Investigation on Achieving Optimum Surface Roughness by Optimizing Variable Machining Conditions in Turning GFRP Composite Using Taguchi Method and ANOVA

Md.Shafiul Alam, Ahmed Yusuf, Abir Rahman, Inzamam-ul-haq

Abstract— The accuracy of achieving required surface finish or surface roughness is of great importance in case of any mass production environment. Thus, understanding and recognizing the optimal process parameters for machining is the key to achieving the required surface roughness and gaining competitive advantage. This research is concerned with obtaining the optimal machining process parameters (cutting speed, depth of cut, feed) which will in turn effect in optimizing the surface roughness in turning glass fiber reinforced polymer (GFRP) matrix composite using coated carbide insert. To find the optimal machining process parameters Taguchi design method has been implemented. An L-16 orthogonal array, signal to noise ratio and ANOVA have been implemented to analyze and understand various process parameters in determining possible relationship with surface roughness. The optimum surface roughness value for this experiment is (3.664μm) which is obtained from Taguchi design method. The results from ANOVA conclude that feed is the most influential factor affecting the outcome having a contribution of (56.04%). And the contributions of depth of cut and cutting speed are separately in order of (17.94%) and (16.42%) respectively. This research provides optimal process parameters for any desired value of surface roughness which results in gaining a competitive edge over others in any mass production environment.

Index Terms— ANOVA, Interaction plot, Randomly oriented GFRP, Surface roughness, S/N ratio, Taguchi design, Turning.

1 Introduction

IN this era of intelligent as well as modern engineering and technology, the prospect of utilizing the appropriate use of composite material in various field of engineering is immense. The reason behind having such level of possibilities in this field is that it has incredible material properties that can't be achieved by most of the elements and in some cases none. These excellent properties include high stiffness, high specific strength, light weight, high specific modulus compared to metals and so on. Composite materials are in general made of two separate phases namely fiber and matrix. Each constituent phase has significantly different physical or chemical properties or both that when combined; produce a material with characteristics different from the individual components and better than the individual phases. The types of composite material are pretty vast and GFRP is one of them. Glass fiber reinforced polymer matrix composite material is one of the most frequently used materials in engineering sector. The reason behind this is that it has high strength to weight ratio, high fracture toughness, excellent corrosion and thermal resistance. It is widely used in numerous applications which includes automobiles, aircrafts, space shuttle fuselage, house building, piping, machine tools, storage tanks, robots etc. Due to its superior material properties, numerous applications and low cost, the demand of GFRP is increasing day by day and it will do so for the rest of the days to come. Glass fibers fall into two categories, general purpose fibers and premium or special purpose fiber. Over 90% of all the products made of glass fiber are general purpose fiber. These fibers are known by the designation of E-Glass fiber and are subjected to ASTM specifications. The orientation of glass fiber has no effect on the hardness of the GFRP composite. Difference in orientation has little effect on the density and the impact strength of the composite materials because of the difference in the number of strands per unit area. The greater the volume fraction of fibers means the more strength and stiffness of the composite. Increasing the length of fiber will result in strengthening the structure of the composite material.

The machining of GFRP isn't the same as the conventional materials because it is anisotropic in nature (structure). The level of surface roughness of turned materials depends upon the type of fiber, matrix and the other binding elements. Thus maintaining the product quality in turning GFRP is more difficult than the conventional materials. Surface Roughness and dimensional accuracy are the major factors needed to predict the machining performances of any machining operation [1]. So identifying and understanding the required machining parameters for optimum surface roughness is crucial in determining the quality of the machining operation, thus determining the quality of the product as well. Most of the Surface Roughness prediction models are empirical and they are generally based on experiments conducted in the laboratory. Also it is difficult

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in practice, to keep all factors under control as required to obtain the reproducible results [2]. Optimization of machining parameters increases the utility for machining economics and also increases the product quality to a greater extent [3]. Davimetal [4] studied the influence of cutting parameters on surface roughness in turning glass-fiber reinforced plastics using statistical analysis. The users of FRP are facing so many difficulties when machining it, because technical back ground acquired for conventional materials cannot be applied for such new materials, whose ability in machining is different from that of conventional materials. Thus it is desirable to experimentally investigate the behavior of FRPs during the machining process [5]. Everstine and Rogers [6] proposed an analytical approach of machining FRPs. In their study, they developed a theory of plane deformation of incompressible composites reinforced by strong parallel fibers. Koplevetal [7] studied on the fiber orientation significance on the quality of machined surfaces and tool wear rate. Machining of composite materials depends on the type of fiber inserted in the composites, particularly by the mechanical properties. Thus, the selection of parameters and tool are dependent on the type of fiber inserted in the composites and which is very important in the machining process. Ramuluet al [8] carried out a study on machining of polymer composites and concluded that increment in cutting speed gives good surface finish.

Dr. Genichi Taguchi's approach of finding which factors effect a product in a Design of Experiments can dramatically reduce the number of trails required to gather necessary data. Essentially, traditional experimental design procedures are too complicated and not easy to use. A large number of experimental works have to be carried out when the number of process parameters increases. To solve this problem, the Taguchi method uses a special design of orthogonal arrays to study the entire parameter space with only a few numbers of experiments [9]. Taguchi methods [10] have been widely utilized in engineering analysis and consist of a plan of experiments with the objective of acquiring data in a controlled way, in order to obtain information about the behavior of a given process. The greatest advantage of this method is the saving of effort in conducting experiments; saving experimental time, reducing the cost, and discovering significant factors quickly. Taguchi’s robust design method is a powerful tool for the design of a high-quality system. The Taguchi method is a structured approach for determining the best combination of inputs to produce a product or service. Taguchi technique refers to the Parameter Design, Tolerance Design, Quality Loss Function, Design of Experiments using Orthogonal Arrays and Methodology applied to evaluate measuring systems [11]. Pignatiello [12] has identified two different aspects of Taguchi technique 1) The strategy of Taguchi 2) Tactics of Taguchi. Palanikumar et al [13] developed a procedure to asses and optimize the chosen factors to attain minimum surface roughness by incorporating Taguchi method and analysis of variance (ANOVA) technique.

In this present research, Taguchi design method has been implemented to analyze and understand the effects of various process parameters individually as well as generally on surface roughness in turning GFRP composite material. The factors that were considered in this experiment are cutting speed, feed and depth of cut. Taguchi's L-16 orthogonal array has been employed to layout the experimental data as per levels and factors are considered.

2 Experimental Setup

TABLE 1
EXPERIMENTAL CONDITIONS

Work piece material	GFRP (glass fiber reinforced polymer) matrix Composite (E-glass fiber, Mat type-randomly oriented) Composition- Fiber: 10% , Matrix: 90% Resin: POLYMAL (Unsaturated Polyester resin) 8313WP (NON-UV) Manufacturer: Luxchem Polymer Industries SDN, BHD.
Length of the material	300mm (Initial)
Diameter of the material	100mm (Initial)
Machine	Universal Lathe Machine Model: (CS6266B) Manufacturer: Baoji Zhongcheng Machine Tool Co. Ltd.
Cutting tool	Coated Carbide Insert
Measuring Instrument	Surface Roughness Tester Phase-II SRG-4500, Portable Tracing speed: 0.5 mm/s (length 0.8 mm) Accuracy: <- ±10% Pick-up-stylus: Diamond
Environment	Dry

2.1 EXPERIMENTAL PROCEDURE

This experiment has been executed using Universal Lathe Machine. Glass fiber reinforced plastic composite has been used as work material. After measuring its dimensions, the work piece is mounted on the 3-jaw self-centering chuck of Universal Lathe Machine. Then RPM, feed and depth of cut are being set to initiate the turning process. Now the turning operation has been done in 4-steps. For each step the RPM and feed is changed for a single value of depth of cut. After finishing each step for all the values of RPM and feed, the amount of depth of cut is changed for the next step. But before starting the machining of the next step, the surface roughness of several conditions of this step is measured via Surface roughness tester. The experiment completes after finishing all 4-steps. No cutting fluid is used in this experiment as the condition which is considered is only dry.

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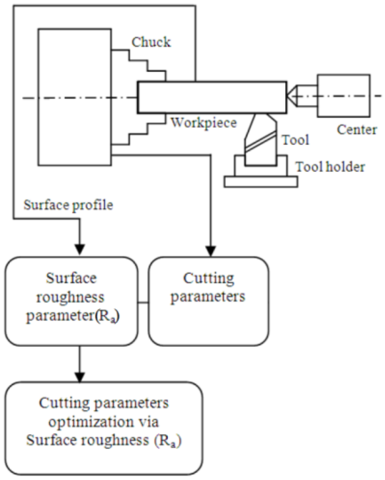

Fig. 1. Schematic Diagram of Experimental Setup of Turning Operation.

3 Experimentation as per Taguchi

The goal of this research is to investigate the effects of cutting parameters on the surface roughness and determine the optimal machining parameter for future applications. A Design of experiments based on Taguchi technique has been used. An orthogonal array, Signal to noise (S/N) ratio and analysis of variance (ANOVA) are employed to investigate the characteristics of surface roughness of glass fiber reinforced polymer (GFRP) composite material using coated carbide insert.

The orthogonal array forms the basis for the experiment analysis in the Taguchi method. It helps to reduce the testing cycle time and analysis in mere. The selection of orthogonal array is concerned with the total degree of freedom of process parameters. The orthogonal array should be greater than or at least equal to that of the process parameters. L16 orthogonal array has been considered where degree of freedom is equal to (16-1=15) 15. But in present case each experiment is conducted four times, therefore total degree of freedom is equal to (16X4-1=63) 63. The machining parameters and their levels, experimental results are depicted in table 2

TABLE 2
Parameters and Levels

Symbol	Parameters	Units	Level 1	Level 2	Level 3	Level 4
A	Cutting Speed	RPM	320	500	630	800
B	Feed	mm/rev	0.1	0.14	0.17	0.20
C	Depth of Cut	mm	0.5	1.0	1.5	2.0

Table 3
Responses observed as per Taguchi design

Trial No	Cutting Speed (A) RPM	Feed (B) mm/rev	Depth of Cut (C) mm	Avg. Surface Roughness (Ra) µm
1	320	0.10	0.5	1.470
2	320	0.14	1.0	2.114
3	320	0.17	1.5	2.714
4	320	0.20	2.0	3.443
5	500	0.10	1.0	2.356
6	500	0.14	0.5	2.492
7	500	0.17	2.0	2.895
8	500	0.20	1.5	3.739
9	630	0.10	1.5	2.457
10	630	0.14	2.0	3.074
11	630	0.17	0.5	2.680
12	630	0.20	1.0	2.732
13	800	0.10	2.0	2.611
14	800	0.14	1.5	3.051
15	800	0.17	1.0	2.939
16	800	0.20	0.5	3.532

In Taguchi Method, S/N ratio stands for the mean (signal) to standard deviation (noise); derived from the quadratic loss function. The formula used to compute S/N ration depends on the objective function. Generally three standard S/N equations are widely used to classify the objective function as, 'larger the better', 'smaller the better' or 'nominal the best'. In the present study, surface roughness is a 'smaller the better' type of quality characteristics since the goal is to optimize the Avg. surface roughness. The standard S/N ratio computing formula for this type of response is-

$$\eta = -10 \log 1/n \sum_{i=1}^{n} yi^2 \qquad (1)$$

Where 'yi' is the value of avg. surface roughness for the *i*-th test to obtain optimal cutting performance and 'n' is the number of trials.

4 Results & Discussions

TABLE 4
S/N Ratio Table

Level	Cutting Speed (A) (RPM)	Feed (B) (mm/rev)	Depth of Cut (C) (mm)
1	-7.315	-6.734	-7.700
2	-9.016	-8.469	-8.010
3	-8.714	-8.958	-9.406
4	-9.587	-10.471	-9.515
Delta	2.273	3.737	1.815
Rank	2	1	3

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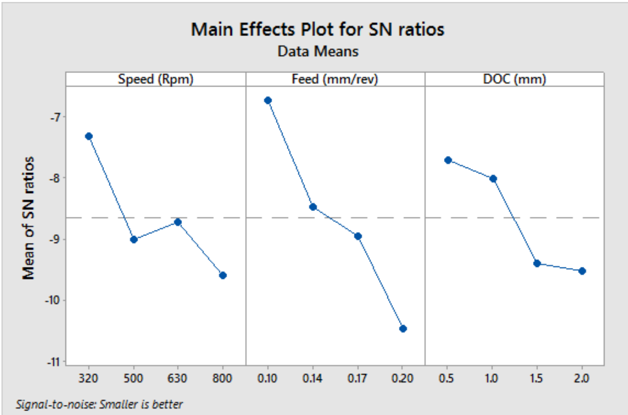

Fig. 2. Taguchi Response Graph

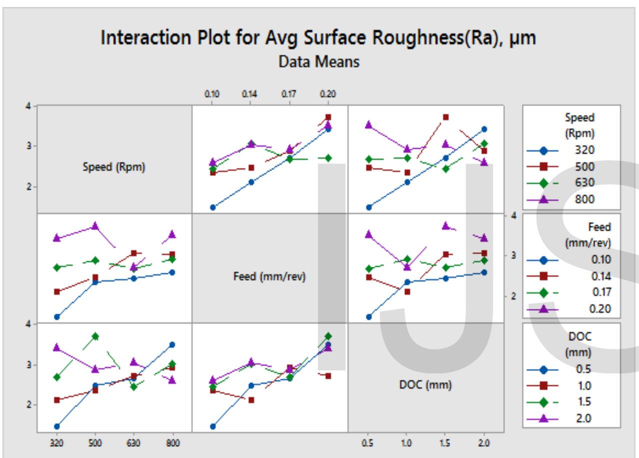

Fig. 3. Interaction Plot for Surface Roughness

From Table 4 of main effect plot for S/N ratio, it is observed that feed has the significant influence out of all parameters and then Cutting speed and Depth of cut both have moderate influence on avg. surface roughness during turning of GFRP composite material. From fig 2 of the main effect plot, it can be observed that the optimum combination parameters for surface roughness are A1B1C1 corresponding to the highest values of S/N ratio. It should be noted that the main effect plot for S/N ratio shows three graphs (for speed, feed and depth of cut) and no one is of linear shape with increasing or decreasing trend. So, we cannot draw a proper conclusion for optimal combination of process parameters from the main effect plot for S/N ratio.

Rather from fig 3 of Interaction Plot for Average Surface Roughness, it will be more appropriate to draw a conclusion for the optimal parameters combination for surface roughness. Interaction plot for average surface roughness shows that A2B4C3 is the optimal combination of parameters for surface roughness. Finally, from the Taguchi Model these optimal combination of parameters result the Avg. Surface Roughness (3.68487µm) with a very negligible error (1.47%) from the Experimental value (3.739µm).

TABLE 5
OPTIMUM VALUES OF MACHINING CHARACTERISTICS

Machining Characteristics	Optimal Combination of Parameters	Predicted Value from Taguchi Model	Experimental value	Error
Avg. Surface Roughness, Ra	A2B4C3	3.68487 µm	3.739 µm	1.47%

5 CONFIRMATION TEST

The purpose of the analysis of variance (ANOVA) is to investigate which design parameter significantly affects the quality characteristic. ANOVA is a general technique that can be used to test the hypothesis that the means among two or more groups are equal by comparing the variance at a specific confidence level. An ANOVA table contains the sources of variation, Degrees of freedom, Sum of squares, Mean square, the F-statistic, and sometimes the P-value. F-value is the test statistic used to determine whether the term is associated with the response and P-value is the probability that measures the evidence against the null hypothesis.

TABLE 6
ANOVA FOR AVERAGE SURFACE ROUGHNESS

Source	DF	Seq SS	Contribution	Adj SS	Adj MS	F Value	P Value
Speed	3	0.7705	16.42%	0.7705	0.25683	3.42	0.093
Feed	3	2.6300	56.04%	2.6300	0.87668	11.68	0.006
DOC	3	0.8420	17.94%	0.8420	0.28065	3.74	0.080
Error	6	0.4505	9.60%	0.4505	0.07509		
Total	15	4.6930	100%				

TABLE 7
MODEL SUMMARY

S	R^2	Adj-R^2	Press	R^2(Pred)
0.274018	90.40%	76%	3.20367	31.74%

In table 6 and table 7,
DF= Degree of freedom,
Seq SS= Squential Sums of Squares,
Adj SS= Adjusted Sums of Squares,
Adj MS= Adjusted Mean Squares, S= Standard Deviation.

The analysis of variance (ANOVA) of the experimental data was done to statistically analyze the relative significance of the parameters under the investigation on the response variable. From Table 6, it is observe that feed has physically and statisti-

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cally most significance (56.04%) on the surface roughness average obtained in turning of GFRP with standard coated carbide insert tool. Depth of cut &Cutting speed factor has moderate significance of (17.94%) and (16.42%) respectively.

6 Concluding Remarks

This research has discussed an application of the Taguchi Method for investigating the optimum surface roughness of GFRP composites under variable machining (turning) condition using lathe machine. Here, Taguchi gives systematic approach and efficient method for determining the optimum operating conditions for generating optimum surface roughness of GFRP composite under variable machining condition. From the analysis of the results of the present study in turning process using the conceptual S/N approach, Taguchi Method and ANOVA technique, the following can be concluded-

- Based on (Design of Experiment) DOE, the Taguchi method has been performed using L16 orthogonal array to analyze the surface roughness as response variable. Conceptual S/N ratio and ANOVA approach for data analysis draws almost similar conclusion.

- Main effect plot for S/N ratio suggest's for optimal combination of parameters as A1B1C1 (taking the highest value).But interaction plot for average surface roughness concludes more appropriate optimal combination of parameters as A2B4C3. Therefore, suggested optimal combination for cutting parameters from this research has been set to A2B4C3 (cutting speed=500 RPM, feed rate=0.2 mm/rev, depth of cut=1.5mm). It results the Avg. Surface Roughness 3.68487µm with a very negligible amount of error 1.47% from the Experimental value of 3.739µm.

- From the response table, it is observed that feed is the most influential parameter that affects the surface roughness and then cutting speed and depth of cut have similar effect on it but have much less influence then feed. The data from ANOVA resulted that feed has the highest percentage of contribution (56.04%) on affecting the surface roughness. On the other hand, depth of cut (17.94%) and cutting speed (16.42%) both affect surface roughness to quite a similar extent but much less than feed.

- Finally, this research demonstrates the effect on surface roughness with the significant influence of Feed and moderate influence of Cutting speed and Depth of cut.

This research provides us the way of using Taguchi's design method in obtaining the optimum parameter and response with minimum number of experiments. Thus, it provides engineers a base to use this method for future manufacturing applications. It can also be used for similar study of other engineering materials and can also be implemented to develop a strategy for appropriate engineering in any mass production environment.

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