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# STUDY AND ANALYSIS OF DRILLING IN WOVEN GLASS FIBER WITH EPOXY RESIN

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## Abstract

Drilling glass fiber reinforced polymers leads to several problems such as delamination, fiber pull out and uncut fibers. One of the major problems in drilling glass fiber is delamination. It causes a reduction in structural integrity and long term performance of the composite materials. The present study evaluates the drilling performance of woven glass fiber reinforced plastics under cryogenic conditions using high speed drill bit with a drilled hole for specified applications. The effects of cryogenic conditions and cutting parameters on drilling performance in drilling GFRP were evaluated based on generating thrust forces and torque. Here we consider 45:55%, 50:50%, and 55:45% of woven fiber and epoxy resin combination and the mechanical properties such as tensile strength, compression strength and impact strength were analyzed as per the ASTM standard. The results reveal the best suitable fiber resin ratio with respect to strength. Both cryogenic conditions and cutting parameters were found to be influenced by thrust forces and torque at different levels. Taguchi design for this experimentation was done by applying L27 orthogonal array by taking the three levels of each factor.

***Keywords**:* Grey Relational Analysis, ANOVA, Regression Equation, Thrust force, Torque

## 1. INTRODUCTION

Now days, woven reinforced glass fiber composite materials are most widely used in automobile and aerospace industries due to their light weight, high strength, excellent corrosion resistance and minimal fatigue concerns. In machining woven glass fiber, care has to be taken as they need very accurate machining since GFRP has a low coefficient of thermal expansion and provide greater dimensional stability. Otherwise, it causes problems such as rapid tool wear and rough surface finish, delamination, least wastes, defects, and cracks in composites. The understanding of machining behavior is another vital part of the experiment as it plays a major role in a traditional machining process. But as far as composite materials are concerned, complicated results are achieved related to the machining behavior. Hence analytical and numerical modeling techniques are adopted in our study to understand the behavior of the machining parameters: point angle, feed rate, and spindle speed during cryogenic conditions (Panagiotis Kyratsis et al.2011).

The endurance limit of aluminum and steel is lower than the composite materials. GFRP which is made up of plastics or resins provide high corrosion resistance. The aim of this study is to find the best suitable fiber resin ratio with respect to strength having minimum thrust and torque on a combination of the drill parameters (Vishal et al.2016). Because of maximum thrust force and torque causes of delamination in GFRP (R.Vimal Sam Singh et al. 2009). And optimization of thrust and torque parameter creates less tool wear (S.Jayabal et al.2010).

## 2. MATERIALS AND METHODS

### *2.1 Introduction*

GFRP are made up of plastics or resins. So, they provide high corrosion resistance. But, aluminum and steel require special heat treatments for attaining high corrosion resistance. The two types of glass fibers commonly used in the fiber reinforced with resin in an industry are E-glass and S-glass. Another type which is used in chemical applications is known as C-glass which has a property of greater corrosion resistance to acids than provided by the E-glass. The E-glass has the lowest cost of all commercially available reinforcing fibers, which is the reason for its wide used in the FRP industry. The S-glass, originally developed for aircraft components and missile casings, has the highest tensile strength among all the fibers in use. However, the compositional difference and the higher manufacturing cost make it more expensive than E-glass. A lower cost version of S-glass called S-2 glass is also available. Although S-2 glass is manufactured with less-stringent non military specifications, its tensile strength and modulus are similar to those S-glasses. Glass fibers are available in the form of continuous strand roving, chopped strands and woven roving. Woven cloth is a composition of wired using twisted continuous strands called as yarns. The form of woven roving is suitable for hand layup molding.

### *2.2 Fabrication of Composite Plates*

Woven E glass fibers made up of silicon oxide with the minimal amount of other oxides are used in the fabrication process. A ratio of 5:1 of epoxy resin and hardener are mixed which is used as the resin for the GFRP sheet. The hand Lay-up technique is adopted to fabricate the GFRP sheets by applying the resin over each layer and allowed to cure for 30 min at room temperature. This process is repeated for several times to attain a thickness of 4.5mm. It required 17 layers of chopped glass fiber of 400 gsm to obtain the thickness. The glass fiber filaments have 5-24μm in diameter with a density of 2.54g/cc. A Three different combination of woven glass fiber and epoxy resin of 45:55%, 50:50% & 55:45% were taken to fabricate a square plate with dimensions of 20 x 20 cm (P-S.Shin et al.2015). The fiber plates are cut into many numbers of pieces at 8x8 cm dimension for the study of the performance of the drill by varying the drilling parameters

### *2.3 Tensile, Compression and Hardnes Test For Various Combinations of Fibers*

By universal testing machine, the tensile, ultimate, yield, breaking strength of fiber plate is found out. The fiber plate is cut into coupon shape for the tensile test purpose. And Compression strength is found by compression testing machine. The Rockwell hardness machine was used to find the hardness of the composition. It is a characteristic of a material, not a fundamental physical property. And also it is defined as the resistance to indentation, and it is determined by measuring the permanent depth of the indentation. More simply put, when using a fixed force (load) and a given indenter, the smaller the indentation, the harder the material.

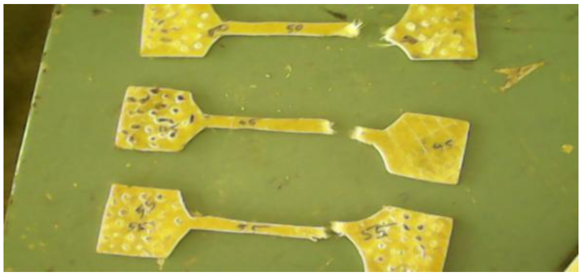

**Figure: 1** Coupon specimen for tensile test

| Fiber & epoxy resin content (%) | Ultimate strength value (kN) | Breaking strength value (kN) | Yield strength value (kN) | Young's Modulus (N/mm²) | Barcol Hardness (BH) |
|---|---|---|---|---|---|
| 45:55 | 5.0 | 3.0 | 2.8 | 27.54 | 28 |
| 50:50 | 7.5 | 3.4 | 3.0 | 56.72 | 32 |
| 55:45 | **7.8** | **7.0** | **6.5** | **85.04** | **35** |

**Figure: 2** Experimental values of tensile and compressive test for various combination of fibers

From figure 2 shows the 55:45% Fiber and Epoxy resin content (%) has better mechanical properties than other combination.

### *2.4 Drilling Parameters and Drill Bit Selection*

The drilling experiment was carried out on radial drilling machine by using various combinations of speed, feed and point angles with 8mm diameter drill bit. The specially made vice is connected with the drill tool dynamometer. A computer is connected with a dynamometer, which is interfaced through IEICOS software from which experimental values of thrust forces and torque are tabulated. High speed steel (HSS) drill bits are taken for our study. The design was prepared by choosing three levels:

- Three levels of the point angle, feed rate and speed have been used.

Three different point angles are used, as 95º, 118º and 140º through which 27 holes were drilled for one plate. The two most important outputs of our research are the thrust force and torque which are analyzed (L.M.P. Durão et al.2010).

### *2.5 Cryogenic Treatment*

For reducing the tool wear of drill bits, having a different point angles the bits were subjected to cryogenic treatment. Liquid nitrogen was used for a time to deep cryogenic treatment. The hardness and carbide distributions were improved by holding it at a time of 36 hours. Cryogenic hardening is a cryogenic treatment procedure where the material is cooled to nearly −185 °C (−301 °F), using liquid nitrogen . It can have a deep effect on the mechanical properties of certain steels, provided their composition and earlier heat treatment is such that they keep some austenite at room temperature. It is considered to increase the amount of martensite crystal structure in the steel, increasing its hardness and strength, sometimes at the cost of toughness. Currently, this treatment is being practiced over tool steels, high-carbon, and high-chromium steels to obtain excellent wear resistance. Modern research displays that there is precipitation of fine carbides (eta carbides) in the matrix during this treatment which imparts very high wear resistance to the steels(J.Y. Huang et al 2003).

| Sample | Control factor | Unit | Level 1 | Level 2 | Level 3 |
|---|---|---|---|---|---|
| A | Point angle | Degree | 95 | 118 | 140 |
| B | Feed | Meter/min | 0.1 | 0.2 | 0.3 |
| C | Speed | Rpm | 340 | 600 | 725 |

**Figure: 3** Input parameters

### *2.6 Taguchi Method*

The Taguchi method is a technically controlled mechanism for evaluating and implementing developments in products, processes, materials, equipment, and facilities. These improvements are expected at improving the preferred characteristics and at the same time reducing the number of defects by reviewing the key variables controlling the process and optimizing the procedures or design to yield the best results.

In Taguchi Method, the word "optimization" denotes "determination of TOP level of control factors". In turn, the BEST or TOP levels of control factors are those that maximize the

Signal-to-Noise ratios. The Signal-to-Noise ratios are log functions of desired output characteristics. The experiments, which are conducted to determine the BEST levels, are based on "Orthogonal Arrays", and are balanced with respect to all control factors and yet are minimum in number. This implies that the resources (materials and time) required for the experiments are also minimum. In this study, there are three parameters at three levels each, L27 (3*3) has been used. Taguchi method was used as a design for experimentation by applying L27 orthogonal array for the three levels of each factor. And smaller-the –better is considered for evaluating Signal to Noise ratio (Abhishek K et al.2014).

### *2.7 Regression Analysis*

Regression analysis is a theoretically simple method for investigating functional relationships among variables.

Normally it denote the response variable by Y and the set of predictor variables by Xl, X 2,..., X p, where p denotes the number of predictor variables. The true relationship between Y and Xl, X 2, ..., Xp can be approximated by the regression model

$$Y = f(x_1, x_2, \dots, x_p) + \varepsilon \qquad (1)$$

Where ε is assumed to be a random error representing the discrepancy in the approximation. It accounts for the failure of the model to fit the data exactly. The function f (Xl, X2,.. , Xp) describes the relationship between Y and Xl, X2, …Xp. An example is the linear regression model

$$Y = \beta_0 + \beta_1 \beta x_1 + \beta_2 x_2 + \cdots + \beta_p x_{p+} \varepsilon \qquad (2)$$

Where β0, β1, ... , βp , called the regression parameters or coefficients, are unknown constants to be determined (estimated) from the data. We follow the commonly used notational convention of denoting unknown parameters by Greek letters.

The predictor or explanatory variables are also called by other names such as independent variables, covariates, repressor's, factors, and carriers. The name independent variable, though commonly used, is the least preferred, because in practice the predictor variables are rarely independent of each other.

## 3. EXPERIMETAL RESULTS

In Taguchi designs, a measure of robustness used to recognize control factors that reduce variability in a product or process by minimizing or maximizing the special effects of uncontrollable factors. Control factors are those design and process parameters that can be controlled. Noise factors cannot be controlled during production or product use, but can be controlled during experimentation. In a Taguchi designed experiment, the noise factors are manipulated to force the variability to occur and from the results, the optimal control factor is identified with the settings that make the process or product robust, or resistant to variation from the noise factors. Higher values of the signal-to-noise ratio (S/N) identify control factor settings that minimize or maximizing the effects of the noise factors.

### *3.1 Smaller the Better*

n = -10 Log10 [mean of sum of squares of measured data] (3)

This is usually the chosen S/N ratio for all undesirable characteristics like "defects "etc. for which the ideal value is zero. Also, when an ideal value is finite, and its maximum or minimum value is defined then the difference between measured data and ideal value is expected to be as small as possible. The generic form of S/N ratio then becomes,

n = -10 Log10 [mean of sum of squares of {measured - ideal}] (4)

### *3.2 Grey Relational Analysis*

Grey relational analysis was suggested by Deng in 1989 as cited in (Abhishek K et al.2014) is widely used for measuring the degree of relationship between sequences by grey relational grade. Grey relational analysis is applied by several researchers to Optimize control parameters having multi-responses through grey relational grade (Suhas et al.2014). The use of Taguchi method with grey relational analysis to optimize the drilling operations with multiple performance characteristics includes the following steps:

1. Recognize the performance characteristics and cutting parameters to be evaluated.

2. Define the number of levels for the process parameters.

3. Select the suitable orthogonal array and allocate the cutting parameters to the orthogonal array.

4. Conduct the trials based on the arrangement of the orthogonal array.

5. Normalize the experiment results of cutting Thrust force and Torque.

6. Generate the grey relational and calculate the grey relational coefficient.

7. Calculate the grey relational grade with the help of averaging the GRA coefficient.

8. Examine the experimental results using the grey relational grade and statistical ANOVA.

9. Select the optimal levels of Drill parameters.

10. Verify the optimal drilling parameters through the confirmation experiment.

In tabulations signal to noise was derived with the help of above Eq(3&4) and also rank was provided based on the 'smaller-the-better' classification according to Grey Relational Analysis factor.

In grey relational analysis, the first stage is data pre-processing is accomplished to normalize the random grey data with different measurement units to convert them to dimensionless parameters. Thus, data pre-processing transforms the original sequences to a set of comparable sequences. The original methods are worked to pre-processing grey data depending upon the quality characteristic of the original data. The original reference sequence and pre-processed data (comparability sequence) are represented by $x_0^{(0)}$ and $x_i^{(0)}$ (k), k=1,2,…..,n; i=1,2,…..,m respectively, where n is the total number of observation and m is the number of experiments of data. The three main categories for normalizing the original sequence are identified and the quality characteristic as follows:

If the original sequence data has quality characteristic as 'larger-the-better', then the original data is pre-processed as 'larger-the-best':

$$x_i = \frac{x_i^{(0)}(k) - min x_i^{(0)}(k)}{max\, x_i^{(0)}(k) - min x_i^{(0)(k)}} \quad (5)$$

If the original data has the quality characteristic as 'smaller-the-better', then original data is pre-processed as 'smaller –the-best':

$$x_i^{(k0} = \frac{max x_i^{(0)}(k) - x_i^{(0)}(k)}{max x_i^{(0)}(k) - min\, x_i^{(0)}(k)} \quad (6)$$

However, if the original data has a target optimum value (OV) then quality characteristic is "nominal-the-better' and the original data is pre-processed as 'nominal the better':

$$x_i^*(k) = 1 - \frac{\left|x_i^{(0)}(k) - ov\right|}{max\left\{max\, x_i^{(0)}(k) - ov, ov - min\, x_i^{(0)}(k)\right\}} \quad (7)$$

Also, the original sequence is normalized by a modest method in which all the values of the sequence are divided by the first value of the sequence,

$$x_i^*(k) = \frac{x_i^{(0)}(k)}{x_i^{(0)}(1)} \quad (8)$$

Where max $x_i^{(0)}(k)$ and $min x_i^{(0)}(k)$ the maximum and minimum values respectively of the original sequence are $x_i^*(k)$ is the normalized sequence of original data.

### *3.3 Grey Relational Grade*

Next stage is the calculation of deviation sequence, $\Delta 0i\,(k)$ from the reference sequence of pre-processor data $x_i^*(k)$ and the comparability sequence

$x_i^*(k)$. The grey relational coefficient is considered from the deviation sequence using the following relation:

$$\gamma(x_0^*(k), x_i^*(k)) = \frac{\Delta min + \varepsilon \Delta max}{\Delta oi(k) + \epsilon \nabla max} \quad 0 < \gamma(x_0^i(k), x_i^*(k)) \leq 1 \qquad (9)$$

Where $\Delta oi(k)$ is the deviation sequence of the reference sequence $x_0^*(k)$ and comparability sequence $x_i^*(k)$

$$\Delta oi(k) = |x_0^* 9(k) - x_i^*(k)|; \quad \Delta max = \max_{\forall j \in i} \max_{\forall k} |x_0^*(k) - x_i^*(k)|; \quad \nabla min = \min_{\forall j \in i} \min_{\forall k} |x_0^*(k) - x_i^*(k)|:$$

$\in$ is the distinguishing coefficient $\varepsilon \in [0.1]$. The distinguishing ($\varepsilon$) value is chosen to be 0.5 a grey relational is the weighted average of the grey relational coefficient and is defined as follows:

$$\gamma(x_0^*, x_i^*) = \sum_{k=1}^{n} \beta k \gamma(x_0^*(k), x_i^*(k)), \sum_{k=1}^{n} \beta k = 1 \qquad (10)$$

They grey relational grade $\gamma(x_0^*, x_i^*)$ represents the degree of correlation between the reference and comparability sequences. If two sequences are identical, then relational grade implies that the degree of influence related between the comparability sequence and the reference sequence than the other ones, the grey relational grade for comparability and reference sequence will exceed that for the other grey relational grades. Hence, grey relational grade is an exact measurement of the absolute difference in data between sequences and can be applied to appropriate the correlation between sequences.

| Drill Parameters | | | 45:55% Composition | | | | 50:50% Composition | | | | 55:45% Composition | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Point angle (°) | Feed rate (m/min) | Speed (rpm) | Avg Torque (N-cm) | Avg Thrust (N) | GRA Grade | Rank | Avg Torque (N-cm) | Avg Thrust (N) | GRA Grade | Rank | Avg Torque (N-cm) | Avg Thrust (N) | GRA Grade | Rank |
| 95 | 0.1 | 340 | 28 | 32 | 0.7683 | 6 | 29.5 | 33 | 0.7901 | 6 | **17.5** | **44** | **0.8290** | 1 |
| 95 | 0.1 | 600 | 33.5 | 82 | 0.4881 | 23 | 32.5 | 94 | 0.4728 | 25 | 35 | 56 | 0.5474 | 20 |
| 95 | 0.1 | 725 | 23.5 | 92 | 0.5481 | 18 | 26.5 | 64 | 0.5964 | 17 | 18.5 | 64 | 0.7118 | 7 |
| 95 | 0.2 | 340 | 14 | 93 | 0.6765 | 11 | 31 | 99.5 | 0.5372 | 20 | 24.5 | 63 | 0.6194 | 14 |
| 95 | 0.2 | 600 | 23 | 31 | 0.8250 | 3 | **20** | **69** | **0.9091** | 1 | 25 | 39 | 0.7441 | 5 |
| 95 | 0.2 | 725 | 16.5 | 58 | 0.7263 | 9 | 28.5 | 96 | 0.8347 | 4 | 45 | 51 | 0.5151 | 22 |
| 95 | 0.3 | 340 | 17.5 | 61 | 0.6998 | 10 | 31.5 | 48 | 0.8251 | 5 | 21.5 | 56.5 | 0.6872 | 10 |
| 95 | 0.3 | 600 | 48.5 | 85.5 | 0.4100 | 26 | 18.5 | 82 | 0.6442 | 14 | 17.6 | 74 | 0.7007 | 8 |
| 95 | 0.3 | 725 | 46.5 | 36 | 0.6269 | 14 | 13.5 | 42.5 | 0.7588 | 7 | 18.5 | 54.5 | 0.7494 | 4 |
| 118 | 0.1 | 340 | 36.5 | 76 | 0.4845 | 24 | 36.5 | 61.5 | 0.4735 | 24 | 47 | 64 | 0.4516 | 24 |
| 118 | 0.1 | 600 | 34 | 96 | 0.4587 | 25 | 20 | 31 | 0.6798 | 12 | 35 | 65 | 0.5132 | 23 |
| 118 | 0.1 | 725 | 32 | 73.5 | 0.5182 | 21 | 23 | 34 | 0.4978 | 22 | 41.5 | 73 | 0.4502 | 25 |
| 118 | 0.2 | 340 | 22 | 82.5 | 0.5824 | 16 | 31.5 | 74.5 | 0.5236 | 21 | 63 | 57 | 0.4271 | 26 |
| 118 | 0.2 | 600 | 37.5 | 63.5 | 0.5156 | 22 | 26.5 | 53 | 0.6462 | 13 | 29.5 | 47.5 | 0.6353 | 13 |
| 118 | 0.2 | 725 | 26 | 31.5 | 0.7906 | 4 | 28.5 | 42.5 | 0.6996 | 10 | 23.5 | 50 | 0.6892 | 9 |
| 118 | 0.3 | 340 | 54 | 45 | 0.5348 | 19 | 16.5 | 54.5 | 0.4737 | 23 | 32.5 | 50 | 0.5953 | 17 |
| 118 | 0.3 | 600 | 68 | 99 | 0.3333 | 27 | 30 | 57 | 0.3857 | 27 | 63.5 | 91 | 0.3333 | 27 |
| 118 | 0.3 | 725 | 35 | 57.5 | 0.5519 | 17 | 52.5 | 67 | 0.5746 | 19 | 30 | 61.5 | 0.5654 | 19 |
| 140 | 0.1 | 340 | 19.5 | 60.5 | 0.6744 | 12 | 14.5 | 48 | 0.6375 | 15 | 23.5 | 38 | 0.7723 | 3 |
| 140 | 0.1 | 600 | 26 | 87 | 0.5337 | 20 | 24.5 | 67.5 | 0.6910 | 11 | 23 | 81.5 | 0.5886 | 18 |
| 140 | 0.1 | 725 | 27 | 47 | 0.6589 | 13 | 27.5 | 37 | 0.8838 | 2 | 26 | 59 | 0.6161 | 15 |
| 140 | 0.2 | 340 | 16.7 | 48.5 | 0.7676 | 7 | 79.5 | 49 | 0.7542 | 8 | 27.5 | 59 | 0.5995 | 16 |
| 140 | 0.2 | 600 | 18 | 32 | 0.8745 | 2 | 62 | 88.5 | 0.5982 | 16 | 34.5 | 37.5 | 0.6677 | 11 |
| 140 | 0.2 | 725 | **14.5** | **36.5** | **0.8865** | 1 | 36 | 54 | 0.4499 | 26 | 35 | 27.5 | 0.7840 | 2 |
| 140 | 0.3 | 340 | 38 | 27 | 0.7647 | 8 | 25.5 | 42 | 0.7291 | 9 | 31.5 | 34 | 0.7258 | 6 |
| 140 | 0.3 | 600 | 28 | 60 | 0.5901 | 15 | 26.5 | 65.5 | 0.5909 | 18 | 20 | 71 | 0.6619 | 12 |
| 140 | 0.3 | 725 | 26 | 32.5 | 0.7799 | 5 | 14.5 | 41.5 | 0.8736 | 3 | 62 | 38.5 | 0.5417 | 21 |

**Figure: 4** Experimental values for various fibers and resin compositions

| S.No | Point angle (°) | | | Feed rate (m/min) | | | Speed (rpm) | | |
|---|---|---|---|---|---|---|---|---|---|
| Composition percentage | 45:55 | 50:50 | 55:45 | 45:55 | 50:50 | 55:45 | 45:55 | 50:50 | 55:45 |
| 1 | 0.6410 | **0.7076** | **0.6782** | 0.5703 | 0.6359 | **0.6341** | 0.6614 | 0.6382 | **0.6782** |
| 2 | 0.5300 | 0.5505 | 0.5178 | **0.7383** | **0.6614** | 0.5991 | 0.5588 | 0.6242 | 0.5261 |
| 3 | **0.7256** | 0.6898 | 0.6620 | 0.5879 | 0.6506 | 0.6247 | **0.6764** | **0.6855** | 0.6620 |

**Figure: 5** response table for grey relational grade level factor

## 4. DISCUSSIONS

The thrust force and torque is generated using IEICOS instrument which is attached to the CNC milling machine. At first, thrust force and torque are calculated by varying speed and feed rate at a particular point angle as per Taguchi L27 orthogonal array.

Based on the experimental values 95° point angle is suitable for 50:50% and 55:45% of compositions. The various speed and feed rate combination with 95° point angle drill bit provides the minimum value thrust force and torque. The maximum thrust force and torque generates at the various combination of federate and speed with 118° point angle.

Considering the feed rate lower values provide an optimum value of output for all composition. The effect of changing the feed rate is more prominent compared to that of cutting speed.

In calculating the torque at lower cutting speeds that effect of changing the feed rate is not prominent, but

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as the speed increases, the effect of changing the feed rate becomes more prominent. The value of torque increases with the increase of cutting speed and feed rate.

From the contour plot graph for the 55:45% composition plate shows the feed rate plays the significant role in the generating optimum torque and thrust force value, subsequently In the point angle combining with speed graph shows the minimum point angle with various speed achieve the optimum thrust force and torque.

### *4.1 Regression Equations*

Regression equations are calculated for thrust force and torque of various combinations of woven glass fiber and resin with respect to factors of point angles, feed, and speed.

**Regression equation for 45% of fiber and 55% of resin**

Torque (N-cm) = 26.2802 - 0.0879636 Point angle + 56.3889 Feed rate + 0.0050265 Speed

Thrust (N) = 120.128 - 0.339862 Point angle - 79.1667 Feed rate - 0.00737633 Speed

**Regression equation for 50% of fiber and 50% of resin**

Torque (N-cm) = 15.105 + 0.19481 Point angle - 3.05556 Feed rate - 0.0136042 Speed

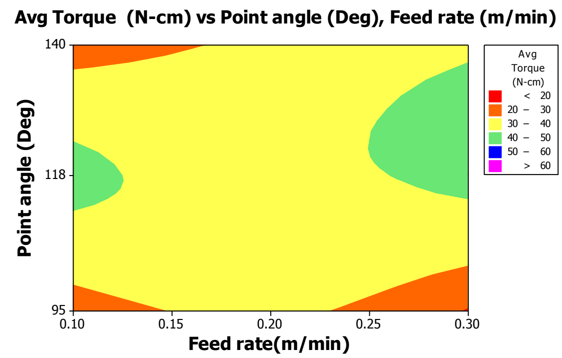
Thrust (N) = 95.9318 - 0.336406 Point angle + 16.6667 Feed rate -0.00103062 Speed

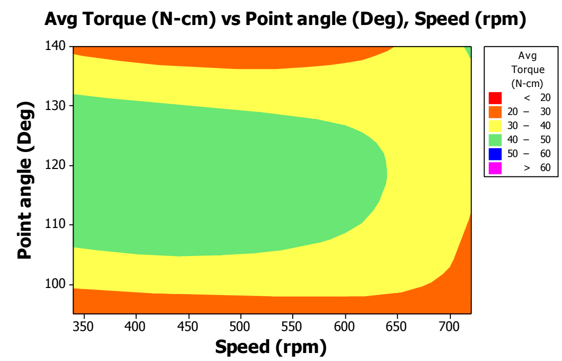
**Regression equation for 55% of fiber and 45% of resin**

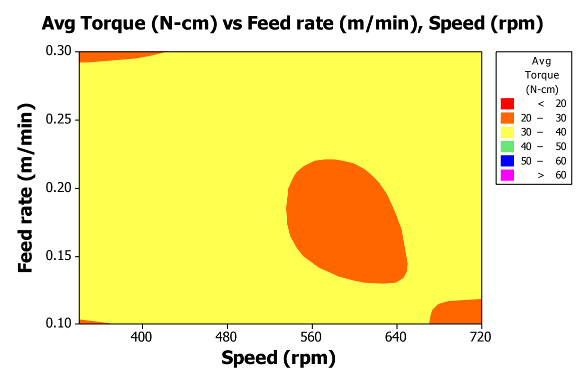
Torque (N-cm) = 9.69675 + 0.15199 Point angle + 16.7222 Feed rate + 0.00245092 Speed

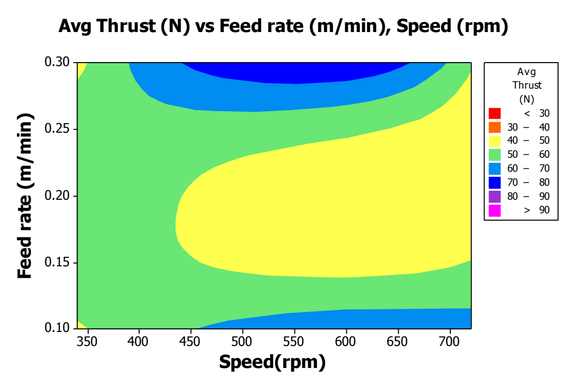
Thrust (N) = 67.6955 - 0.13514 Point angle - 7.5 Feed rate + 0.00997742 Speed

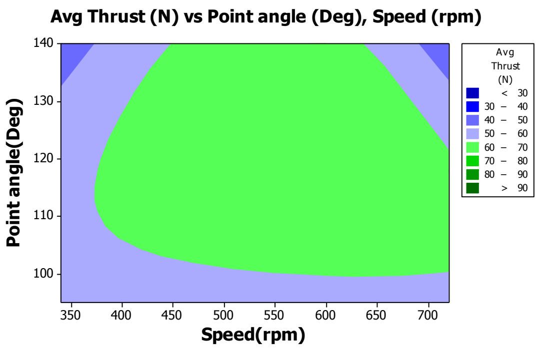
Contour Plot was drawn for plate which has greater mechanical properties (55:45%)

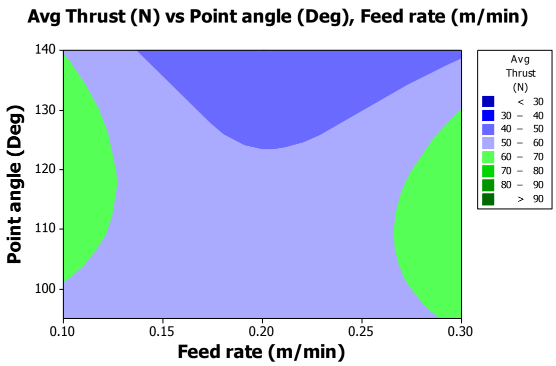





## 5. CONCLUSION

This paper has presented the GRA based an orthogonal array of the Taguchi method was used for the optimization the CNC drilling process on a various composition of woven fiber and resin with multiple performance characteristics. The analytical results are summarized as follows:

1. From the response table of the average grey relational grade, it is found that the largest value of the grey relational grade for the 45:55% composition was Point angle $140^0$, the feed rate of 0.2 m/min, and the cutting speed is 725 rpm. Similarly for other compositions like 50:50% and 55:45% are $95^0$, 0.2 m/min and 725 rpm and $95^0$, 0.1 m/min and 340 rpm. It is the recommended levels of the controllable parameters of the CNC drilling operations as the minimization of the thrust force and torque considered.

2. The order of the importance of the controllable factors to the average torque, in sequence, is the feed rate, the cutting speed, and the Point angle. Similarly, the order to the average thrust force, in sequence, is the feed rate, the point angle, and the cutting speed.

3. The Regression equation was derived for all composition of the plate in the form of drill parameters.

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