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# A nova Based Optimization of Machining Parameters in Drilling of Glass Fiber Reinforced Polymer (GFRP) Composites

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**Abstract:** *The interest in Glass Fiber Reinforced Polymer composite materials is rapidly growing both in industrial applications and fundamental research.The use of composite parts, especially in aeronautics, is increasing at an exponential rate.However, machining of this material is complicated due to different phenomena such as delamination, resin, and cutting edge failure. Drilling of GFRP composite material with a K10 solid carbide tool was performed.The aim of the present study is to optimize cutting conditions such as Delamination Factor (DF) and Surface roughness (R) of GFRP composite. To minimize the number of experiments, $L_{27}$ orthogonal array was used along with the input parameters as spindle speed, point angle, and feed rate. The influence over the variable is analyzed by using ANOVA.*

**Keywords:** *ANOVA, GFRP, Optimization, Drilling*

## 1. Introduction

The glass fibre-reinforced polymer composite materials is rapidly springing up both in conditions of their industrial applications and underlying research. Glass fibres are an excellent raw materials for production of wide range of composites for different applications. Because of their availability, renewability, low density, price and satisfactory mechanical properties make them an attractive fibres used for the manufacturing of composites. The glass fibre-containing composites are used in transportation, military applications, building and construction industries and consumer products. The price of polymer composites reinforced with glass fibers is two to three times lower than that of other polymers which make them feasible for comosite applications.

Lu et al. investigates optimization design of the cutting parameters for rough cutting processing high-speed end drilling on SKD61 tool steel. The major characteristics indexes for performance selected to evaluate the processes are tool life and metal removal rate, and the corresponding cutting parameters are milling type, spindle speed, feed per tooth, radial depth of cut, and axial depth of cut. The results of confirmation experiments reveal that grey relational analysis coupled with principal component analysis can effectively acquire the optimal combination of cutting parameters [1].

AzlanMohdZain et al. presents the ANN model for predicting the surface roughness performance measure in the machining process by considering the Artificial Neural Network (ANN) as the essential technique for measuring surface roughness. In that, 24 samples of data concerned with the milling operation are collected based on eight samples of data of a two-level DOE 2k full factorial analysis, four samples of centre data, and 12 samples of axial data. All data samples are tested in real machining by using uncoated, TiAIN coated and SNTR coated cutting tools of titanium alloy (Ti-6A1-4V). The Matlab ANN toolbox is used for the modelling purpose with some justifications. Feed forward back propagation is selected as the algorithm with traingdx, learngdx, MSE, logsig as the training, learning, performance and transfer functions, respectively. This study concludes that the model for surface roughness in the milling process could be improved by modifying the number of layers and nodes in the hidden layers of the ANN network structure, particularly for predicting the value of the surface roughness performance measure [2].

BharathiRaja et al. presented a technique that could able to find the optimal machining parameters for the required surface roughness in machining. Here experimental investigations are carried out on aluminium material to study the effect of machining parameters such as cutting speed, feed, and depth of cut on the surface roughness and to obtain the desired surface roughness on face milling process. He also developed a Mathematical model for surface roughness prediction using Particle Swarm Optimization (PSO) on the basis of experimental results. The model developed for optimization has been validated by confirmation experiments. Physical constraints for both experiment and theoretical approach are the proposed machining parameters and surface roughness [3].

Panneerselvam et al. analysed the cutting tools behaviour on GFRP. He used Grey Relational Analysis approach for the study and optimized the machining parameters such as Tool Condition, number of flutes, cutting speed and feed rate on milling of GFRP in order to minimize the surface delamination, machining forces, cutting torque and surface roughness [4].

Baharudin et al. outlined the use of the Taguchi method to find the optimal surface roughness when HSS insert face cutting on material AL6061. The milling parameters of the study were evaluated based on various factors such as spindle speed, feed rate and axial rake angle. An orthogonal array $L_9$, the signal-to-noise (S/N) ratio and the analysis of variance (ANOVA) was carried out to investigate and identify the significant factors that are affecting to the surface roughness [5].

MohamadSyahmiShahromet al. investigated into Minimum Quantity Lubricant (MQL) and wet machining in milling processes of AISI 1060 Aluminum work material with the main objective of determining the effect of lubrication conditions on the surface roughness. The other parameters considered in the study are feed rate (FR), depth of cut (DOC) and cutting speed (CS).There are four levels in each parameters. He used the Taguchi method was used to predict the surface roughness. He found that, MQL produced better surface finish as compared to wet machining [6].

AzlanMohdZain et al. carried out an experiment to observe the optimal effect of the radial rake angle of the tool, combined with speed and feed rate cutting conditions in influencing the surface roughness result. In machining, the surface roughness value is targeted as low as possible and is given by the value of the optimal cutting conditions. In that study he attempts the application of GA to find the optimal solution of the cutting conditions for giving the minimum value of surface roughness. The analysis of the study proves that the GA technique is capable of estimating the optimal cutting conditions that yield the minimum surface roughness value [7].

Palanisamy et al. outlined a mathematical model based on both the material behavior and the machine dynamics to determine cutting force for milling operations. The system used for optimization is based on powerful artificial intelligence called Genetic Algorithms (GA). The machining time is considered as the objective function and constraints are tool life, limits of feed rate, depth of cut, cutting speed, surface roughness, cutting force and amplitude of vibrations while maintaining a constant material removal rate. The result of his work shows that how a complex optimization problem is easily handled by a genetic algorithm and how it converges very quickly. Experimental end milling tests have been performed on mild steel to measure surface roughness, cutting force using milling tool dynamometer and vibration using a FFT (Fast Fourier Transform) analyzer for the optimized cutting parameters in a universal milling machine using an HSS cutter [8].

The main intentions behind is to study machinability features and applying ANOVA to find the optimum conditions. In the present study, K10 solid carbide drill is used for machining process and was machined under parameters, viz., spindle speed (A), feed rate (B) and point angle (C). Variance analysis has been adopted for optimizing multiple performance features such as surface roughness and delamination factor.

**Table 1.** *Properties of the Laminate*

| **Density ($kg/m^3$)** | **Weight ($kg/m^2$)** | **Tensile Strength (MPa)** | **Tensile Modulus (GPa)** | **Hardness (Hv)** |
|---|---|---|---|---|
| 1234 | 10.534 | 64 | 1.71 | 20 |

## 2. EXPERIMENTAL DESIGN

The experiments were carried out using TCA-70BV drilling Machine. The work piece used for the experiments is GFRP with epoxy resin composite. The size of the specimen used was 150x150x10 mm. The properties of the laminate are mentioned in Table 1. The cutting tool used for the machining was K10 solid carbide end mill. The input parameters and their levels selected for the experimental design are listed below in Table 2. The experiment was conducted on the basis of $L_{27}$ orthogonal array.

**Table 2.** *factors and levels*

| Symbol | Machining Parameters | Level 1 | Level 2 | Level 3 |
|---|---|---|---|---|
| A | Speed (rpm) | 1000 | 2000 | 3000 |
| B | Point Angle (°) | 100 | 118 | 135 |
| C | Feed rate (m/min) | 0.05 | 0.1 | 0.15 |

As per the Taguchi design, $L_{27}$ orthogonal array was selected because there were three factors and each factor had three levels being considered.

**Figure 1.** *TCA-70BV Drilling Machine*

## 3. ANOVA

Analysis of variance (ANOVA), a statistical approach is used for interpreting experimental data. With ANOVA, interaction between different parameters can be evolved and helps to find out the average performance difference of the parameters. The intention of ANOVA is to show the variation of each factor with respect to the total variation observed in the result.The lowest response value will be classified by the main effect plots identified from each level. With ANOVA, Significant and non significant factors are identified which helps the machining process to be easier and cost effective.

## 4. MACHINING PERFORMANCE MEASURES

In this study, Delamination Factor (DF) and Surface Roughness (Ra) were considered as the output parameter affecting the results of machining process. Mitutoyo make Subsonic Surface Tester was used to find out the Surface Roughness. The Table 3 shows the orthogonal array ($L_{27}$) experimental design, input and output parameters.

**Table 3**. *Orthogonal array (l27) experimental design, input and output parameters*

| Sl No. | Spindle Speed(rpm) | Point Angle(°) | Feed Rate(m/min) | Delamination Factor(DF) | Surface Roughness(Ra) |
|---|---|---|---|---|---|
| 1 | 1000 | 100 | 0.05 | 1.1696 | 3.16210 |
| 2 | 1000 | 100 | 0.1 | 1.2400 | 3.51500 |
| 3 | 1000 | 100 | 0.15 | 1.2810 | 3.88570 |
| 4 | 1000 | 118 | 0.05 | 1.1940 | 3.21010 |
| 5 | 1000 | 118 | 0.1 | 1.2750 | 3.56130 |
| 6 | 1000 | 118 | 0.15 | 1.3170 | 3.72950 |

| | | | | | |
|---|---|---|---|---|---|
| 7 | 1000 | 135 | 0.05 | 1.1832 | 3.01130 |
| 8 | 1000 | 135 | 0.1 | 1.2360 | 3.42610 |
| 9 | 1000 | 135 | 0.15 | 1.2880 | 3.70000 |
| 10 | 2000 | 100 | 0.05 | 1.3270 | 3.45600 |
| 11 | 2000 | 100 | 0.1 | 1.3972 | 3.54400 |
| 12 | 2000 | 100 | 0.15 | 1.4173 | 3.96600 |
| 13 | 2000 | 118 | 0.05 | 1.3831 | 3.41200 |
| 14 | 2000 | 118 | 0.1 | 1.4041 | 3.58000 |
| 15 | 2000 | 118 | 0.15 | 1.4235 | 4.07000 |
| 16 | 2000 | 135 | 0.05 | 1.3678 | 3.27100 |
| 17 | 2000 | 135 | 0.1 | 1.3782 | 3.52400 |
| 18 | 2000 | 135 | 0.15 | 1.4223 | 3.85200 |
| 19 | 3000 | 100 | 0.05 | 1.3840 | 3.87000 |
| 20 | 3000 | 100 | 0.1 | 1.4295 | 4.01320 |
| 21 | 3000 | 100 | 0.15 | 1.4600 | 4.47700 |
| 22 | 3000 | 118 | 0.05 | 1.3980 | 3.92500 |
| 23 | 3000 | 118 | 0.1 | 1.4350 | 3.99800 |
| 24 | 3000 | 118 | 0.15 | 1.4780 | 4.49200 |
| 25 | 3000 | 135 | 0.05 | 1.3810 | 3.71340 |
| 26 | 3000 | 135 | 0.1 | 1.4440 | 3.96900 |
| 27 | 3000 | 135 | 0.15 | 1.4640 | 4.32700 |

## 5. RESULTS AND DISCUSSIONS

The experiments were conducted on the bases of the developed $L_{27}$ orthogonal array and the responses such as the DF and Ra were analysed with the aim of relating the influences of the spindle speed, point angle and feed rate. The input parameters were optimized by using ANOVA for determining the optimal machining input parameters with the consideration of multiple performance characteristics and finally verified. Table 4 shows the ANOVA table for Surface Roughness, Ra as a function of the cutting parameters. From the ANOVA tables, the optimal machining parameters setting can be obtained by considering minimum Delamination and minimum surface roughness simultaneously. Furthermore, this approach is feasible to obtain optimal machining parameters for a desired surface roughness and minimum delamination factor by Analysis of Variance.

**Table 4**. *ANOVA table for Surface Roughness $R_a$*

| Analysis of Variance | | | | | | |
|---|---|---|---|---|---|---|
| Factors | Cutting Parameters | Degrees of Freedom | Sum of Squares | Mean of Squares | F-Test | Contribution(P, %) |
| A | Spindle Speed | 2 | 1.86062 | 0.930309 | 211.89 | 49.801 |
| B | Point Angle | 2 | 0.09665 | 0.048323 | 11.01 | 2.587 |
| C | Feed Rate | 2 | 1.69106 | 0.845528 | 192.58 | 45.262 |
| | Error | 20 | 0.08781 | 0.004391 | | 2.35 |
| | Total | 26 | 3.73613 | | | 100 |

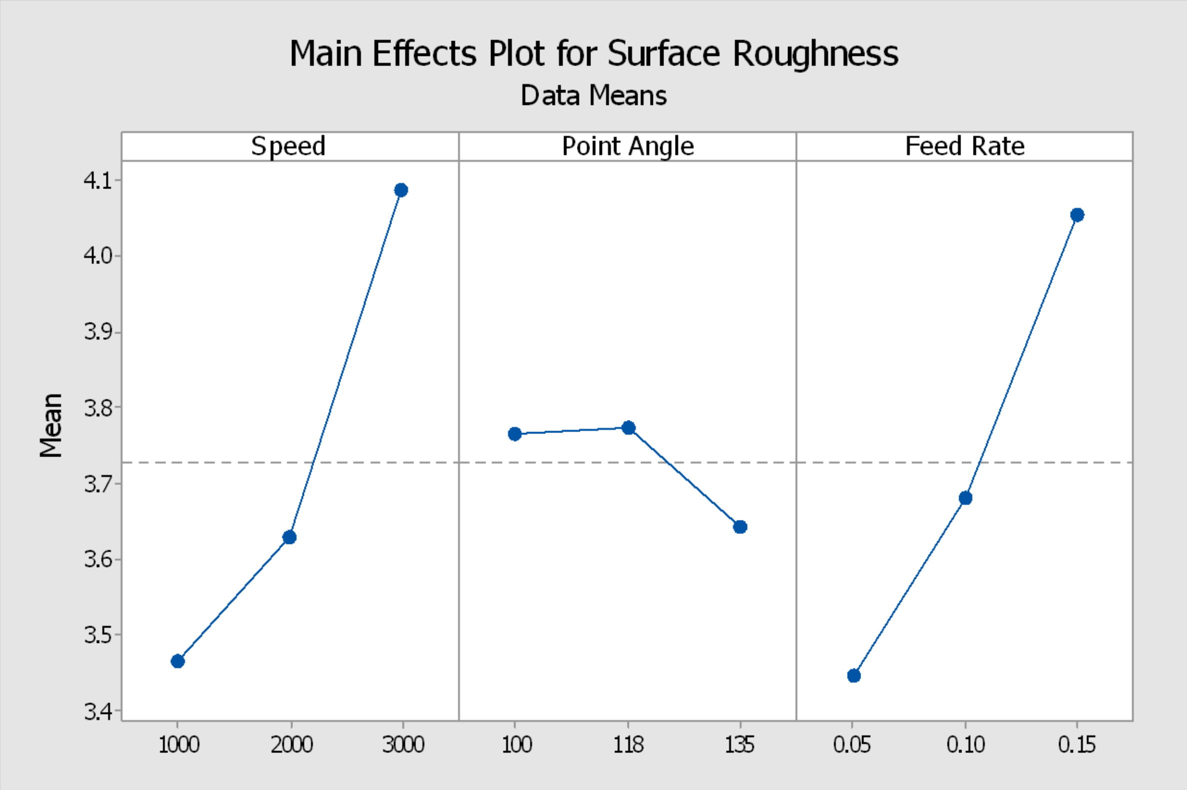


**Figure 2.** *Main Effect Plot for Surface roughness($R_a$)*

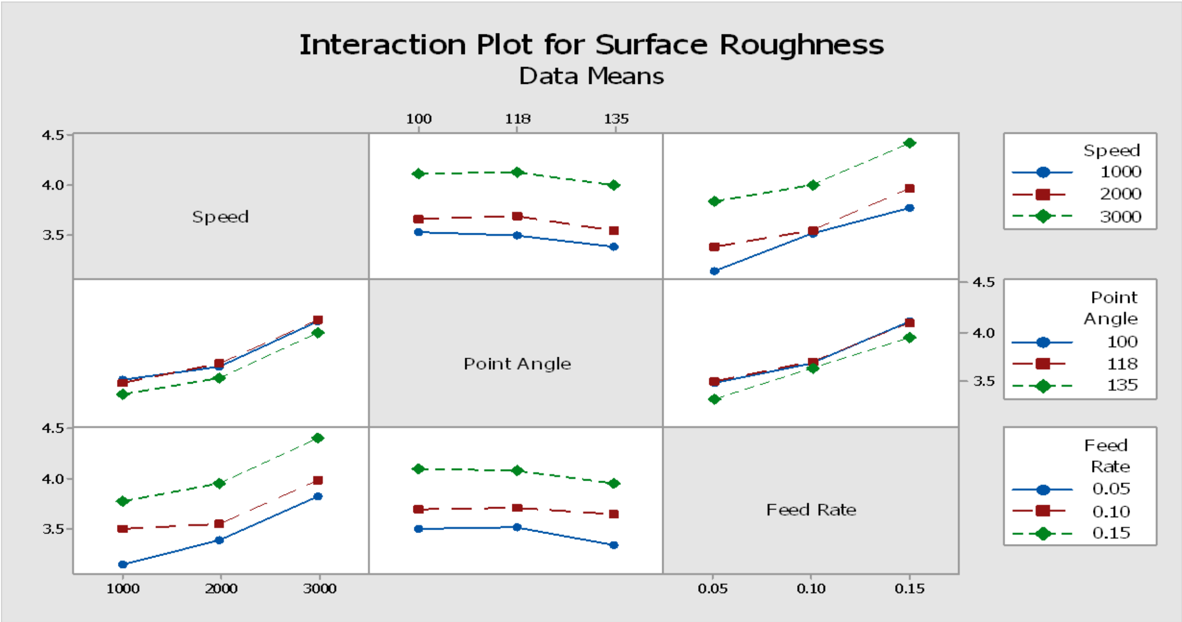


**Figure 3.***Interaction Plot for Surface roughness($R_a$)*

## 5.1 Effect of Parameters on Surface Roughness (Ra)

From the graphs obtained, observations shows that the value of Ra shows an increasing trend towards spindle speed of 1000, 2000 and 3000 rpm. In case of point angle, Ra is constant for 100° and 118° while trend decreases for 135°. Feed rate shows same trend of spindle speed. As the feed rate increases, the surface roughness also increases. It means that at Ra is lower at 0.05m/min. From the analysis of Variance, it was found that spindle speed and feed rate have about same effect on surface roughness (Ra). Point angle have only very minute effect on the surface roughness (Ra). Table 5 shows the model summary for the surface roughness, Ra.

**Table 6**. *ANOVA table for Delamination Factor, DF*

| Analysis of Variance | | | | | | |
|---|---|---|---|---|---|---|
| Factors | Cutting Parameters | Degrees of Freedom | Sum of Squares | Mean of Squares | F-Test | Contribution(P, %) |
| A | Spindle Speed | 2 | 0.176536 | 0.088268 | 423.04 | 81.790 |
| B | Point Angle | 2 | 0.002401 | 0.0012 | 5.75 | 1.110 |
| C | Feed Rate | 2 | 0.032735 | 0.016368 | 78.44 | 15.160 |
| | Error | 20 | 0.004173 | 0.000209 | | 1.94 |
| | Total | 26 | 0.215845 | | | 100 |

### 5.2 Effect of Parameters on Delamination Factor(DF)

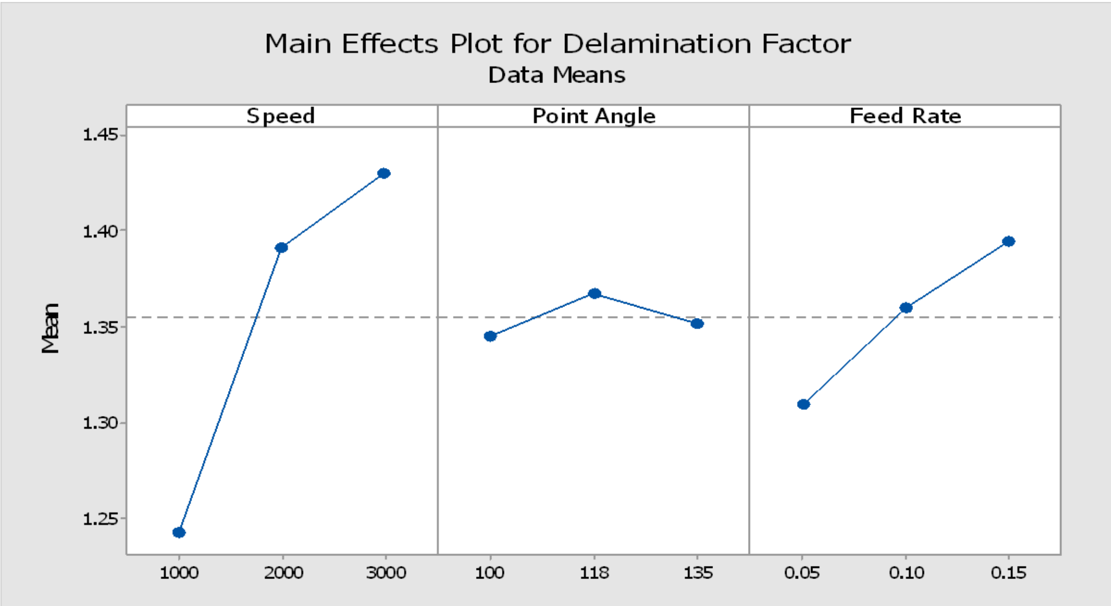


**Figure 5.***Main Effect Plot for Delamination Factor(DF)*

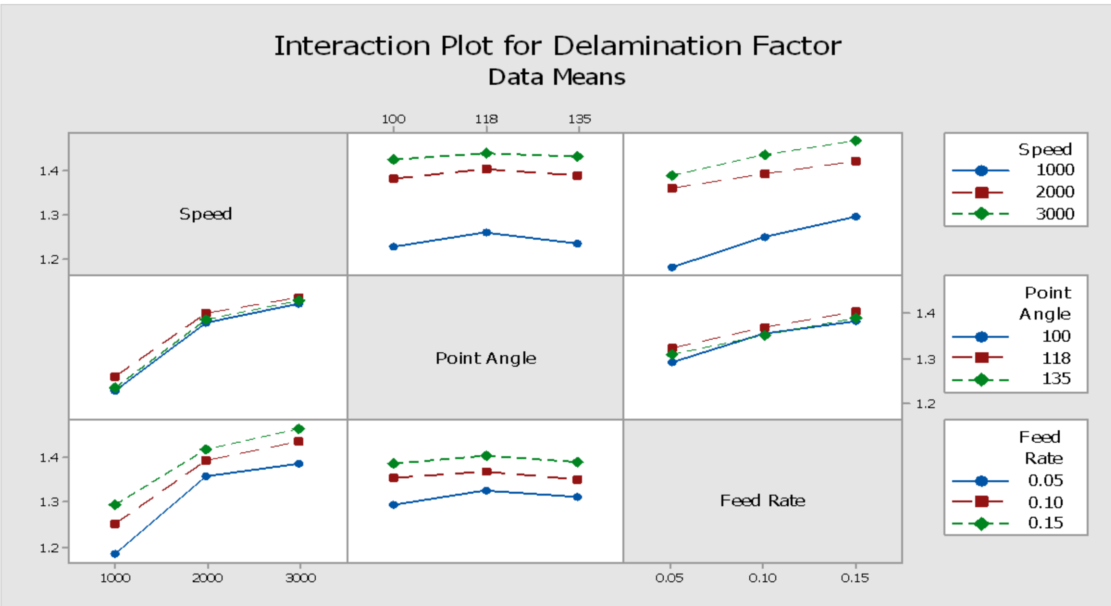


**Figure 6.***Interaction Plot for Delamination Factor(DF)*

From the main effect plots obtained, observations shows that Delamination Factor (DF) shows an increasing trend from 1000 to 3000 rpm. In case of point angle, DF first shows an increasing trend from 100° to 118° which again decreases towards point angle of 135°. Delamination increases on increasing feed rate. It means that at Delamination Factor is lower at 0.05m/min. From the analysis of Variance, it was found that spindle speed have maximum effect on Delamination Factor (DF). Feed rate and Point angle have only very minute effect on the Delamination Factor (DF). ANOVA table for delamination factor is shown in Table 6. Below shows the regression equation for Surface Roughness and Delamination Factor.

**Table 8**. *Regression equations*

| Parameter | Equation |
|---|---|
| Surface Roughness | 3.7282 - 0.2614 A1 - 0.0976 A2 + 0.3590A3 + 0.0373B1 + 0.0471B2- 0.0844B3 - 0.2803C1 - 0.0470C2 + 0.3273C3 |
| Delamination Factor | 1.35473 - 0.11209A1 + 0.03643A2 + 0.07566A3 - 0.00967B1+ 0.01279B2- 0.00312B3 - 0.04499C1+ 0.00516C2 + 0.03983C3 |

## 6. CONCLUSION

The present work shows the use of ANOVA to find out optimal machining parameter. With ANOVA, we determine means of all the parameters. Machining Parameters namely Spindle Speed (A), Point Angle(B), Feed Rate(C) were optimized to meet the objective. From the study, the following conclusions are drawn:

- The observation result shows that the primary factor affecting the surface roughness is spindle speed, subsequently followed by feed rate and point angle also the spindle speed is the major factor effecting the delamination factor.
- The optimized control factors for minimizing the Surface roughness Ra were

  Spindle speed $A_1$=1000rpm, Point Angle $B_3$=135°, Feed Rate $C_1$=0.5m/min.
- The optimized control factors for minimum Delamination Factor DF were

  Spindle speed $A_1$=1000rpm, Point Angle $B_1$=100°, Feed Rate $C_1$=0.5m/min.

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