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DETERMINING OPTIMAL WORKING PARAMETERS OF GFRP COMPOSITE DURING TURNING OPERATION USING TAGUCHI & CONTROL CHART ANALYSIS

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ABSTRACT:

Metal cutting is one of the important and widely used manufacturing processes in Engineering Industries. Glass fibre reinforced polymer (GFRP) composite materials are a feasible alternative to engineering materials and are being extensively used in variety of engineering applications in the present days.

In any manufacturing processes engineering judgment is still relied upon to optimize the multi-response problems. In this context the experimental report targets the machining of GFRP as a work piece with poly crystalline diamond insert tool by using Taguchi methodology, various input parameters such as Spindle speed, feed rate and depth of cut and their importance in deciding the temperature distribution and cutting rate. The experimental program introduces a Tool-thermo couple setting can reduce the cost and which establishes the optimal processing regime. The paper also deals with the diseases that can be harmful to machine tool operator caused by exposure to Dust generation in machining. Finally, constraint functions due to respect of quality and to limiting cutting phenomena are evaluated using Control Chart Analysis.

KEYWORDS: *Tool-thermo couple, Taguchi, Control Chart Analysis, Infrared pyrometer.*

1. INTRODUCTION

Most engineering materials can be classified into one of four basic categories as metals, ceramics, polymer or composites Composite materials are two different materials that, when combined together, produce a material with properties that exceed the constituent materials[4]. Fiber-reinforced plastics (FRP) have been widely used in industry due to their excellent properties such as high specific modulus, specific strength and damping capacity. They are being commonly used in the aerospace and automotive industries, marine applications, sporting goods and biomedical components. The machining of fiber-reinforced materials requires special considerations about the wear resistance of the tool. High speed steel (HSS) is not suitable for cutting owing to the high tool wear and poor surface finish. The machinability of composite materials is influenced by the type of fiber embedded in the composites, and more particularly by the mechanical properties.

Lee (2001) investigated the machinability of glass fibre reinforced plastics by means of tools [2]-made of various materials and geometries. Three parameters, namely cutting speed, feed rate and depth of cut, were selected. Single crystal diamond, poly crystal diamond and cubic boron nitride were used for the turning process. It was concluded that the single crystal diamond tool is excellent for GFRP cutting. Dhavamani and Alwarsamy (2011) presented a new methodology for Optimization of cutting parameters of composite materials using genetic algorithm. Taguchi's method was used for the experimental design [9]. Three parameters, cutting speed, feed and diameter of cut, were selected to minimize the surface roughness, volume fraction, machining time, metal removal rate, specific energy and flank wear. It was found that the machining performance can be improved effectively through this approach. Kumar et al. (2012) investigated the turning process of the unidirectional glass fibre reinforced plastic (UD-GFRP) composites [10].

A polycrystalline diamond (PCD) tool on the turning machine was used and the influence of six parameters, tool nose radius, tool rake angle, feed rate, cutting speed, depth of cut and the cutting environment (dry, wet and cooled (5-7° temperature)), on the surface roughness was measured. It was found that the feed rate is the factor which has the greatest influence on surface roughness, followed by cutting speed.

Palanikumar, Latha, Senthilkumar and Karthikeyan (2009) investigation focused on the multiple performance optimizations of machining characteristics of glass fibre reinforced plastics composites by using a non-dominated sorting genetic algorithm[5]. Three parameters, cutting speed, feed rate and depth of cut, were selected to minimize the surface roughness and tool flank wear and to maximize the material removal rate. A polycrystalline diamond tool was used for the turning operation.

Hussain et al. (2010) developed a surface roughness prediction model for the machining of GFRP pipes using a response surface methodology by using a carbide tool (K20). Four parameters, cutting speed, feed rate, depth of cut and work piece (fiber orientation), were selected to minimize the surface roughness[7]. It was found that the depth of cut has the least effect on the surface roughness compared to the other parameters.

A damkhan et al. (2011)have carried out machining studies on GFRP composites using two alumina cutting tools. The machining process was performed at different cutting speeds at constant feed rate and depth of cut[8]. The performance of the alumina cutting tool was evaluated by measuring the flank wear and surface roughness of the machined GFRP composite material.

As seen from the literature, only limited work has been carried out on the machinability aspects of Glass fiber Reinforced Plastics (GFRP) composites. Thus, this present work aims at investigating the effects of spindle speed, feed and depth of cut on some aspects of machinability of GFRP composites. In the present investigation, the machinability aspects have been evaluated in terms of cutting rate and temperature distribution during the turning of GFRP composites using PCD tool has been analyzed by Taguchi and Control chart analysis.

2. MATERIAL & EXPERIMENTALTECHNIQUE

2.1. Work material

The work material used for the present investigation is glass fibre reinforced plastics (GFRP) bar. The diameter of the work piece is 32 mm and length 320 mm respectively shown in Figure 1. The fiber used in the pipe is E-glass and resign used is epoxy. The important properties of the material used in this work are given in Table 1.

Table 1. Specifications of fiber and resign

Fiber: type	E-glass – R099 P556
Manufacturer	Saint Gobain vetrotex India Ltd.
Content	Alumina-borosilicate glass
Linear Density,	2.58(g/cm3)
Tensile strength	3445(MPa)
Compressive strength	1080(MPa)

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Fig 2.1: GFRP Composite bar Specimens

2.2 Tool Materials

Poly crystalline diamond tool: CNMG (with rake angle 5-6 degree). PCD tools maintain thermal stability and hardness levels in higher temperature applications. Diamond also has high strength, good wear resistance, and a low friction coefficient. It allows faster speeds and feed when compared to any other conventional tools.

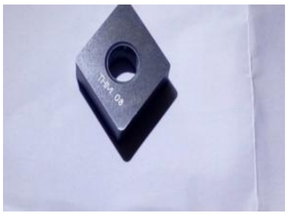

Fig 2.1: PCD cutting insert

2.3 Machine tool setup: The experiments were carried out on manually operated lathe of series TURN MASTER 40 (manufactured by Mysore kirloskar India limited, India) machine tool.

Fig 2.3: TURN MASTER-40 Engine Lathe

Code	Control factors	Levels		
		1	2	3
A	Spindle Speed, s (rpm)	630	1000	1600
B	Feedrate, f(mm/rev)	0.10	0.14	0.20
C	Depth of cut, d (mm)	0.5	0.7	1.0

2.4 Design of Experiments

The experimental strategy frequently practiced by the industries is one factor at-a time approach in which the experiments are carried out by varying one input factor and keeping the other input factors constant. This approach fails to analyze the combined effect, when all the input factors vary together which simultaneously govern the experimental response. Designed experiments can be used to systematically investigate the process or product variables that influence product quality.
Table4.2: Process parameters and DOE

Taguchi techniques have been used widely in engineering and scientific community because they are easy to adopt and apply for users with limited knowledge in statistics [13, 14]. An orthogonal array provides a set of well-balanced experiments in which factor levels are weighted equally across the entire design.

Table 4.5: Taguchi Matrix Design

Run	Speed (rpm)	Feed (mm/rev)	Depth of cut (mm)
1	630	0.10	0.50
2	630	0.14	0.70
3	630	0.20	1.00
4	1000	0.10	0.70
5	1000	0.14	1.00
6	1000	0.20	0.50
7	1600	0.10	1.00
8	1600	0.14	0.50
9	1600	0.20	0.70

2.5 EXPERIMENTATION

The experiments were accomplished on a TURN MASTER-40 conventional Lathe machine. With L9– orthogonal array. In this set-up, the work piece is fixed in chuck and the cutting tool is connected to the thermocouple by using a heating coil and by using pyrometer the temperature of the work piece can be known by changing the speeds according to the depth of cut and feed.

After each trail the final diameter of the bar measured by using digital Vernier calipers for finding the metal removal rate and temperatures of the work piece and cutting tool by using thermocouple and pyrometer as shown in Fig:(2.4 & 2.5) and determine the metal removal rate by using following formulae.

MRR = π*L*d*D/time mm^3/min
d = initial dia-final dia /2 (mm)
D = initial dia-final dia /2 (mm)

While performing the experiments, the following precautionary measures were taken:
1. To reduce error due to experimental set up, each experimental MRR was recorded with three times of average in each of the trial conditions. 2. The order and replication of experiment was randomized to avoid bias, if any, in the results.

3. METHODOLOGY

Engineers do a variety of activities such as developing new products, improving previous designs, maintain, controlling and improving on-going manufacturing process and repairing products, among others. As experimentation is a frequent task in those activities, engineers end up using statistics regardless of their background in it. Therefore the issue is not whether they use statistics or not, but how good they are at it. The aim of this paper is to stimulate the engineering community to apply an efficient technique to experimentation.

3.1 Method of measurements

Infrared Pyrometer

A pyrometer is a type of remote-sensing thermometer used to measure the temperature of a surface (fig: 3.1). The tool-chip interface temperature was measured using an infrared pyrometer. This technique is likely the most suitable in turning where high temperatures can be captured easily as there is no direct contact with the heat source.

Run	Speed (rpm)	Feed (mm/min)	DOC (mm)	MRR (mm3/min)	TD °C
1	630	0.1	0.5	0.38	0.82
2	630	0.14	0.7	0.8788	0.70
3	630	0.2	1	1.6542	0.67
4	1000	0.1	0.7	1.1472	0.64
5	1000	0.14	1	1.9054	0.53
6	1000	0.2	0.5	0.9508	0.75
7	1600	0.1	1	2.1605	0.50
8	1600	0.14	0.5	1.6634	0.62
9	1600	0.2	0.7	3.5142	0.53

Fig: 3.1: Infrared pyrometer

Thermocouple

Commercial Thermocouples are widely used in science and industry. These are inexpensive, interchangeable, are supplied with standard connectors, and can measure a wide range of temperatures (fig: 3.2). In contrast to most other methods of temperature measurement, thermocouples are self-powered and require no external form of excitation. The main limitation with thermocouples is accuracy; system errors of less than one degree Celsius (°C) can be difficult to achieve.

Fig 3.2: Thermocouple mounting

4. Results and Analysis

Based on orthogonal array of L_9 the experiments were conducted to predict the material removal rate (MRR) and temperature distribution the main objective of this experiment is to predict the better operating conditions and also the influence of each parameter is evaluated.

Table 4.1 Experimental results for MRR and TD

4.1. Taguchi Analysis

Therefore the experiments are conducted with cutting tool poly crystalline diamond on GFRP composite material. From the experimental data Taguchi analysis is carried out which is explained as follows.

Analysis of material removal rate (MRR)

Table 4.1: Response table for S/N ratio

Level	Speed (rpm)	Feed (mm/min)	Doc (mm)
1	-1.7183	-0.1735	-1.4742
2	2.1181	2.9658	3.6622
3	7.3424	4.9499	5.5542
Delta	9.0606	5.1233	7.0284
Rank	1	3	2

Table 4.2: Response Table for means

Level	Speed (rpm)	Feed (mm/min)	Doc (mm)
1	0.9710	1.2292	0.9981
2	1.3345	1.4825	1.8467

3	2.4460	2.0397	1.9067
Delta	1.4750	0.8104	0.9086
Rank	1	3	2

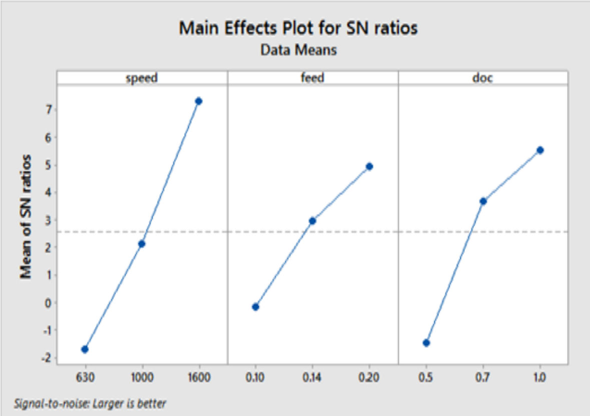

Fig 4.1: main effects Plots for S/N ratio

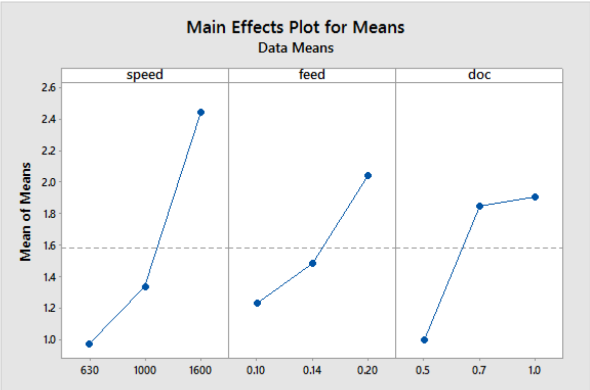

Fig 4.2: main effects Plots for means

The response tables (4.1 and 4.2) shows the average of each response characteristic (S/N data, means) for each level of each factor. The tables include ranks based on delta statistics, which compare the relative magnitude of effects. The delta statistic is the highest minus the lowest average for each factor. Minitab assigns ranks based on delta values; rank 1 to the highest The ranks and the delta values show that speed have the greatest effect on material removal rate and is followed by depth of cut, feed in that order. As MRR is the "higher the better" type quality characteristic, it can be seen from Figure 4.1 that the third level of speed (A3), third level of feed (B3), third level of depth of cut (C3), provide the best levels for maximum material removal rate in Dry turning process.

Analysis of Temperature distribution (TD)

Table 4.3: Response table for S/N ratio

Level	Speed	Feed	Doc
1	2.767	3.874	2.792
2	3.963	4.255	4.163
3	5.229	3.831	5.005
Delta	2.462	3.831	2.213
Rank	1	3	2

Table 4.4: Response Table for means

Level	Speed	Feed	Doc
1	0.7300	0.6533	0.7300
2	0.6400	0.6167	0.6233
3	0.5500	0.6500	0.5667
Delta	0.1800	0.0367	0.1633
Rank	1	3	2

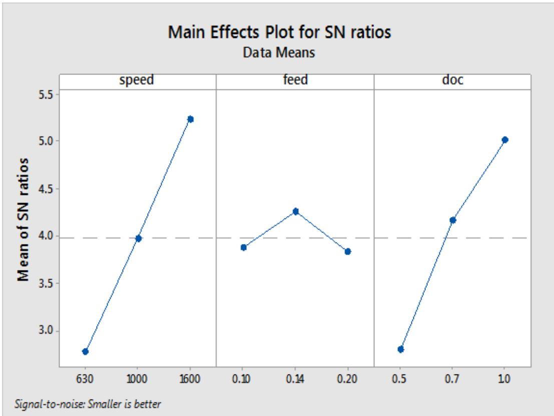

Fig 4.3: main effects Plots for S/N ratio

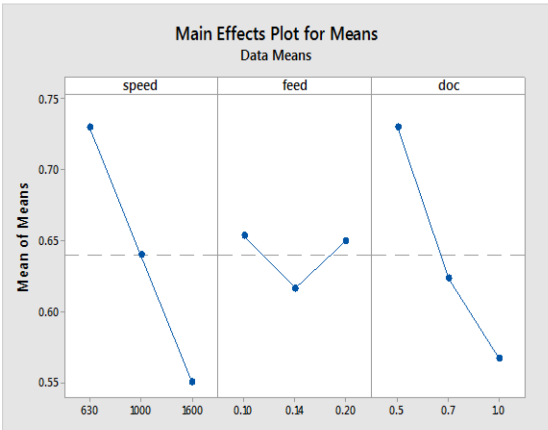

Fig 4.4: main effects Plots for means

Response tables and plots for means and S/N ratio have been developed with the help of MINITAB software. As TD is the "Smaller the better" type quality characteristic, it can be seen from Figure 4.3 that the first level of speed (A1), third level of feed (B3), firs level of depth of cut (C1),provide the best levels for temperature distribution.

Table 4.5: **Optimum Level Combinations**

Output characteristics	Optimal set condition
MRR	1600, 0.20, 1.0
TD	630, 0.20, 0.5

4.2 Control chart Analysis

A control chart is a simple graphical device for knowing, at a given instance of time, whether or not a process is under control. The statistical data can be divided into: (1) variables data , a dimension of a part measured such as diameter and length, temperature in degree centigrade, weight in Kgs. and (2) Discrete data, No. of defective pieces found in a sample, tubes having cracks, etc.

Control Charts for Variables: These charts are used for the quality characteristics which are specified as variables, i.e., on the basis of actual readings taken. The mainly used variable charts are X -chart and R –chart. The present work is enough to analyze by using Range chart. Table 4.4: Upper control limit & lower control limit

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Control limits	MRR	TD
UCL	0.171889	0.105156
LCL	0.017	0.0104

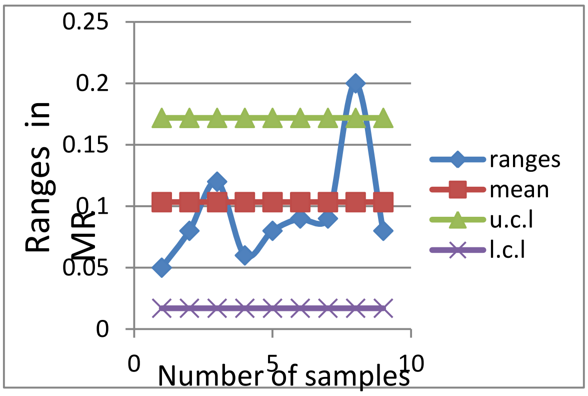

Fig.4.5: Range plot for material removal

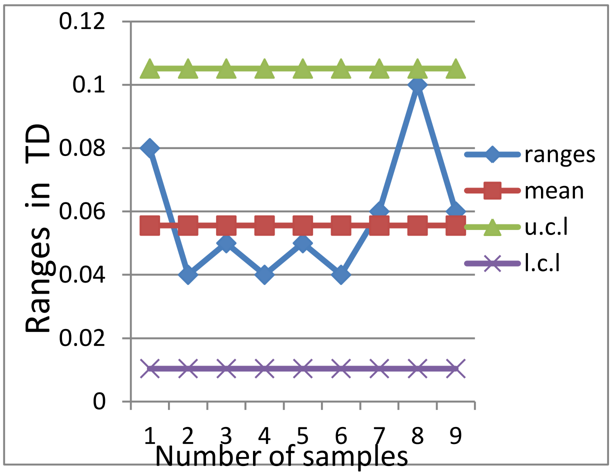

Fig.4.5: Range plot for temperature distribution

Draw the centre horizontal line of the graph with value equal to average of ranges (R), Draw the UCL and LCL horizontal lines above and below average (R). Plot the points R of all the samples in the graph and join all the successive points to obtain the chart (refer table4.4).Ranges of MR/TD is within the control limit (LCL<MR/TD<UCL) then the process is in control.

5. CONCLUSIONS

The experimental tests conducted to turn GFRP composite material by using PCD tool at three levels by employing Taguchi technique to determine the optimal levels of parameters. The results revealed that the speed is the significant one followed by the depth of cut for material removal rate and temperature distribution. The optimal value for maximum MRR and TD is obtained at A3-B3-C3 = 3.2236 mm^3/min and A1-B2-C1 = 0.83 degree centigrade.

The test data is multivariate and it arises-quality control problems, when monitored with two or more related quality variables. The applied control chart analysis detects abnormal process behaviour with the process is out of control due to in-significance of feed rate. Also, during the machining, the fibre glass dust to be reasonably anticipated as human carcinogen i.e. inhalable and irritate the eyes, skin.

6. FUTURE SCOPE

Although the machining has been thoroughly investigated for GFRP work material, still there is

a scope for further investigation. The following scope may prove useful for future work:
1. The effects of machining parameters on recast layer thickness and overcut should be investigated. 2. Efforts should be made to investigate the effects of process parameters on performance measures in a cryogenic cutting environment. 3. The weightages to be assigned to various characteristics in multi response optimization models should be based upon requirements of industries.

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