Lathe Parameters Optimization for UD-GFRP Composite Part Turning with PCD Tool by Taguchi Method

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Abstract: *The aerospace and automobile sectors are widely utilized the polymer composites. The composite materials, like unidirectional glass fiber reinforced polymer (UD-GFRP), is difficult to machine due to its anisotropic that is non-homogeneous character and such material requires special cutting tools. The proposed work is going to examine the tool wear, quality of the surface and forces generated in the various stages of inputs given to the machining of unidirectional glass fiber reinforced polymer (UD-GFRP) composites. The assessment of the machining incorporates tool wear investigations, surface roughness investigations and quality of material by varying input parameters. The Taguchi optimization technique with experimental design of L9 orthogonal array employed. The parameters range identified by trail runs and observations of conducted machining utilized for optimization. The Turning process parameters of cutting velocity or speed, rate of tool movement or feed rate and cutting depth on composite part or depth of cut were considered. The other factors, like tool material i.e., Poly-Crystalline Diamond (PCD) tool, its cutting regime (dry), profile of cutting tool are considered as constant parameters. The responses, like tool wear, surface finish, and cutting force, were measured against various input parameters, while machining the composite (UD-GFRP) composite part. The objective of this research is to establish relationship among various operating parameters to achieve desired results. That is major focus of the work on the economic condition for getting better values based on setting of input parameters.*

Key Words: *Lathe, PCD tool, UD-GFRP work, Taguchi optimization method, surface finish, dry cutting*

1. INTRODUCTION

Composites are used for the special purpose where good mechanical properties required as compared to the other metals. The composite material prepared out of two constituents like resin and fiber are made in plates and rods, which are used for the general purposes. The mechanical properties of the composites are superior than their individual material. The composite augment the stiffness, strengths enough to resist various loads/forces including the impact load. In the part of fibers, there are several fibers available, like glass fibers, aramid fibers and carbon fibers etc. The most common predictable fiber for polymer composites is the glass fiber as it has many success story with many polymer matrix composites in particularly

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with epoxy resin. Machining of composites is different from metal machining because fibers are pull out from the composite part. Composites are generally used for structures, water boat bodies, swimming pool sheets, vehicle bodies, shower backs off, showers, storing tanks and emulate stone nutsand bolts for light applications.

The most splendid cases perform routinely on transport and plane in requesting conditions. Now-a-days people are using concrete using drastically more than another human-made material. Around 7.46 billion cubic meters of material concrete is used each year. Alternatively composite bricks are utilized un the architecture industry, specially glass fiber composites, are utilized by automobile and aerospace industries.

Some of the machinability studies on UD-GFRP composite reported in the literature. [1] reported that, irrespective of cutting regime, the material removal rate and surface roughness are affected by the increase of values of input parameters and their contribution can be ranked as tool feed rate, tool depth, and velocity of cutting. [2] highlighted in his experimental results using carbide tool that, though additionally variables were considered, like rake angles of the tool, nose radius, the feed rate has a greater influence than other factors.

[3] reported that selection of cutting tool and compromising the feed rate are more important for obtaining desired surface finish. The low cutting force and good surface finish can be achieved in machining GFRP by means of single crystal diamond cutting tool. [4] experimented with carbon fiber reinforced polymer composite part with six different fiber orientations, by using uncoated carbide tip inserted turning tool and suggested that tool characteristics decide the tool life in machining such hard materials.

[5] reported that higher feed rate while machining Carbon fiber reinforced polymer (CFRP) causes excessive compressive which cause the effects of poor surface finish. And better surface quality can be achieved while machining polymer composites by setting high cutting speed for low feed rate. [6] employed with High speed steel tool at CNC lathe and found excessive tool wear while machining GFRP parts and suggested diamond and carbide tipped tools for machining them. [8] reported that the delimitation is root cause for difficult to cut issue in glass fibre reinforced polymer work material and the author suggested from his experimental findings that appropriate selection of cutting tool geometry and its material overcome issue and lead to achieve the excellent machining of glass fibre reinforced polymer parts. [9] suggested cemented carbide tools and PCD tools to machine glass fibre reinforced polymer parts. [10] optimized the drilling process parameters for glass fibre reinforced polymer parts. [11] optimized the design parameters as well as operating parameters in Turing unidirectional glass fiber reinforced composite material with tool insert of TAEGUTEC TCMT 16T304 MT T3000.

[12] experimented various GFRP fiber part’s angle orientation within the range of [30º-90º], with different tools like PCD, Cubic Boron Nitride (CBN) and Carbide (K-20) to develop a mathematical model which helps to predict the level process parameters for a desired response. This work focuses dry Turing process at lathe of UD-GFRP parts with PCD tool. The important factors like tool feed rate, tool depth while cut and velocity of cutting were opted by conducting the trial runs for preventing surface finish issues. The cutting force is considered as response is considered in this research.

2. MATERIALS AND METHODS

For understanding machining behavior the process parameters tool related parameters like feed speed and depth of cut were varied at 3 levels and responses measured in terms of surface roughness, tool forces. The process parameters setting details are furnished in Table 1. The unidirectional Glass fiber reinforced polymer (GFRP) parts of 20 mm diameter (Fig. 2) are produced by pultrusion process. The fabricated GFRP composite parts are cut into small segments of length 150mm and machined (Fig. 3 to Fig. 6) with the help of the CNC machine (Fig. 1) by changing input parameters (depth of cut, cutting speed and tool feed) and the cutting force estimated by the dynamometer of CNC Machine. After each trial, the wear of the tool is estimated by using the tool maker's microscope (Fig. 8). The composite parts are then positioned on roughness tester (Fig. 7) to find out surface roughness values. These resultant parameters are assessed by using the Taguchi and ANOVA in Minitab programming to find economical values with respect to given input values:

- Cutting parameters: cutting speed, feed rate, depth of cut,
- Regime parameters: dry condition,
- Cutting tool parameters: tool geometry, tool material,
- Work piece material: metals, composite materials

Table 1. The fixed and variable process parameters

Input parameters	Level 1	Level 2	Level 3
Depth of the cut in mm	0.5	1	1.5
Tool Feed in mm	0.05	0.1	0.15
Cutting speed in rpm (m/min)	1000 (1047.19)	1200 (1256.63)	1500 (1570.79)
Tool material	PCD	PCD	PCD
Tool rake angle in°	6	6	6
Cutting regime	Dry Condition	Dry Condition	Dry Condition

Fig. 1 – Super Jobber 500 type CNC Machine

Fig. 2 – UD-GFRP Composite part

Fig. 3 – Setup of UD-GFRP Composite job

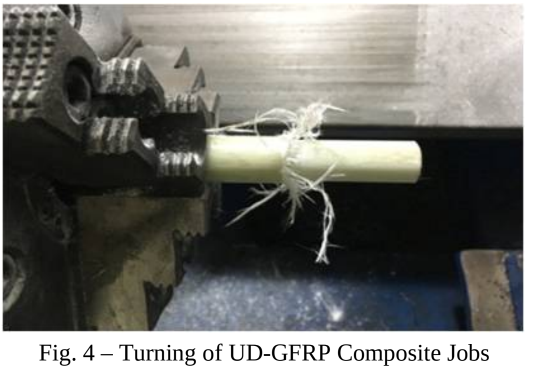

Fig. 4 – Turning of UD-GFRP Composite Jobs

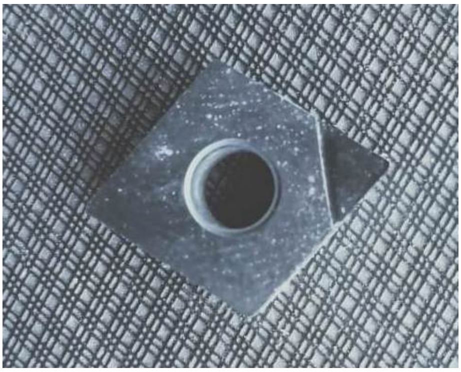

Fig. 5 – the PCD tool

Fig. 6 – CNC turned composite parts

Fig. 7 – Surface roughness tester

Fig. 8 – Toolmaker’s microscope

Table 2. Properties of Polycrystalline Diamond Tool

S.No	Description of Property/Feature	Specification
1	Clearance angle	6º
2	Hardness	1600 Vickers kg/mm^2
3	Grade	M10
4	Density (g/cm^3)	3.80 to 4.50
5	Thermal conductivity (W/m K)	150 to 550
6	Compressive strength (N/mm^2)	7000 to 8000
7	Thermal expansion coefficient (10% C)	3.2 to 4.6
8	Young's modulus (GPa)	800 to 900
9	Cutting edge inclination	6º
10	Front clearance	10
11	Tool rake angle	6º
12	Transverse rupture strength	1200...1700 N/mm^2
13	Tool nose radius	0.04 cm

The properties and specific features of UD-GRFP composite part are listed in the Table 2; similarly, the properties and specific features of Poly-Crystalline Diamond tool (PCD-Tool) composite part are listed Table 3.

The experimental setup and various operations tools and equipments used are photographically shown in Fig. 1 to Fig. 8.

3. EXPERIMENTATION

The turning of glass fiber reinforced composite part with PCD insert was examined by varying the process parameters. The cutting instrument was used as a part of directing the

Table 3. Properties of UD-GFRP Composite Part

S. No.	Description of Property/ Feature	Specification	Unit
1	Glass content (by weight)	75 ± 5	%
2	Tensile strength	-650	(N/mm^2)
3	Epoxy resin content (by weight)	25 ± 5	%
4	Reinforcement, unidirectional	‘E’ glass roving	E
5	Water absorption	0.07	%
6	Density	1.95 to2.1	g/cc
7	Shear strength	255	(N/mm^2)
8	Modulus of elasticity	3200	(N/mm^2)
9	Compression strength	600	(N/mm^2)
10	Weight of part 500 mm in length	1.6	Kg

Table 4. Taguchi experimental design (L9 Orthogonal array)

Exp No.	Cutting Speed (rpm)	Cutting Speed (m/min)	Tool Feed (mm/rev)	Depth of cut (mm)
1.	1000	1047.19	0.05	0.5
2	1000	1047.19	0.10	1.0
3	1000	1047.19	0.15	1.5
4	1200	1256.63	0.05	1.0
5	1200	1256.63	0.10	1.5
6	1200	1256.63	0.15	0.5
7	1500	1570.79	0.05	1.5
8	1500	1570.79	0.10	0.5
9	1500	1570.79	0.15	1.0

Table 5. Experimental Results

Exp No.	Speed (rpm)	Speed (m/min)	Feed (mm/rev)	Depth of cut (mm)	Average Tool wear (mm)	Average Surface Roughness (Ra)	Average Cutting Force (N)
1	1000	1047.19	0.05	0.5	0.14	0.163	0.16
2	1000	1047.19	0.1	1	0.09	0.125	0.10
3	1000	1047.19	0.15	1.5	0.2	0.175	0.19
4	1200	1256.63	0.05	1	0.07	0.090	0.04
5	1200	1256.63	0.1	1.5	0.3	0.148	0.17
6	1200	1256.63	0.15	0.5	0.59	0.410	0.58
7	1500	1570.79	0.05	1.5	0.05	0.051	0.06
8	1500	1570.79	0.1	0.5	0.2	0.234	0.22
9	1500	1570.79	0.15	1	1.12	0.090	1.87

Fig. 9 – Surface Quality (Ra)

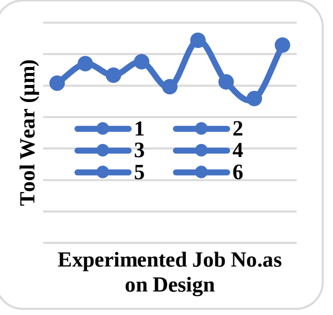

Fig. 10 – Average Tool Wear

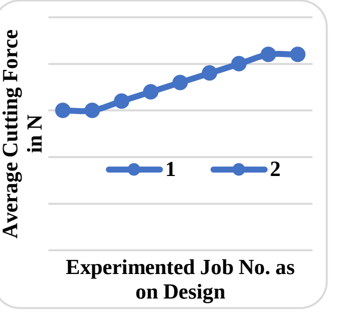

Fig. 11 – Average Cutting Force

different machinability tests.

The cutting instrument was used as a part of directing the investigations by PCD inserts. The UD-GFRP bar of 20 mm diameter and length of 1 m is taken and cut into small pieces of length 150mm.

These pieces are machined in Super Jobber 500 CNC (Siemens 802 D SL) and are presented in Fig. 3.

The Experiments were carried out as per Taguchi Experimental Design and concerned parts were named with is trial/ experiment number, as depicted in Table 4.

The observations of average surface quality in terms of average surface roughness value and depicted in the Fig. 9, similarly the average tool wear as well as average cutting force incurred responses observed and graphically furnished in the Fig. 10 and Fig. 11 respectively.

The three observations were done on each response and their average was considered for the analysis.

The average values of responses were considered and presented in Table 5.

4. RESULTS AND DISCUSSIONS

The MINITAB software utilized in identifying the impacts of variable process parameters like tool feed, depth of cut and cutting speed individually and collectively on the roughness of the surface, wear of tool wear and forces incurred while cutting have been created utilizing multiple regression model.

The analysis of variance (ANOVA) Taguchi L9 orthogonal array has been applied to consider the impact of the input parameters on its reaction, surface harshness, Tool wear and cutting forces.

4.1 Taguchi analysis for Ra

Figure 12 shows the mainly influencing parameters for roughness of surfaces. There are three parameters considered like speed, feed and depth of cut. The combination parameters speed of 1570.79 m/min (1500 rpm), Feed 0.15 and depth of cut 0.015 shows the less surface roughness .i.e., high surface finish.

Figure 13 is a S/N Ratio based main effects plot for surface roughness. Figure 13 shows good economical surface quality (in terms of Ra values), obtained at 1047.19 m/min (1000 rpm) of speed, with 0.15 cm depth of cut and 0.015 cm of tool feed.

This condition may be used for effective roughness values of machining process (Refer Table 6).

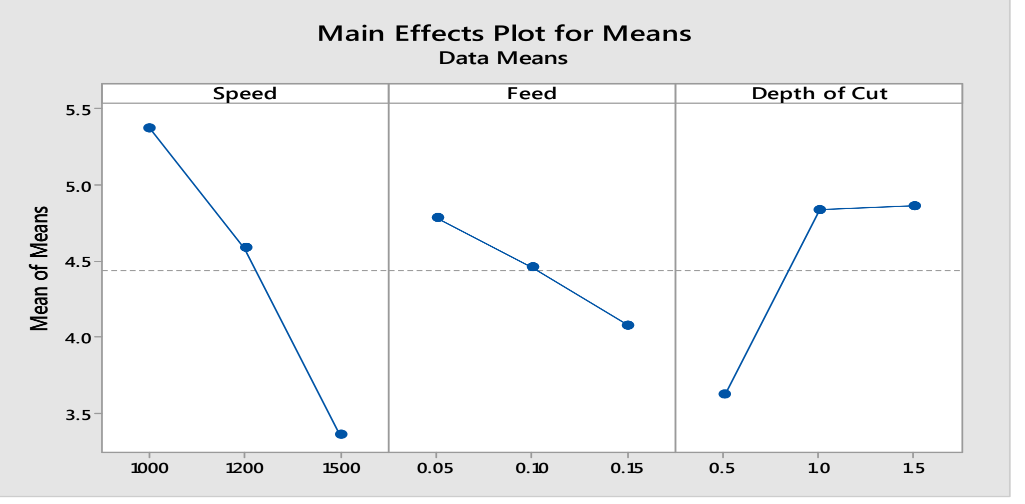

Fig. 12 –The means based main effects plot Tool wear

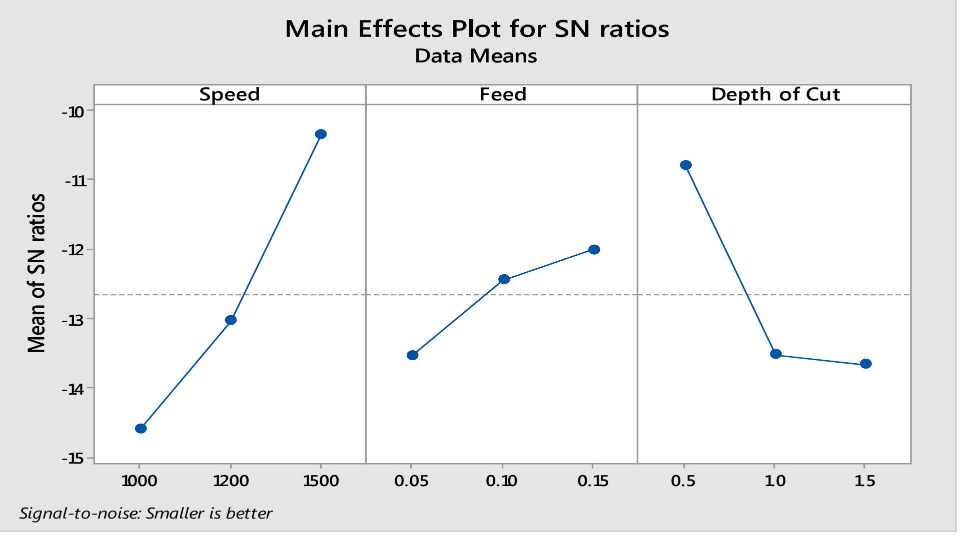

Fig. 13 – The S/N Ratio based main effects plot

Table 6. The Table of Response for S/N ratio

Stage	Cutting speed	Tool feed	Depth of cut
1	-14.6	-13.53	-10.79
2	-13.03	-12.44	-13.52
3	-10.35	-12.01	-13.67
Delta	4.24	1.53	2.87
Rank	1	2	3

4.2 Taguchi analysis for tool wear

Figure 14 shows the main effecting parameter of tool wear for different speed, feed and depth of cut is as speed for the 1047.19 m/min (1000 rpm) influencing more and speed of 1570.79 m/min (1500 rpm) is the good economical condition. The feed part parameter of 0.05 mm influences more and also the depth of cut of 1.5mm parameter influences more. Figure 15 shows the economical value for various parameters and Table 7 shows these values. The figure shows to getting good economical tool wear obtained at 1200 rpm of speed, 0.05 mm of depth and 1.5 mm depth of cut. This condition may be used for effective tool wear of machining process.

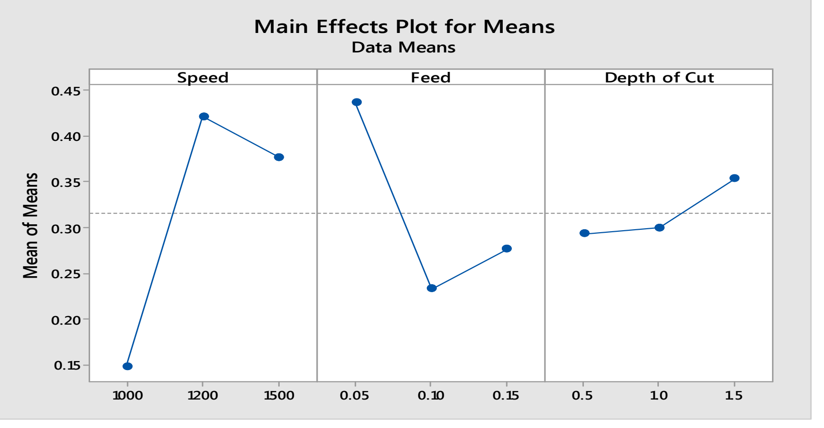

Fig. 14 – The Means based Main Effects Plot

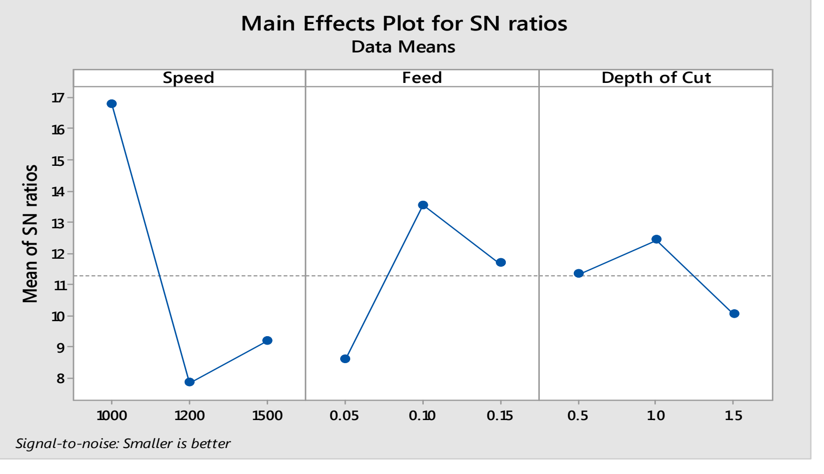

Fig. 15 – The S/N ratios based main effects plot

Table 7. The table of Response for S/N ratio

Stage	Cutting speed	Tool Feed	Depth of Cut
1	16.81	8.578	11.335
2	7.834	13.55	12.434
3	9.174	11.69	10.048
Delta	8.975	4.972	2.386
Rank	1	2	3

4.3 Taguchi analysis for cutting force

Figure 16 shows the economical for various parameter and response table shows the values. It also shows how to get good economical cutting force, as obtained at 1500 rpm of speed, 0.15 mm of depth and 0.5 mm depth of cut. This condition is used for effective tool wear of machining process.

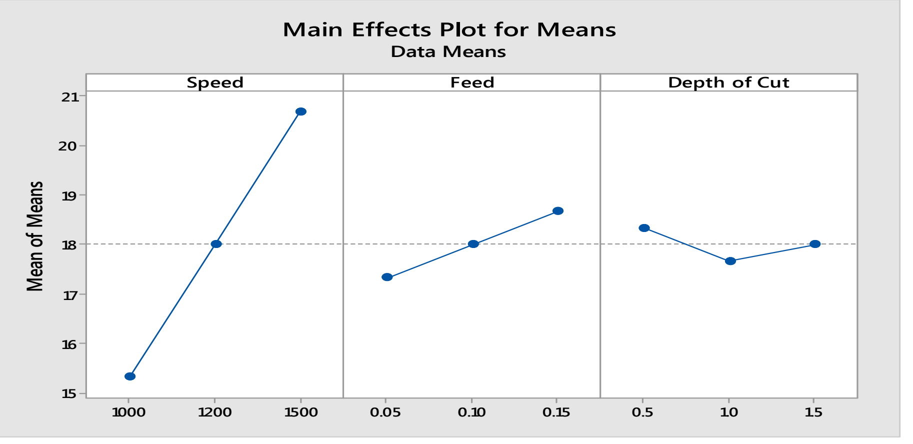

Fig. 16 – Means Based Main Effects plot

Figure17 shows the economic value for various parameters and the response Table 8shows the values. The figure shows how to get good economical cutting force, as obtained at 1000 rpm of speed, 0.05 mm of depth and 1.0 mm depth of cut. This condition may be used for effective economical cutting force of machining process.

Table 8. Response table for S/N ratio

Stage	Cutting speed	Tool Feed	Depth of Cut
1	-23.71	-24.71	-25.72
2	-25.1	-25.02	-24.86
3	-26.3	-25.37	-25.07
Delta	2.59	0.65	0.32
Rank	1	2	3

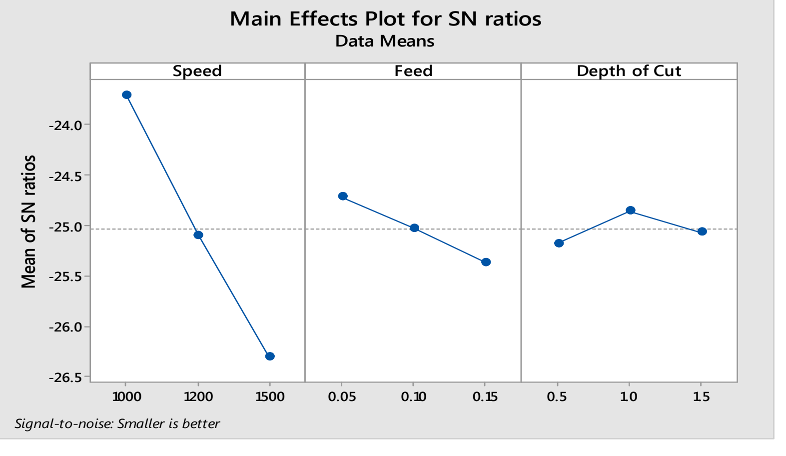

Fig. 17 –The S/N ratio based Main Effects plot

5. CONCLUSIONS

The paper illustrates the Taguchi optimization method based on process parameters optimization in turning of UD-GFRP composite CNC machine by using PCD tool. The experiment considered three basic parameters, at 3 different settings, and the remaining parameters, like cutting regime, tool profiles and tool material are kept constant. The experimental findings can be summarized as follows.

- The cutting forces on the UD-GFRP composites while CNC turning depends on the tool feed rate and cutting depth of the tool on the part. That is cutting force on UD-GFRP composites parts is directly proportional to the tool feed rate and the cutting tool depth on the part.
- The increase of process parameter values, like tool depth while cutting, cutting speed and tool feed rate, increases the roughness on surfaces in CNC turning of UD-GFRP composite parts, when cutting with PCD tool.
- The influence of cutting tool depth, in CNC turning of UD-GFRP composite part is found less.
- The cutting force is influenced by the process parameters in the descending order of tool feed, cutting speed and cutting depth.
- The tool wear is directly proportional to the cutting speed.
- Lower cutting force offers lower surface roughness value, as well as lower tool wear.
- But the intermediate range could be preferred for an economical machining.

The further investigation planned to investigate CNC Turning of UD-GFRP composite part with same PCD tool or with different hard tools under different cutting regimes, like wet, mist and cryogenic cooling regimes. Secondly, it is planned that more process variables to be included for further fine tuning of the results.

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