**Research Article**

# Experimental investigation and Taguchi optimization of turning process parameters for glass fiber reinforced plastics (GFRP)

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## Abstract
*The recent research work has been carried out under the parameters of cutting speed, feed rate and depth of cut in which the material removal rate, machining time and the surface roughness  on the glass fiber reinforced plastic (GFRP) composite  material during the turning process was analyzed. The objective of this work, is to focus the machining characteristics of GFRP are inspected under the Taguchi Design method. And hence the experimental results are carried out as per the Taguchi experimental design and an L9 orthogonal array is observed through the design of experiment and it is used to study the influence of surface quality parameters. This method is to achieve the optimal control factor of the machining process parameters such as surface roughness, machining time and material removal rate. And finally to determine the optimal levels of the parameters the analysis of means (ANOM) will be performed. In addition to identify the level of importance of the machining parameters the analysis of variance (ANOVA) has to be employed. These analysis results revealed that the major contribution of the process parameter such as surface roughness was the most influential factor on the feed rate, and for machining time, speed is the major influencing factor and for material removal rate, Depth of cut (DoC) is the main influence factor are observed.*

## Keywords
*GFRP, Composite material, Taguchi design, Surface roughness, ANOVA.*

## 1.Introduction
In these days the replacement of traditional engineering materials is fiber reinforced plastics (FRPs) because of their superior advantage over other engineering materials. The advantages encompass high strength to weight ratio, wear resistance, high fracture toughness, electrical conductivity, excellent corrosion and thermal resistance. In various fields the glass fiber reinforced plastic (GFRP) are being broadly used such as aerospace, automobile, chemical industries, offshore power plants, pulp and paper, refinery, oil and gas etc. In addition to that of the application of GFRP composites,  expands the prospect of machining such as cutting, turning, milling and drilling etc., and has improved for its fabrication. Since knowledge and experience acquired for conventional materials cannot be applied to such new materials, of which machinability is entirely different from that of conventional materials.

In recent years the usage of GFRP composite has been increased which is simultaneously leading to an increased demand for machining. On the other hand users of GFRP composites are facing difficulties while machining it, because of delamination damage, fiber fuzzing, fiber pull out, short tool life, matrix debonding, burning and formation of powder like chips. However, the blemish of composite material lies in their vulnerability to machining damage when subjected to improper machining conditions. In order to minimize the damage in machining, it is important to monitor process Parameters such as cutting speed, feed, depth of cut etc.

Kechagias et al. [1] have done the analysis of surface texture parameters during turning of a reinforced polymer composite. In that analysis observed that the arithmetic mean roughness is mainly depends on the feed rate parameter. Aravindan et al.  [2] has described the surface finish of  GFRP pipes and investigated technique through Taguchi design

method. And also determines the percentage of improvement in surface finish and tool wear. Kumar et al. [3] has performed the machinability of unidirectional GFRP composite in turning process. And also evident that the surface roughness increases as feed rate increases. Ntziantzias et al. [4] has found that the cutting force of the glass fiber reinforced polymer composite by Kienzle–victor model. Palanikumar et al. [5] has been established analysis of drilling of GFRP composites using grey relational analysis. Gupta and Kumar [6] have investigated the machinability of unidirectional glass fiber reinforced plastics (UD-GFRP) composite in turning process. In his work, he followed Taguchi L18 orthogonal array is used for experimental design. From that an attempt has been made to model the two response variables, i.e. surface roughness and material removal rate using principal component analysis. Parida et al. [7] has found that the optimum machining condition which leads to minimum surface roughness in the drilling of GFRP composite by means of a response surface methodology. Tank et al. [8] have done the analysis for desirability functional analysis combined with Fuzzy logic to optimize the machining parameters for Turning of GFRP, in order to achieve the best surface characteristics. Karatas and Gökkaya [9] have reviewed the machinability properties and related approaches for GFRP Composites by use of Taguchi optimization techniques. Vasudevan et al. [10] has performed an optimization study on machining of randomly oriented GFRP composite rods in order to determine the best factor level condition.

In the present work, the main objective is to attain the optimal control factor for GFRP while the turning operation is undergone with the process parameters by Taguchi technique and ANOVA. And with the help of MINITAB software to identify the quality characteristics the signal-to-noise (S/N) ratio was also obtained.

## 2.Materials
Nowadays, most of the fibers used in long lasting plastics are glass fibers shown in *Figure 1*, as they are economical, easy to accumulate and have high strength and stiffness with respect to the plastics, with which they are used as reinforcement material. The most important properties are low density; resistance to chemicals, lagging capacity is the other beneficial characteristics of the glass fiber. The substrate and the resin are included according to the volume of fraction of the material. The resin tends to be more resistant over time to degradation than

polyester resin and is more flexible. The toughness of the composite will increase when the matrix is added. Finally, in the end, while fibers have the good tensile strength they usually have the awful compression strength. The matrix gives compression strength to the composite. Nowadays the polymer composite commonly used matrix is polyester resins. In this work, we have chosen unsaturated isophthalic polyester resin, and it is capable of being cured from a solid state when subject to the right conditions. It has an advantage of high non corrosive resistant content and it has high strength.



**Figure 1** Glass fiber

## 3.Experimental details
The experimental design methods are not very easy to use because they are too complex. In addition, when there is an increase in the number of the process parameters a large number of experiments have to be carried out. In order to solve, the Taguchi method uses a special design of orthogonal arrays to study the entire process parameter with a minimal number of experiments. To measure the quality characteristics deviating from the desired values. In that experimental results are then transformed into a S/N ratio with help of Minitab17 software. And the cutting tool used for machining of GFRP composite is cubic boron nitride. It is the hardest tool material and it is used for machining GFRP. During machining shows in *Figure 2*, it is obviously seen that in lay direction of glass fiber reinforced composites, are cut across and along. While it is difficult to machine the glass fiber reinforced composites because of their properties of the matrix, orientation of fibers, not a uniform character of the material, and also the occurrence of high fiber volume concentration. When machining under a higher depth of cut conditions other than that the ceramic tools are used for roughing and surface finishing operations. The cubic boron nitride (CBN) tools are mainly used for finish turning operation and it is also economical. Machining of glass fiber

reinforced composite with CBN tool material it is to be at a certain temperature for high speed machining. This will improve the rate of production of the component, while GFRP is undergoing Turning operations with the process parameters by Taguchi's technique and ANOVA. The experimental results were evaluated using Taguchi's technique. The surface roughness tester setup of GFRP is shown in *Figure 3*.



**Figure 2** Machining setup of GFRP



**Figure 3** Surface roughness tester setup of GFRP

# 4.Results and discussion
## 4.1. Design of orthogonal array
With the help of MINITAB17 the orthogonal array is formed by means of three process parameters such as Speed, Feed, Depth of cut (DoC); and S/N ratios are calculated. *Figure 4* shows the workpieces of GFRP composite. *Table 1* presented an orthogonal array L9 formation.



**Figure 4** GFRP composite work pieces

**Table 1** An orthogonal array L9 formation

| Trial No. | Designation | Speed | Feed | DoC |
|---|---|---|---|---|
| 1 | A1B1C1 | 1000 | 0.04 | 0.9 |
| 2 | A1B2C2 | 1000 | 0.06 | 1.1 |
| 3 | A1B3C3 | 1000 | 0.08 | 1.3 |
| 4 | A2B1C2 | 1500 | 0.06 | 1.1 |
| 5 | A2B2C3 | 1500 | 0.08 | 1.3 |
| 6 | A2B3C1 | 1500 | 0.04 | 0.9 |
| 7 | A3B1C3 | 2000 | 0.08 | 1.3 |
| 8 | A3B2C1 | 2000 | 0.04 | 0.9 |
| 9 | A3B3C2 | 2000 | 0.06 | 1.1 |

## 4.2. Experimental analysis
The graph (*Figure 5*) represents the material removal rate and the main effect plot for S/N ratio. The S/N ratio for the material removal rate (MRR) process parameter is presented in *Table 2* with the help of Minitab17 software. From this analysis; the result reveals that for material removal rate, depth of cut has been playing a major contribution in machining characteristics of GFRP composite.

The graph (*Figure 6*) represents the machining time (MT) and the main effect plot for S/N ratio. The S/N ratio for the machining time process parameter is presented in *Table 3* with the help of Minitab17 software. From this analysis; the result depicts that the process parameter such as speed has been playing a major contribution in machining time of GFRP composite. The graph (*Figure 7*) represents the surface roughness (SR) and the main effect plot for S/N ratio. The S/N ratio for the SR process parameter is presented in *Table 4* with the help of Minitab17 software. From this analysis; the result illustrates that the process parameter feed rate has been playing a major contribution in surface roughness of GFRP composite.

**Table 2** Result analysis for MRR and SN ratios

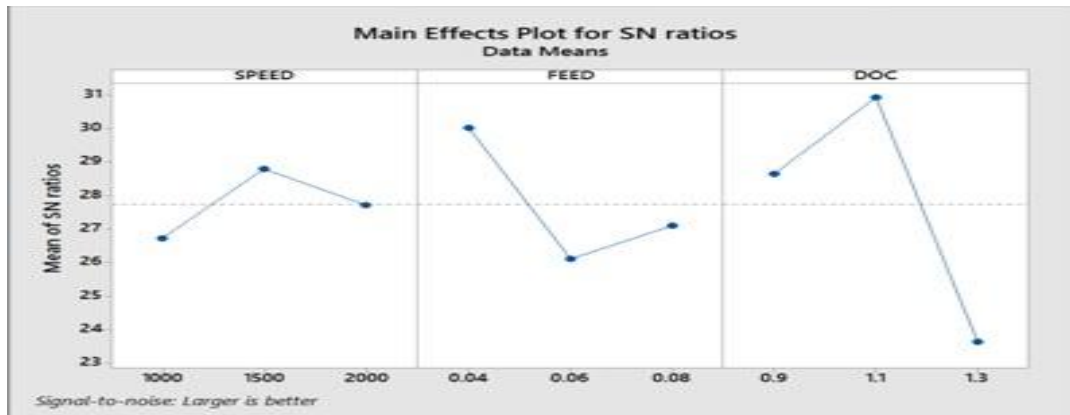| Trial No. | Designation | Speed | Feed | DoC | MRR | SN ratio |
|---|---|---|---|---|---|---|
| 1 | A1B1C1 | 1000 | 0.04 | 0.9 | 38.24 | 28.2119 |
| 2 | A1B2C2 | 1000 | 0.06 | 1.1 | 19 | 31.3499 |
| 3 | A1B3C3 | 1000 | 0.08 | 1.3 | 14 | 23.5218 |
| 4 | A2B1C2 | 1500 | 0.06 | 1.1 | 57.5 | 34.8859 |
| 5 | A2B2C3 | 1500 | 0.08 | 1.3 | 17.41 | 25.1680 |
| 6 | A2B3C1 | 1500 | 0.04 | 0.9 | 20.81 | 26.7731 |
| 7 | A3B1C3 | 2000 | 0.08 | 1.3 | 14.45 | 21.9034 |
| 8 | A3B2C1 | 2000 | 0.04 | 0.9 | 24.94 | 27.2119 |
| 9 | A3B3C2 | 2000 | 0.06 | 1.1 | 39.78 | 31.5452 |



**Figure 5** Main effects plot for SN ratios of MRR

**Table 3** Result analysis for MT and SN ratios

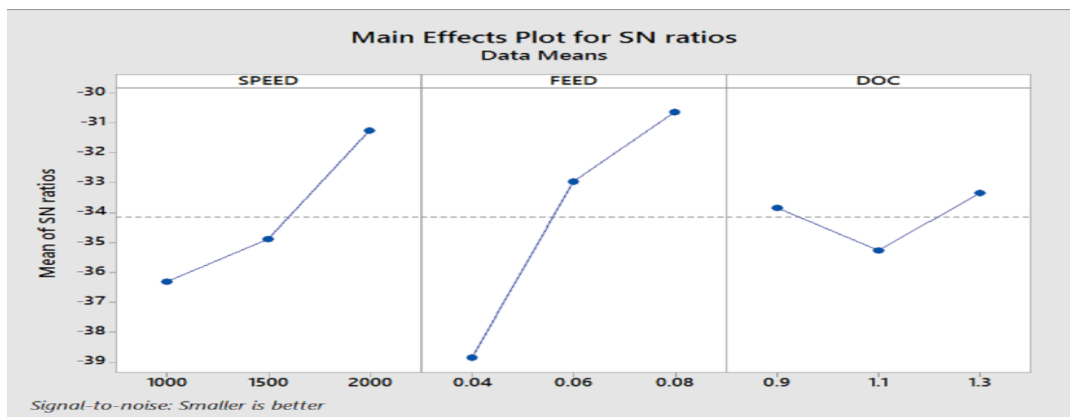| Trial No. | Designation | Speed | Feed | DoC | MT | SN ratio |
|---|---|---|---|---|---|---|
| 1 | A1B1C1 | 1000 | 0.04 | 0.9 | 106 | -42.461 |
| 2 | A1B2C2 | 1000 | 0.06 | 1.1 | 60 | -37.560 |
| 3 | A1B3C3 | 1000 | 0.08 | 1.3 | 44 | -33.284 |
| 4 | A2B1C2 | 1500 | 0.06 | 1.1 | 120 | -35.124 |
| 5 | A2B2C3 | 1500 | 0.08 | 1.3 | 43 | -31.327 |
| 6 | A2B3C1 | 1500 | 0.04 | 0.9 | 33 | -43.267 |
| 7 | A3B1C3 | 2000 | 0.08 | 1.3 | 53 | -28.412 |
| 8 | A3B2C1 | 2000 | 0.04 | 0.9 | 34 | -36.125 |
| 9 | A3B3C2 | 2000 | 0.06 | 1.1 | 27 | -32.342 |



**Figure 6** Main effects plot for SN ratios of MT

**Table 4** Result analysis for SR and SN ratios

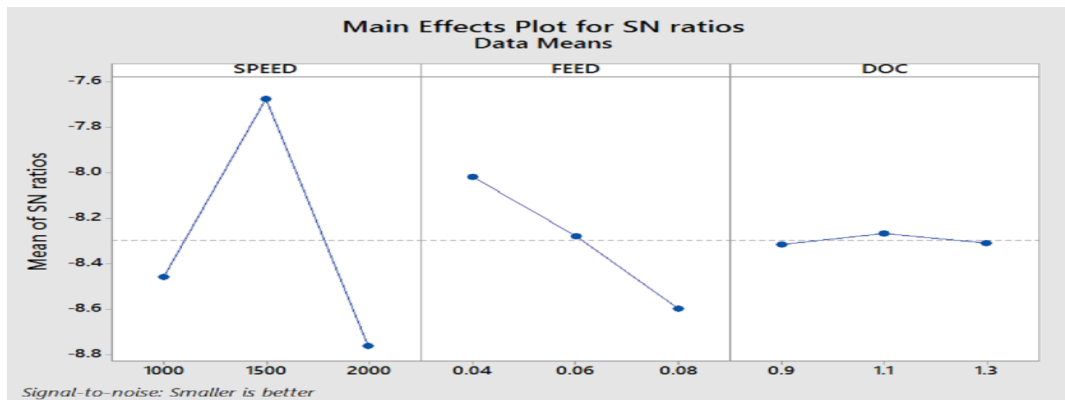| Trial No. | Designation | Speed | Feed | DoC | SR | SN ratio |
|-----------|-------------|-------|------|-----|------|----------|
| 1 | A1B1C1 | 1000 | 0.04 | 0.9 | 0.494 | 7.951 |
| 2 | A1B2C2 | 1000 | 0.06 | 1.1 | 0.757 | 2.432 |
| 3 | A1B3C3 | 1000 | 0.08 | 1.3 | 0.698 | 3.765 |
| 4 | A2B1C2 | 1500 | 0.06 | 1.1 | 0.296 | 9.143 |
| 5 | A2B2C3 | 1500 | 0.08 | 1.3 | 0.347 | 8.245 |
| 6 | A2B3C1 | 1500 | 0.04 | 0.9 | 0.629 | 3.482 |
| 7 | A3B1C3 | 2000 | 0.08 | 1.3 | 0.786 | 2.658 |
| 8 | A3B2C1 | 2000 | 0.04 | 0.9 | 0.696 | 3.452 |
| 9 | A3B3C2 | 2000 | 0.06 | 1.1 | 0.745 | 2.557 |



**Figure 7** Main effects plot for SN ratios of SR

## 5.Conclusions

Based on this work under dry conditions while GFRP is undergoing turning operations with the process parameters by using Taguchi's technique and ANOVA. The experimental results were evaluated using Taguchi's technique. The conclusions are as follows:

Optimal Control Factor

- For material removal rate is A3 (Speed-2000 rpm) B2 (Feed- 0.04mm/rev) C1 (DoC-0.9mm).
- For machining time is A2 (Speed-1500 rpm) B1 (Feed- 0.06 mm/rev) C3 (DoC- 1.1mm).
- For surface roughness is A1 (Speed -1000 rpm) B3 (Feed-0.04 mm/rev) C2 (DoC- 0.9 mm).

The major contribution of process parameters are

- Surface roughness- Feed.
- Machining time- Speed.
- Material removal rate-DoC.

For the future continuation of this work, optimization of machining parameters of milling operations for GFRP composite and natural fiber reinforced composite materials to be investigated in automobile applications.

## Conflicts of interest

The authors have no conflicts of interest to declare.

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