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Optimization of Various Process Parameters for CFRP Composite Materials Machining

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Abstract*: This paper mainly focused on the understanding of machining processes in turning of carbon fiber reinforced polymer composite using carbide cutting tool. Machining of Carbon Fiber Reinforced Polymer composite has to be done on CNC turner lathe by varying the cutting parameters such as cutting speed, feed and depth of cut. Taguchi L9 orthogonal array has to be used for conducting design of experiments (DOE) on CFRP composite and mild steel. Different fiber orientations of the composite rods are to be machined for testing the surface roughness. Hardness test is to be conducted for finding the strength of the CFRP composite and mild steel. For measuring the surface roughness tally surface tester is to be used.*
Keywords: *Taguchi,hardness,deisgn of experiments, surface roughness, CFRP composite.*

I. Introduction

Carbon Fiber Reinforced Polymer has started replacing conventional materials a long back due to the excellent properties they possess various applications in engineering and technology. But machining of carbon fiber reinforced polymers are completely different than that of conventional material (metals) because of CFRP composites are having anisotropic and non-homogeneous properties. S.K. Choudhury and I.V.K. Appa Rao [1], presented a new approach for improving the cutting tool life by using optimal values of velocity and feed throughout the cutting process. From experimental results they showed an improvement in tool life by 30 %. Yusuf Sahin and A. Riza motorcu [2], conducted experiments on mild steel with Tin coated carbide cutting tool by varying the cutting parameters such as speed, feed, and depth of cut. From results surface roughness model is developed by them in terms of cutting speed, feed rate and depth of cut using response surface methodology. Finally they concluded that feed rate was main influencing factor on surface roughness. Nikhil Ranjan Dhar et al [3], evaluated the performance of MQL system on tool wear, surface roughness and dimensional deviation in turning AISI-4340 steel by using cutting speed, feed rate,depth of cut as controllable variables. They improved the tool life in minimum quantity lubricant (MQL) system. M. A. H. Mithu et al [4], evaluated the effect of minimum quantity lubrication on turning AISI 9310 alloy steel using vegetable oil based cutting fluid. From results they have found that chip-tool interface temperature as well as tool wear gets reduced. S. Thamizhamanii and H Sulaiman [5], conducted turning experiments for machinability of hard stainless steel and alloy steel using Polycrystalline cubic boron nitride tools. They conducted experiments with different cutting velocity, feed rate and a constant depth of cut. From experiments they measured cutting force, surface roughness, tool wear and specific cutting pressure with various measuring instruments. From results they summarized that machinability by stainless steel is good than alloy steel due to cutting force. IlhanAsiltürk and Harun Akkus [6], focused on optimizing turning parameters based on the Taguchi method to minimize surface roughness using hardened AISI 4140 (51 HRC) with coated carbide cutting tools. From results they indicated that the feed rate has the most significant effect on surface roughness. They found that the effects of two factor interactions of the feed rate-cutting speed and depth of cut-cutting speed appear to be important. Surinder Kumar et al [7], conducted turning operation for optimizing the cutting parameters on surface roughness of unidirectional glass fiber reinforced plastic. Experimentation was done by them with polycrystalline diamond cutting tool. From results they developed a second order mathematical model in terms of machining parameters for predicting the surface roughness by using multiple regression methodology. M.A. Xavior [8], conducted CNC turning experiments on AISI 304 stainless steel using alumina inserts in order to understand the machinability characterization. The machinability is evaluated by him in terms of surface roughness which is achieved on the machined work piece, tool wear encountered and tool life achieved by the inserts for various machining time. Finally he determined the tool life achieved by alumina while machining AISI 304.Osarenmwinda. J. O. [9], developed an empirical model for estimating the surface roughness of machined components using regression analysis software. The center lathe was used by him to turn the components at different speed at constant depth of cut and feed. He compared the values obtained from empirical models with experimental results and found in good agreement. J. Satish et al [10], used CNC turning operation and Taguchi's L8 orthogonal array for experimental design. From the experimental results they optimize the effects of three viz. parameters cutting velocity (V), feed rate(f), depth of cut (d) on the surface roughness values(Ra and Rz). They also performs ANOVA analysis to know the effects of these three factors on the responses using statistical software MINITAB 16. From results they concluded that moderate cutting velocity, lower feed rate and higher depth of cut are the ideal machining conditions for machining Aluminum Silicon Carbide Composite. Syed Altaf Hussain et al [11], conducted turning experiments on Glass Fiber Reinforced polymer composites in order to understand the machinability characterization. They conducted experiments by varying three parameters namely cutting speed, feed rate, depth of cut and work piece (fiber orientation) with poly crystalline diamond. Taguchi's L25 orthogonal array was used by them for design of experiments. They optimized the surface roughness (Ra) of GFRP composite and developed a second order mathematical model using RSM. They also optimized the surface roughness prediction model coupling with Geometric Algorithm (GA). Asaithambi and Gowri [12], optimized the machining parameters for surface roughness, cutting temperature and tool wear during the machining of carbon fiber reinforced polymer (CFRP). They conducted several experiments with different values of cutting g parameters and different cutting tools such as uncoated and tin coated polycrystalline cubic boron nitride cutting tools. From experimental results they concluded that Tin coated Polycrystalline cubic boron nitride cutting tool gave the best overall performance than uncoated Polycrystalline cubic boron nitride cutting tool.

II. Work Piece And Cutting Tool Specifications

Work Piece: Three workpieces such as mild steel rod of 50 mm diameter and 200 mm in length, Carbon Fiber Reinforced Polymer (CFRP) winded in 45^0 and 90^0 for 5 mm thickness on mild steel rod are considered for studying the machining characterization and validation. For studying the characterization of the workpieces three variable parameters had been chosen such as speed, feed and depth of cut. The CFRP of 90^0 orientation while winding on mild steel rod is shown in Fig. 1.

Cutting Tool: Tungsten carbide cutting insert (CNMG120408) is used in this present work for machining of CFRP of 45^0 and 90^0 orientations and mild steel rods. The Tungsten carbide cutting insert used in this work is shown in Fig. 2. The cutting insert specifications are:

ISO specification of cutting inserts- CNMG120408, C = 80 Degree Rhombus, N = Insert clearance angle (0°)
M= Tolerance class (N), G = Type of insert, Hole , 12 = Edge length (12mm) , 04 = Insert thickness (4.76mm)
04 = Radius (0.4mm).

Fig. 1: CFRP of 90^0 Orientation

Fig. 2: Cutting Inserts Tungsten Carbide

III. Surface Roughness And Hardness Test Results

Surface Roughness:

Selection of particular orthogonal array from the entire standard depends on the number of factors, levels of each factor and orthogonal array was selected using Taguchi technique. The L9 Array in Taguchi's method represents; 3 levels and 3 parameters which make a nine set of experiments. The surface roughness is measured using SJ-410 (Mitutoyo) tester. The variable speed, feed and depth of cut at which the surface roughness values is taken are shown in Table 1. The surface roughness values measured at variable speed, feed and depth of cut are shown in Table 2.

Table 1: L9 Orthogonal Array for Experimentation

Exp. No.	Surface roughness for mild steel (µm)	Surface roughness for CFRP 45^0 (µm)	Surface roughness for CFRP 90^0(µm)
1	3.970	1.452	1.734
2	5.370	1.711	1.832
3	7.261	1.460	1.902
4	6.956	1.544	1.605
5	6.718	1.835	1.746
6	4.280	1.409	1.830
7	4.390	2.474	1.510
8	1.140	2.036	1.703
9	4.010	1.733	1.821

Table 2: Experiment Results for Surface Roughness

Exp. No.	Speed (RPM)	Feed rate(mm/rev)	Depth of cut(mm)
1	200	0.05	0.25
2	200	0.15	0.50
3	200	0.20	1.00
4	300	0.05	0.50
5	300	0.15	1.00
6	300	0.20	0.25
7	600	0.05	1.00
8	600	0.15	0.25
9	600	0.20	0.50

Hardness:

By using Brinell hardness tester the hardness of the mild steel rod, Carbon Fiber Reinforced Polymer (CFRP) of 45^0 and 90^0 orientation rods was calculated. The hardness was calculated by average of three measure values from Brinell hardness test. The hardness values obtained for various workpieces are shown in Table 3.

Table 3: Hardness values from Brinell Hardness Tester

Sl. No.	Workpiece	Reading 1 (BHN)	Reading 2 (BHN)	Reading 3 (BHN)	Average of three values (BHN)
1	Mild Steel	108	112	95	105
2	CFRP of 45^0 orientation	68	55	59	60.66
3	CFRP of 90^0 orientation	63	60	50	57.66

IV. Optimization Using Taguchi Methodology

Taguchi method is a scientifically disciplined mechanism for evaluating and implementing improvements in products, process, materials and equipment's. These improvements are focusing at improve the desire characteristics and minimize the number of defects and optimizing the procedure or design to get best results. A series of experiments are conducted on work materials with tungsten carbide insert. S/N ratios for surface roughness values are calculated using smaller-the-better characteristic proposed by taguchi and are shown in table 4. Mean effects plot for Mild steel, Carbon Fiber Reinforced Polymer (CFRP) composite rods winded in 45^0 and 90^0 are shown from Fig. 3 to Fig. 5. Response for means of Mild steel, Carbon Fiber Reinforced Polymer (CFRP) composite rods winded in 45^0 and 90^0 are shown in Table 5 to Table 7. From Fig. 3 and Table 5 it is observed that speed and depth of cut are most influencing factors for surface roughness of mild steel. It is observed from Fig. 4 and Table 6 that from the means graph and response table, speed is the most influencing factor compare to other for surface roughness of CFRP of 45^0 orientation composite rod. From Fig. 5 and Table 7 it is observed that speed and feed rate are most influencing factors for surface roughness of CFRP of 90^0 orientation composite rod. Means effects plot for S/N ratios of Mild steel, Carbon Fiber Reinforced Polymer (CFRP) composite rods winded in 45^0 and 90^0 are shown from Fig. 6 to Fig. 8. Response of S/N ratios for surface roughness of Mild steel, Carbon Fiber Reinforced Polymer (CFRP) composite rods winded in 45^0 and 90^0 are shown in Table 5 to Table 7.

Table 4: S/N Ratios for Various Workpieces

Exp. No	` Mild steel	CFRP 45^0	CFRP 90^0
1	-11.9758	-3.23933	-4.78098
2	-14.5995	-4.66500	-5.25851
3	-17.2199	-3.28706	-5.58421
4	-16.8472	-3.77295	-4.10950
5	-16.5448	-5.27272	-4.84088
6	-12.6289	-2.97822	-5.24902
7	-12.8493	-7.86799	-3.57954
8	-1.1381	-6.17556	-4.62429
9	-12.0629	-4.77597	-5.20620

From Fig. 6 and Table 8 it is observed that based on the smaller the better concept the optimum parameters settings for minimum surface roughness of mild steel are 600 RPM speed, 0.15 mm/rev feed rate, 0.25 mm depth of cut. It is observed that the optimum parameters settings for minimum surface roughness of CFRP 45^0 orientation rod are 200 RPM speed, 0.20 mm/rev feed rate, 0.25 mm depth of cut from Fig. 7 and Table 9. From Fig. 8 and Table 10 it can be observed that the optimum parameters settings for minimum surface roughness of CFRP 90^0 are 600 RPM speed, 0.05 mm/rev feed rate, 1.00 mm depth of cut.

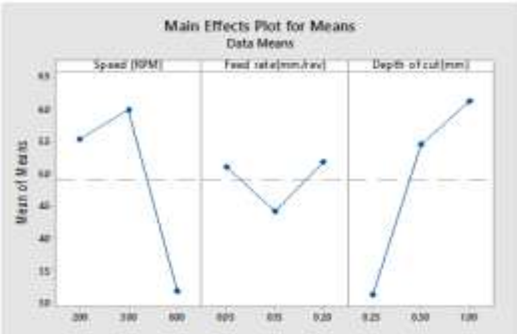

Fig. 3: Mean Effects Plot for Mild Steel

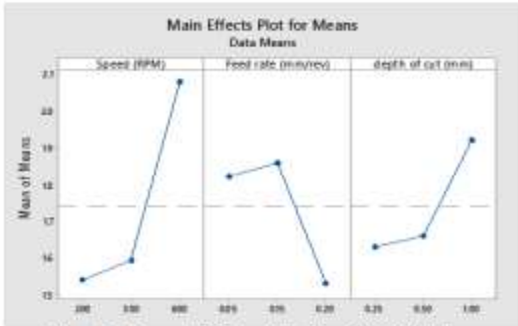

Fig. 4: Mean Effects Plot for CFRP 45^0 Orientation Rod

Fig. 5: Mean Effects Plot for CFRP 90^0 Orientation Rod

Fig. 6: S/N Ratios for Mild Steel

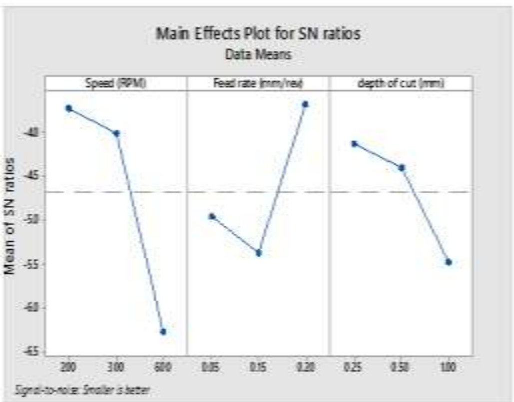

Fig. 7: S/N Ratios for CFRP 45^0 Orientation Rod

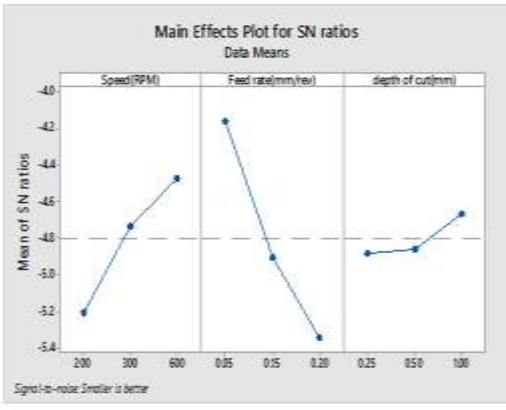

Fig. 8: S/N Ratios for CFRP 90^0 Orientation Rod

Table 5: Response Table for Means of Mild Steel

Level	Speed(RPM)	Feed rate(mm/rev)	Depth of Cut (mm)
1	5.534	5.105	3.130
2	5.985	4.409	5.445
3	3.180	5.184	6.123
Delta	2.805	0.774	2.993
Rank	2	3	1

Table 6: Response Table for Means of CFRP 45⁰ Orientation Rod

Level	Speed(RPM)	Feed rate(mm/rev)	Depth of Cut (mm)
1	1.541	1.823	1.632
2	1.596	1.861	1.663
3	2.081	1.534	1.923
Delta	0.540	0.327	0.291
Rank	1	2	3

Table 7: Response Table for Means of CFRP 90⁰ Orientation Rod

Level	Speed(RPM)	Feed rate(mm/rev)	Depth of cut(mm
1	1.823	1.616	1.756
2	1.727	1.760	1.753
3	1.678	1.851	1.719
Delta	0.145	0.235	0.036
Rank	2	1	3

Table 8: Response Table of S/N Ratios for Surface Roughness of Mild Steel

Level	Speed (RPM)	Feed rate(mm/rev)	Depth of cut (mm)
1	-14.598	-13.891	-8.581
2	-15.340	-10.761	-14.503
3	-8.683	-13.971	-15.538
Delta	6.657	3.210	6.957
Rank	2	3	1

Table 9: Response Table of S/N Ratios for Surface Roughness of CFRP 45⁰ Orientation Rod

Level	Speed (RPM)	Feed rate(mm/rev)	Depth of cut (mm)
1	-3.730	-4.960	-4.131
2	-4.008	-5.371	-4.405
3	-6.273	-3.680	-5.476
Delta	2.543	1.691	1.345
Rank	1	2	3

Table 10: Response Table of S/N Ratios for Surface Roughness of CFRP 90⁰ Orientation Rod

Level	Speed (RPM)	Feed rate(mm/rev)	Depth of cut (mm)
1	-5.208	-4.157	-4.885
2	-4.733	-4.908	-4.858
3	-4.470	-5.346	-4.668
Delta	0.738	1.190	0.217
Rank	2	1	3

V. Conclusions

On the basis of experimental results, calculated S/N ratios the following significant conclusions are drawn from the present work.

- From the Taguchi methodology, Minimum surface roughness of mild steel is obtained at 600 RPM speed, 0.15 mm/rev feed rate and 0.25 mm depth of cut.
- For CFRP of 45⁰ orientation rod optimum parameters for minimum surface roughness are 200 RPM speed, 0.20 mm/rev feed rate and 0.25 mm depth of cut.
- For CFRP of 90⁰ orientation rod optimum parameters for minimum surface roughness are 600 RPM speed, 0.05 mm/rev feed rate and 1 mm depth of cut.

Based on minimum number of experiments conducted to arrive at the optimum cutting parameters, Taguchi's seems to be an efficient methodology to find the optimum cutting parameter.

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