roughness value of FDM and tried to achieve good surface finish and accuracy with minimum material wastage. Hybridization of additive and subtractive system manufacturing will give us benefits of both the system by overcoming the limitations of both systems. This hybridization can give FDM output a place of final product instead of using it only for prototyping. Wei-chen Lee et al. (20014) Shown innovative design idea of combining FDM in CNC machine they have used the flexibility of five-Axis machine to fabricate parts from FDM technique. They attached FDM tool on the rotary axis of five-axis CNC machine. FDM extruder is attached to the opposite side of cutter spindle [6]. We have used three- axis CNC machine with FDM designed tool which is capable of fitting into ATC and mount on the spindle with the collect like other cutting tools. The objective is to develop an FDM extruder for a CNC machine to make a Hybrid workstation to take advantages of both processes to achieve a good surface finish with minimum material wastage and minimum process time. This process should be cost effective. Production cost should be reduced using Hybrid manufacturing. Some control

parameters have an effect on the process, the objective is also to find out an optimized combination of the significant control parameter to achieve good surface finish, minimum process time and minimum material wastage cost effectively.

2. Extruder holder design and Tool path generation

This section presents the design of FDM setup, how the setup is integrated into CNC machine and toolpath generation for additive manufacturing.

2.1 Design Extruder holder

FDM setup is designed by considering ATC of CNC machine. So that this setup should be fitting into all criteria of CNC machine tools and no extra work should be done on the machine to attach a setup. The idea is, this tool should be made as a standard tool that can fit into any CNC machine.To attach FDM set up into CNC machine's spindle holder is designed. Using L-angle plate by welding one rod on it this design is shown in figure 1. The whole FDM unit consists of FDM head, FDM holder, and circuit this unit is combined with CNC machine to deposit material. Attached FDM setup to CNC machine is shown in figure 2. Using this FDM setup in CNC we can hybridize two processes at oneworkstation to utilize advantages of each process and at the same time disadvantages of each process can be overcome and the product can be manufactured with minimum material wastage, minimum process time and with the goodsurface finish.

2.2 Tool path generation for deposition

For building prototype tool paths are generated the for FDM and machining respectively. A commericial Master cam package was used to generate the tool paths.Where if we consider 3D printing, then raster width of the component is controlled in Mastercam by using step over distancewhich includes consideration of nozzle diameter and deposition layer thickness, roughing angle can be used as a raster angle. Tool path for deposition is shown in figure 3 and figure 4 shows how similar shape is achieved by subtractive operation.

Figure 1. FDM extruder holder design   **Figure 2.** FDM setup attached to CNC machine.
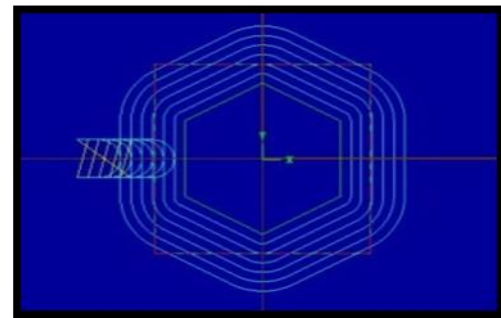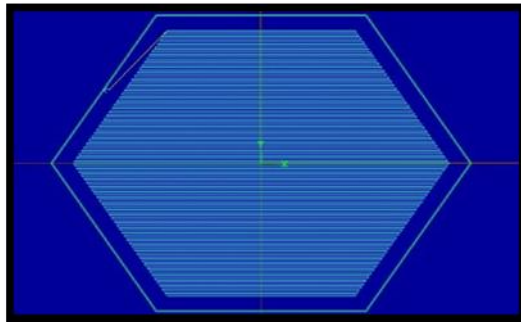
Figure 3. Tool path for the Additive operation   **Figure 4.** Tool path for the Subtractive operation

3. Experimentation

3.1Experiments for comparing components from RPT and CNC

The advantages of each process and scope of overcoming the disadvantages related to each process that is rectified by comparing both processes using the parameter as layer thickness for FDM in RPT machine and depth of cut in CNC machining. Specimen shape used here is a hexagonal block of 50mm diameter and 30mm height.Comparison for material wastage, process time and surface roughness in both process is done considering parameters like layer thickness and depth of cut. CNC machine used for experimentation is LV45 3-axis and RPT machine used with 3D printing software stratasys-SMG3D. Components manufactured by CNC machining process using CNC 3-axis machine with different depth of cut as 0.17mm, 0.25mm, and 0.33mm are shown in figure 5. The components fabricated from Fused Deposition process using RPT machine with different layer thickness is shown in figure 6. In CNC machining 1200rpm speed and 500mm/min feed rate are considered constant. In RPT machine raster angle is set to 0°. The air gap is kept 0.00mm which is the default value.
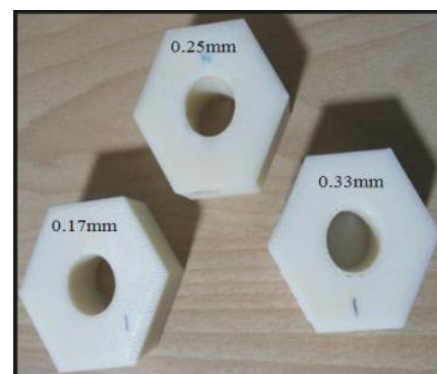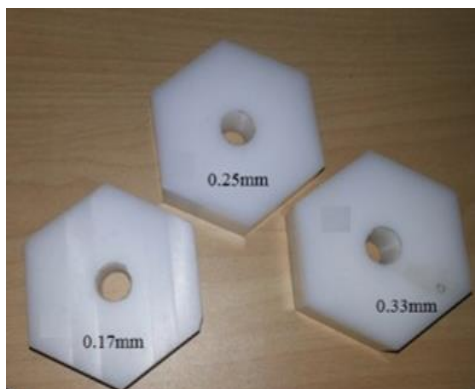
Figure 5. Machined specimen with different depth **Figure 6.** Fabricated components with of cut
     by subtractive manufacturing in CNC   different layer thickness from RPT.

3.2 Hybrid Manufacturing Design of Experiment

Hybridization of Additive and Subtractive manufacturing is done at a single workstation that is 3-axis CNC machine. In CNC machine FDM tool is mounted on spindle using collet fixing with FDM tool. To optimize the process of hybridizing both systems at one workstation with all advantages Taguchi method with Grey Relational analysis to optimize these parameters to get better results and to

find out each parameter influence on the process[6]. Using Taguchi design, experiments are design factors affecting the process are layer thickness, raster angle, and depth of cut. Here layer thickness and raster angle are factors affecting material deposition and depth of cut affecting the material removal after deposition is completed to improve the surface roughness [7]. Material is removed with different depth of cut.The hybrid experiment is designed by Taguchi Design of Experiment with parameters as layer thickness: 0.1mm, 0.2mm, 0.3mm, Raster angle: 0°, 30°, 45°, Depth of cut: 0.3mm, 0.4mm, 0.5mm these parameters is selected. Taguchi design with three different factors and three level using L9 design is shown in Table 1. These experiments are carried out toachieve three objectives responses as minimum material wastage, process time requirement,and surface roughness [8]. Manufactured components with these parameters are shown in Figure 7. Feed rate is maintained as 500mm/min and spindle speed is zero or we can say as the spindle is not rotating.

Table 1. L9 Orthogonal Array for Experimental Parameter of Hybrid Manufacturing

Experiment No.	Layer Thickness(mm)	Raster Angle(°)	Depth of Cut(mm)
1	0.1	0	0.3
2	0.1	30	0.4
3	0.1	45	0.5
4	0.2	0	0.5
5	0.2	30	0.3
6	0.2	45	0.4
7	0.3	0	0.4
8	0.3	30	0.5
9	0.3	45	0.3

Figure 7. Specimen manufactured with different parameters in the Hybrid system

4. Results and Discussion

In this section obtained values and their inferences are discussed. Obtained results from the experiment where three different depth of cut are considered as a parameter in CNC machining as shown in Table 2 and experiments performed using RPT machine with different layer thickness is

shown in Table 3.From the Table 2 and Table 3 comparative parameter are the depth of cut and layer thickness, three similar values are selected to analyze the responses as material wastage, process time and surface finish.In a comparison of time which is called as machining time for machining experiments and process time for FDM process. Here it can be seen that for 0.17mm depth of cut to achieve required shape it requires 126.48 minutes for achieving the same shape with 0.17mm layer thickness time requirement is 71minutes.

It is observed that time is reducing in RPT machine to produce same shape and size and considering material wastage, wastage is very high in machining process that is for 0.17mm depth of cut wastage of material is 450g but for similar parameter in FDM process RPT machine wastage is 0.52g wastage is 99.88% less in RPT machine for 0.17mm layer thickness. Similarly, for 0.25mm layer thickness; 99.80% less wastage is there, for 0.33mm layer thickness; 99.77% less wastage is there as compared to the machining process.

Table 2. Machining Experiments Using CNC Machine

Sr. No.	Depth Of Cut (mm)	Machining Time (min)	Material Wastage(g)	Surface Roughness (μm)
1	0.17	126.48	450.0	0.6987
2	0.25	86	449.5	0.2898
3	0.33	65.15	447.7	0.4152

Table 3.Additive Manufacturing Experiment Using RPT Machine

Sr. No.	Layer Thickness (mm)	Process Time (min)	Material Wastage(g)	Surface Roughness (μm)
1	0.17	71	0.52	5.2967
2	0.25	33	0.86	4.0427
3	0.33	24	1.02	6.5410

This shows the advantage of saving material and time,using additive manufacturing. But, considering surface roughness for each process from obtained values it is observed that surface roughness values are more in FDM process. This suggests the hybrid process gives all advantage with good surface quality, less time requirement, and less material wastage

4.1 Hybrid manufacturing experimental results

Three parameters, three levels Taguchi design is used for this experiments output response is considered as Process time, Material wastage, and Surface roughness. Experimental results are shown in Table 4.

4.1.1 Signal to Noise Ratio Analysis

To calculate the optimum parameter for each individual response is calculated from S/N ratio analysis. If only the one individual response is considered then which level of each parameter gives the better results is calculated. The calculated values for S/N ratio is shown in Table 5. Equation 1 is to calculate S/N ration of each response.

$$\text{S/N ratio} = -10 \log \left[\frac{1}{n}\right] \sum \left[\frac{1}{Y^2_{ij}}\right] \tag{1}$$

Where:
1. Y_{ij} is each individual response values for each experiment.
2. n is a number of replication for each response.

Table 4. Experimental Results for Hybrid Manufacturing

Exp No	Layer Thickness (mm)	Raster Angle (°)	Depth Of Cut (mm)	Process Time (min)	Material Wastage (g)	Surface Roughness values before machining (µm)	Surface Roughness values after machining(µm)	Percentage reduction in Surface Roughness (%)
1	0.1	0	0.3	71	0.89	4.3674	0.941	78.45
2	0.1	30	0.4	72.55	0.90	4.4286	1.6748	62.18
3	0.1	45	0.5	71.68	0.88	5.6928	3.4752	38.95
4	0.2	0	0.5	33.68	1.25	5.8047	2.4484	40.13
5	0.2	30	0.3	34.52	1.14	4.8893	1.8497	62.16
6	0.2	45	0.4	34.55	1.79	7.5998	1.3146	82.70
7	0.3	0	0.4	24.55	2.15	6.5843	4.6456	29.44
8	0.3	30	0.5	24.68	2.17	7.2447	1.0939	84.90
9	0.3	45	0.3	25.51	2.20	15.6547	0.9526	93.91

Table 5. S/N Ratio for Process Time, Surface Roughness, Material Wastage.

Sr .No.	S/N ratio for Time	S/N ratio for Surface Roughness	S/N ratio for Material Wastage
1	-37.0252	0.528208	1.0122
2	-37.2127	-4.47926	0.91515
3	-37.108	-10.8196	1.110347
4	-30.5474	-7.77765	-1.9382
5	-30.7614	-5.34203	-1.1381
6	-30.769	-2.37587	-5.05706
7	-27.801	-13.3408	-6.64877
8	-27.8469	-0.77955	-6.72919
9	-28.1342	0.421788	-6.84845

Average of S/N ratio for each level of each factor is calculated to find the optimum parameter values this average for a response as Process time is shown in Table 6, Material wastage is shown in Table 7, Surface roughness is shown in Table 8. The greater value of each factor's S/N ratio that is optimum level for that factor.

Table 6. Average Response S/N Ratio for Process Time

Sr. No.	Parameters	Level 1	Level 2	Level 3
1	Layer Thickness	-37.11	-30.69	**-27.92**
2	Raster Angle	**-31.79**	-31.94	-32.00
3	Depth Of Cut	**-31.88**	-31.96	-31.89

Table 7. Average Response S/N Ratio for Material Wastage**.**

Sr. No.	Parameters	Level 1	Level 2	Level 3
1	Layer Thickness	**1.01**	-2.71	-6.74
2	Raster Angle	-2.52	**-2.31**	-3.59
3	Depth Of Cut	-3.59	-2.62	**-2.22**

Table 8. Average response S/N ratio for Surface Roughness

Sr. No.	Parameters	Level 1	Level 2	Level 3
1	Layer Thickness	-4.92	-5.16	**-4.84**
2	Raster Angle	-6.86	**-3.53**	-4.53
3	Depth Of Cut	**-0.87**	-3.94	-9.83

4.1.2 Grey Relational Analysis for Optimizing Hybrid Manufacturing Parameters

Grey Relational analysis is done for multiple objective problems as here three objectives are considered this method is best suitable for optimizing parameters. Using this method significance of each parameter on the whole output is calculated. For combined result of each parameter on three consider output responses can be calculated here by Grey Relational analysis.The first step to Grey Relational analysis we need to normalize calculated S/N ratio as shown ing Table 5.This normalized S/N ratio is shown in Table 9.

Table 9. Normalized S/N ratios

Sr. No.	Normalized S/N Ratio of Time	Normalized S/N Ratio of Surface Roughness	Normalized S/N Ratio of Material Wastage
1	0.9800	0	0.0123
2	1	0.3610	0.0245
3	0.9888	0.8182	1
4	0.2918	0.5988	0.3830
5	0.3145	0.4232	0.2825
6	0.3153	0.20939	0.7749
7	0	1	0.9749
8	0.0048	0.09429	0.9850
9	0.035	0.00767	1

Table 10. Mean of Grey grade for Each Level of Factors

Sr. No.	Factors	Level 1	Level 2	Level 3	Delta	Rank
1	Layer Thickness	**0.7697**	0.6314	0.6107	0.1590	2
2	Raster Angle	0.5966	0.6585	**0.7567**	0.1601	1
3	Depth of Cut	0.6619	0.6709	**0.6790**	0.0171	3

5. CONCLUSION

This study shows that additive and subtractive manufacturing has their own limitations. To concur or overcome these limitations we hybridized the process. Hybrid workstation gives us advantages for overcoming the problem associated with each process. Hybrid manufacturing, attaching FDM extruder into CNC machine gives us cost effective hybrid machine workstation and advantages like minimum material wastage, shorter process time, good quality products. FDM hybrid in CNC allows the machine to shift between the two processes without any additional actuation system, thusshortening the mechanism complexity and decreasing the time to find the position of the cutter absolute to the FDM part for succeeding machining.

Otimum values ofparametersand for their significance inference of S/N ratio is considered.The optimal levels for all the factors are always selected based on maximum average S/N ratio of the response, accordingly, the best factors level for Process Time consideration are Layer thickness 0.3mm, Raster Angle 0°, Depth of cut 0.3mm. The best factors level for Surface Roughness consideration is Layer thickness 0.3mm, Raster Angle 30°, Depth of cut 0.3mm.The best factors level for Material wastage consideration is Layer thickness 0.1mm, Raster Angle 30°, Depth of cut 0.5mm.It is observed that for combined response consideration of Process Time, Surface Roughness and Material Wastage optimum factors are: 0.1mm layer thickness, 45˚ Raster angle and 0.5mm depth of cut. According to Ranking, it is observed that Raster Angle is more effective parameter among all other parameters used for the experiment.

6. References

[1] Eric J. McCullough, Vamsi K Yadavalli 2013 Surface modification of fused deposition modeling   ABS to enable rapid prototyping of biomedical microdevices, *Journal of Material Processing Technology*. **213,** 947-954.
[2] Gibson, D.W.Rosen and B. Stucker 2010 Additive Manufacturing Technologies, Springer Science

[3]   lberto Boschetto, Luana Bottini, Francesco Veniali 2016 Finishing of Fused Deposition Modeling part by CNC machining, *Robotics and Computer -Integrated Manufacturing*. **41,** 92-101

[4]   P.M. Pandey, N.V. Reddy, S.G.Dhande 2013 Improvement of surface finish by staircase machining in fused deposition modeling, *Journal of materials process technology*. **132,** 323-331

[5]   R.Anitha, S.Arunachalam, P.Radhakrishan 2001 Critical parameters influencing the quality of prototypes in fused deposition modeling, *Journal of materials Processing Technology*. **118,** 385-388

[6]   Wei-chen Lee, Ching- Chih Wei, Shan-chenchung 2014 Development of hybrid rapid prototyping system using Low- cost fused deposition modeling and five axis machining", Journal of materials processing technology. **214,** 2366-2374

[7]   JoesphM.Flynn, Alborzshokrani, Stephen T.Newman, VimalDhokia, "Hybrid additive and subtractive machine tools- Research and industrial developments, *International journal of machine tools & Manufacture,* **101,** 79-101

[8]   S.H. Choi, S.Samavedam 2002 Modelling and optimization of rapid prototyping, *Computer in industry*, **47,** 39-53