iJRASET
International Journal For Research in
Applied Science and Engineering Technology

# INTERNATIONAL JOURNAL FOR RESEARCH

IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY

**Volume:** 7 **Issue:** VI **Month of publication:** June 2019

**DOI:** http://doi.org/10.22214/ijraset.2019.6166

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.177
Volume 7 Issue VI, June 2019- Available at www.ijraset.com

# Optimization of process parameters in Drilling of CFRP Reinforced with Different Percentage of $Si_3N_4$ using Taguchi method

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***Abstract: The evolution of composite materials has made it a prominent choice in the field of engineering like Aerospace, automotive etc., due to its excellent mechanical properties like strength, stiffness and also mainly due to reduction in its weight, machining of these components is necessary for the purpose of fabrication. Drilling is one of the major machining operations performed to drill holes in the materials for the purpose of assembly and other fabrication purpose. In this paper a critical review on the mechanical drilling of composite laminates is presented and aimed to study the entire parameters that contribute to the increase in productivity in terms of circularity, cylindricity, surface roughness of the holes and the pulling out of fiber while drilling. The drilling carried out on the basis of Taguchi $L_{27}$ orthogonal array with five parameters weight % of $Si_3N_4$, Speed, Feed rate, Diameter of drill bit and machining time at three levels each . The results are tabulated and are optimized for the best productivity, using Minitab software.***

***Keywords: Speed, Surface roughness, Cylindricity, Circularity, weight % of $Si_3N_4$***

## I. INTRODUCTION

### *A. Composite materials*

Composites have proved its effectiveness in all ways in the present era. Due to their excellent properties like high strength to weight ratio, high stiffness to weight ratio, thereby replacing the conventional metals in most of the application in the field of Aerospace, Defense. The composite materials known to be composed of more than one have two parts matrix and reinforcement. Polymer matrix composites are the materials which has Polymer material like epoxy resin and reinforcements like carbon fibers are widely used and known as Carbon fibers reinforced polymers (CFRP) are made as laminates as shown in the figure 1. The widely used geometries for continuous fiber composites called laminates. Laminates are made of plies in which all fibers are oriented in different orientations often have same direction. The fibers in it is much stronger compared to the matrix. So the ply is stiffer and stronger in the direction of fiber. The orientation of fibers depends on the application like the direction of loading.

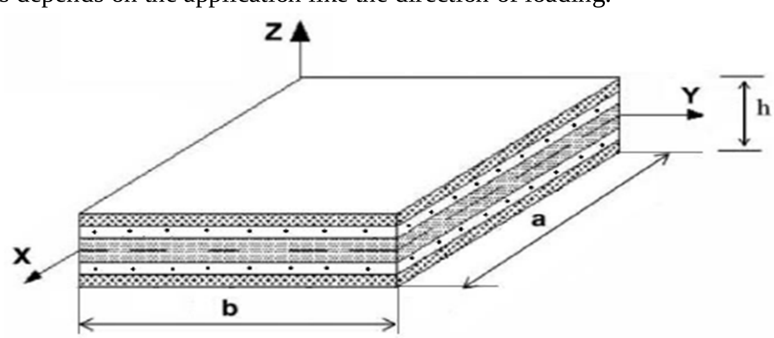


Figure 1: Composite Laminates

### *B. Drilling*

Drilling operation is the common machining operation performed for various applications like fabrication and the- quality of holes determine the safety and efficiency of fabrication. So it is important to have high productivity in drilled holes.

The orthotropic nature of the composites, i.e. the orientation of fibres in different directions makes the drilling operation cumbersome in the areas of rich fibres and also the hardness, abrasiveness it possesses makes the selection of process parameters significant. The undesirable damages like fibre pull out generally known as delamination damage induced by drilling drastically reduce strength against fatigue, thus degrading the long term performance.

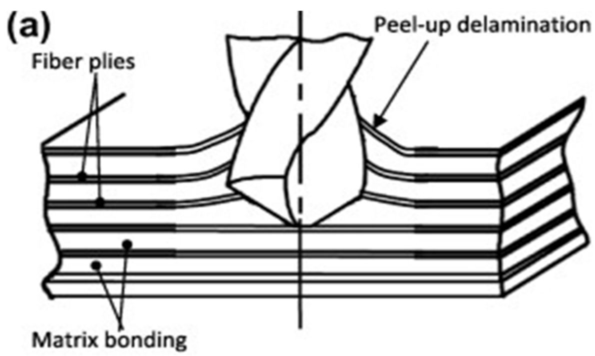


Figure 2: Peel up delamination

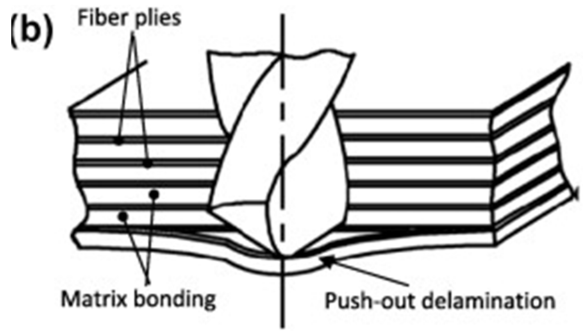


Figure 3: Push-out delamination

### *C. Optimization of process parameters*

The parameters chosen as the control variables at different levels like weight % if Si3N4, Speed, Feed rate, Diameter of drill, Machining time plays major role in the quality of drilled holes in the compoites in terms of circularity, cylindricity, surface roughness. The optimization of these parameters for the best quality holes can be done by choosing the optimum levels of the parameters to have good response. And to minimize the errors in quality terms. The optimization can be done using the mean effect plots and the S/N plots by analyzing the results using the Taguchi technique. And by performing ANOVA to know the degree of the effect of each parameter on the end result there by studying the effect of each parameter at chosen levels. Softwares like MINITAB has the features of creating array for combinations, analysis using Taguchi's technique and also ANOVA which makes the process simpler.

## II. LITERATURE REVIEW

Vignesh V[1]In this paper the objective of the work is to optimize process parameter such as cutting speed, feed, and drill diameter. Taguchi methods are widely used for design of experiments and analysis of experimental data for optimization of processing conditions. The research contributions are classified into methodology for investigation and analysis, input processing conditions and response variables. This paper focuses on the optimization of drilling parameters using the Taguchi technique to obtain minimum surface roughness (Ra). A number of drilling experiments were conducted using the L9 orthogonal array on a radial drilling machine. The experiments were performed on 7075 alloy with carbide tool drill. Analysis of variance (ANOVA) was employed to determine the most significant control factors affecting the surface roughness. The cutting speed, feed rate and drill diameter were selected as control factors. After the nine experimental trials, it was found that the drill diameter was the most significant factor for the surface roughness. The results of the confirmation experiments showed that the Taguchi method was notably successful in the optimization of drilling parameters for better surface roughness. Commercial software package MINITAB17 is used for performing the analysis. Ahmet Can[2]**.**This paper has presented and discussed machinability in the drilling of SMC (Sheet Mould Compound) A-Class composite materials using Taguchi's DoE method. The thrust forces, surface roughness and push-out - peel-up delamination behavior in drilling process for glass fibre reinforced SMC composites have been evaluated. The experimental results and the contribution ratio of parameters on machinability outputs have been statistically analysed by ANOVA. Analysis of variance shows that drill bit angle is the prominent parameter followed by feed rate and cutting speed that contributes towards output responses. Confirmation experiments performed with the optimum parameter condition levels show a reduction in thrust force, surface roughness, push-out delamination and peel-up delamination A detailed deformation analysis was investigated for SMC composites. For the empirical modelling of machinability, outputs of SMC composites can be modelled with the quadratic polynomial regression model in a higher range of accuracy. Sumesh A S[3] Focused on the optimization of drilling parameters using the Taguchi technique to obtain minimum surface roughness (Ra). A number of drilling experiments were conducted using the L9 orthogonal array on a radial drilling machine. The experiments were performed on cast iron using HSS twist drills. Analysis of variance (ANOVA) was employed to determine the most significant control factors affecting the surface roughness. The cutting speed, feed rate and drill diameter were selected as control factors. After the nine experimental trials, it was found that the drill diameter was the most significant factor for the surface roughness. The results of the confirmation experiments showed that the Taguchi method was notably successful in the optimization of drilling parameters for better surface roughness. Commercial software package MINITAB17 is used for performing the analysis. J.P. Davim and Pedro Reis[4] Presented a new comprehensive approach to select cutting parameters for damage-free drilling in carbon fiber reinforced epoxy composite material. The approach is based on a combination of Taguchi's techniques and on the analysis of variance

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(ANOVA). A plan of experiments, based on the techniques of Taguchi, was performed drilling with cutting parameters prefixed in an autoclave carbon fiber reinforced plastic (CFRP) laminate. The ANOVA is employed to investigate the cutting characteristics of CFRP using high speed steel (HSS) and Cemented Carbide (K10) drills. The objective was to establish a correlation between cutting velocity and feed rate with the delamination in a CFRP laminate. The correlation was obtained by multiple linear regression. Finally, confirmation tests were performed to make a comparison between the results foreseen from the mentioned correlation.

## III. EXPERIMENTATION AND RESULTS

The experimental work consists of drilling various % weight of $Si_3N_4$ in CFRP composite using Carbide drill bit. The machining was carried out in a CNC drilling machine. The spindle speeds,feed rate, drill diameters chosen from the literature survey are listed in the table below. The surface roughness of the hole drilled is determined using Surfcom flex, Delamination, Circularity, Cylindricity is measured using video measuring machine and CMM respectively. The Dynamometer is used to measure the thrust force and torque induced while drilling the composites. And Heat spy to measure the temperature of the tool. The recorded results from the experiments are noted in below tables.

Figure 4: CNC drilling machine

Table 1: Experimental results

| RUN | %VOL. OF Si3N4 | SPEED (RPM) | FEED RATE (mm/Rev.) | DIA. OF DRILL BIT (mm) | MACHINING TIME (Seconds) | TOOL TIP TEMP(0C) | THRUST FORCE (N) | TORQUE (N-m) |
|---|---|---|---|---|---|---|---|---|
| 1 | 0 | 360 | 0.095 | 6 | 30 | 52 | 25.42 | 0.55 |
| 2 | 0 | 490 | 0.190 | 6 | 60 | 54 | 41.18 | 0.77 |
| 3 | 0 | 680 | 0.285 | 6 | 90 | 64 | 36.28 | 0.84 |
| 4 | 0 | 360 | 0.095 | 8 | 60 | 65 | 40.2 | 0.79 |
| 5 | 0 | 490 | 0.190 | 8 | 90 | 70 | 56.8 | 1.36 |
| 6 | 0 | 680 | 0.285 | 8 | 30 | 72 | 41.18 | 1.54 |
| 7 | 0 | 360 | 0.095 | 10 | 90 | 60 | 34.32 | 1.59 |
| 8 | 0 | 490 | 0.190 | 10 | 30 | 65 | 51.97 | 2.24 |
| 9 | 0 | 680 | 0.285 | 10 | 60 | 69 | 41.18 | 2.48 |
| 10 | 6 | 360 | 0.285 | 8 | 60 | 59 | 49.03 | 1.59 |
| 11 | 6 | 490 | 0.095 | 8 | 90 | 52 | 42.17 | 0.97 |
| 12 | 6 | 680 | 0.190 | 8 | 30 | 42 | 44.13 | 1.43 |
| 13 | 6 | 360 | 0.285 | 10 | 90 | 53 | 45.11 | 2.38 |
| 14 | 6 | 490 | 0.095 | 10 | 30 | 56 | 29.42 | 1.55 |
| 15 | 6 | 680 | 0.190 | 10 | 60 | 61 | 33.34 | 2.24 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 16 | 6 | 360 | 0.285 | 6 | 30 | 45 | 20.59 | 0.79 |
| 17 | 6 | 490 | 0.095 | 6 | 60 | 49 | 21.57 | 0.38 |
| 18 | 6 | 680 | 0.190 | 6 | 90 | 52 | 18.63 | 0.70 |
| 19 | 10 | 360 | 0.190 | 10 | 90 | 45 | 44.13 | 2.12 |
| 20 | 10 | 490 | 0.285 | 10 | 30 | 55 | 53.93 | 2.47 |
| 21 | 10 | 680 | 0.095 | 10 | 60 | 56 | 34.32 | 1.54 |
| 22 | 10 | 360 | 0.190 | 6 | 30 | 41 | 43.15 | 0.79 |
| 23 | 10 | 490 | 0.285 | 6 | 60 | 44 | 58.84 | 0.89 |
| 24 | 10 | 680 | 0.095 | 6 | 90 | 50 | 21.57 | 0.57 |
| 25 | 10 | 360 | 0.190 | 8 | 60 | 43 | 61.78 | 1.32 |
| 26 | 10 | 490 | 0.285 | 8 | 90 | 51 | 94.14 | 1.55 |
| 27 | 10 | 680 | 0.095 | 8 | 30 | 56 | 29.42 | 0.98 |

Table 2: Experimental results

| RUN | %VOL. OF $SI_3N_4$ | SPEED (RPM) | FEED RATE (mm/Rev.) | DIA. OF DRILL BIT (mm) | MACHINING TIME (Seconds) | CYLINDRICI-TY (mm) | Ra(µm) | CIRCULAR-ITY(mm) | DELAMINATION ENTRY | DELAMINATION EXIT |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 0 | 360 | 0.095 | 6 | 30 | 0.101 | 5.77 | 0.010 | 1.075 | 1.071 |
| 2 | 0 | 490 | 0.190 | 6 | 60 | 0.046 | 4.77 | 0.002 | 1.083 | 1.081 |
| 3 | 0 | 680 | 0.285 | 6 | 90 | 0.170 | 6.15 | 0.006 | 1.092 | 1.07 |
| 4 | 0 | 360 | 0.095 | 8 | 60 | 0.032 | 9.91 | 0.009 | 1.083 | 1.089 |
| 5 | 0 | 490 | 0.190 | 8 | 90 | 0.097 | 4.74 | 0.016 | 1.072 | 1.068 |
| 6 | 0 | 680 | 0.285 | 8 | 30 | 0.071 | 7.23 | 0.010 | 1.066 | 1.093 |
| 7 | 0 | 360 | 0.095 | 10 | 90 | 0.073 | 6.60 | 0.031 | 1.07 | 1.077 |
| 8 | 0 | 490 | 0.190 | 10 | 30 | 0.056 | 11.04 | 0.012 | 1.046 | 1.076 |
| 9 | 0 | 680 | 0.285 | 10 | 60 | 0.070 | 13.41 | 0.038 | 1.05 | 1.057 |
| 10 | 6 | 360 | 0.285 | 8 | 60 | 0.021 | 7.641 | 0.014 | 1.066 | 1.092 |
| 11 | 6 | 490 | 0.095 | 8 | 90 | 0.036 | 9.08 | 0.034 | 1.073 | 1.087 |
| 12 | 6 | 680 | 0.190 | 8 | 30 | 0.021 | 4.86 | 0.019 | 1.068 | 1.098 |
| 13 | 6 | 360 | 0.285 | 10 | 90 | 0.081 | 6.62 | 0.016 | 1.083 | 1.126 |
| 14 | 6 | 490 | 0.095 | 10 | 30 | 0.059 | 12.17 | 0.015 | 1.072 | 1.098 |
| 15 | 6 | 680 | 0.190 | 10 | 60 | 0.047 | 4.54 | 0.025 | 1.067 | 1.112 |
| 16 | 6 | 360 | 0.285 | 6 | 30 | 0.059 | 5.61 | 0.038 | 1.07 | 1.115 |
| 17 | 6 | 490 | 0.095 | 6 | 60 | 0.023 | 9.47 | 0.011 | 1.075 | 1.119 |
| 18 | 6 | 680 | 0.190 | 6 | 90 | 0.058 | 4.07 | 0.004 | 1.052 | 1.12 |
| 19 | 10 | 360 | 0.190 | 10 | 90 | 0.038 | 3.813 | 0.012 | 1.035 | 1.095 |
| 20 | 10 | 490 | 0.285 | 10 | 30 | 0.054 | 4.20 | 0.002 | 1.031 | 1.086 |
| 21 | 10 | 680 | 0.095 | 10 | 60 | 0.075 | 3.69 | 0.018 | 1.043 | 1.078 |
| 22 | 10 | 360 | 0.190 | 6 | 30 | 0.186 | 3.55 | 0.100 | 1.031 | 1.077 |
| 23 | 10 | 490 | 0.285 | 6 | 60 | 0.040 | 2.72 | 0.010 | 1.023 | 1.063 |
| 24 | 10 | 680 | 0.095 | 6 | 90 | 0.043 | 4.94 | 0.012 | 1.036 | 1.069 |
| 25 | 10 | 360 | 0.190 | 8 | 60 | 0.049 | 4.45 | 0.011 | 1.027 | 1.062 |
| 26 | 10 | 490 | 0.285 | 8 | 90 | 0.027 | 4.5 | 0.022 | 1.037 | 1.056 |
| 27 | 10 | 680 | 0.095 | 8 | 30 | 0.011 | 1.21 | 0.014 | 1.032 | 1.048 |

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
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## IV. OPTIMISATION OF CUTTING PARAMETERS WHILE DRILLING CFRP- $Si_3N_4$ MATERIAL

The current work concerns with the drilling of CFRP material. The CFRP material selection is mainly due to the specific characteristics and heavy usage in the field of engineering and manufacturing sectors. The experiments were performed based on Taguchi's L27 orthogonal array. The input parameters were % weight of $Si_3N_4$, speed, feed rate, drill diameter and the response parameters were Delamination, Surface roughness, Circularity, and Cylindricity. The main objective of optimization was performed based on Taguchi's method of analysing results and ANOVA. It uses the S/N ratio as a measure of quality characteristics deviating from or nearing to the desired values. There are three categories of quality characteristics in the analysis of the S/N ratio, i.e. the smaller the better, the higher the better, and the nominal the better. Smaller the better approach is used in the current work. And higher the S\N ratio the efficiency will be more and thereby good productivity is achieved.

Smaller the better: It is used where the smaller value is desired.

The details of the experiments and the results with supporting discussion are presented in this chapter.

### *A. Observations On Circularity*

Typical monitored response plots on Circularity based on S/N ratio are shown in Fig 5.

From the Figure 5 the main effect plots for CFRP composite material that, the factor Feed rate has largest effect on the Circularity as the response variable. The optimum level for a factor is the level that gives the highest value of η in the experimental region.

From the above Figure 5 it is clear that:

1) The deviation in the Circularity of the hole increases with the increase in % weight of $Si_3N_4$ from 0 to 6%, further it decreases when the % reinforcement of $Si_3N_4$is increased from 6 to 10%.
2) The deviation in the Circularity increases continuously with increase in the diameter of drill from 6 to 10 mm.
3) The deviation in the Circularity of the hole decreases with the increase in the speed from 360 to 490rpm, then it increases with further increase in speed from 490 to 680rpm.
4) The deviation in the Circularity of the hole decreases with the increase in the feed rate from 0.095 to 0.190 mm/rev, further it will increase with the increase in feed rate from 0.190 to 0.285 mm/rev.
5) Similar trend follows for the factor machining time as it decreases from 30 to 60 seconds the deviation increases and further it increases with increase in machining time from 60 to 90 seconds.

The optimum levels of the control factors which gives good Circularity is as summarized in the Table 3.

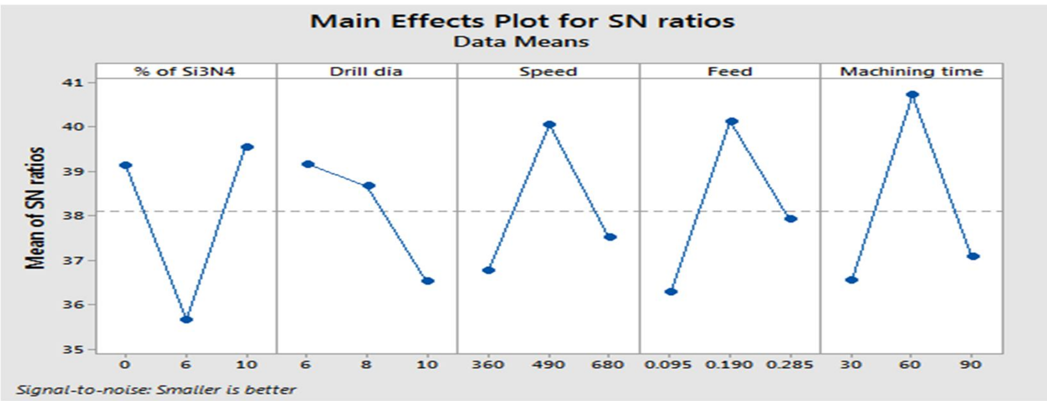


Fig 5: Main effects Plot for Circularity

Table 3: Optimized parameters for CFRP composite material Circularity

| Control Factors | | Optimum level | Unit |
|---|---|---|---|
| A | % weight of $Si_3N_4$ | 10 | % |
| B | Speed | 490 | rpm |
| C | Feed | 0.190 | mm/rev |
| D | Diameter of drill bit | 6 | mm |
| E | Machining time | 60 | sec |

Table 4: Magnitude of effect of various factors on the Circularity

| Level | % weight of $Si_3N_4$ | Speed | Feed | Dia. of drill bit | M/T |
|---|---|---|---|---|---|
| 1 | 22.89 | 24.23 | 24.64 | 27.98 | 25.58 |
| 2 | 27.94 | 29.14 | 26.55 | 25.17 | 27.70 |
| 3 | 26.99 | 24.45 | 26.64 | 24.67 | 24.55 |
| Delta | 5.05 | 4.91 | 2.01 | 3.30 | 3.15 |
| Rank | 1 | 2 | 5 | 3 | 4 |

The term delta in the Table 4 indicates the difference between the higher and lower levels. The rank can also be given based on this value of delta. The MINITAB software directly gives this value for every factor. The larger value of delta means that factor is having more effect on the response variables. The feed rate has larger delta value compare to the other control factors in the table 4, hence the feed rate has got first rank followed by % of $Si_3N_4$.Similarly the responses for the Cylindricity, Surface roughness and delamination can be done.

### *B. Observations On Cylindricity*

Typical monitored response plots on Cylindricity based on S/N ratio are shown in Fig 6.

From the Figure 6 the main effect plots for CFRP composite material that, the factor drill diameter has largest effect on the Cylindricity as the response variable. The optimum level for a factor is the level that gives the highest value of η in the experimental region.

From the above Figure 6 it is clear that:

1) The deviation in the Cylindricity decreases with the increase in % weight of $Si_3N_4$ from 0 to 6%, further it will increase with the increasing of % weight of $Si_3N_4$ from 6% to 10%.
2) The deviation in the Cylindricity decrease with increase in the diameter of drill from 6 to 8mm further it increases with increase in drill diameter from 8 to 10mm.
3) The deviation of the Cylindricity of the material decrease with the increase in the speed from 360 to 680 rpm.
4) The deviation of the Cylindricity of the material increases with the increase in the feed rate from 0.095 to 0.285 mm/rev.
5) As the machining time increases the deviation of Cylindricity value decreases from 30 to 60 seconds and it further increases when M/T is increased from 60 to 90 seconds.

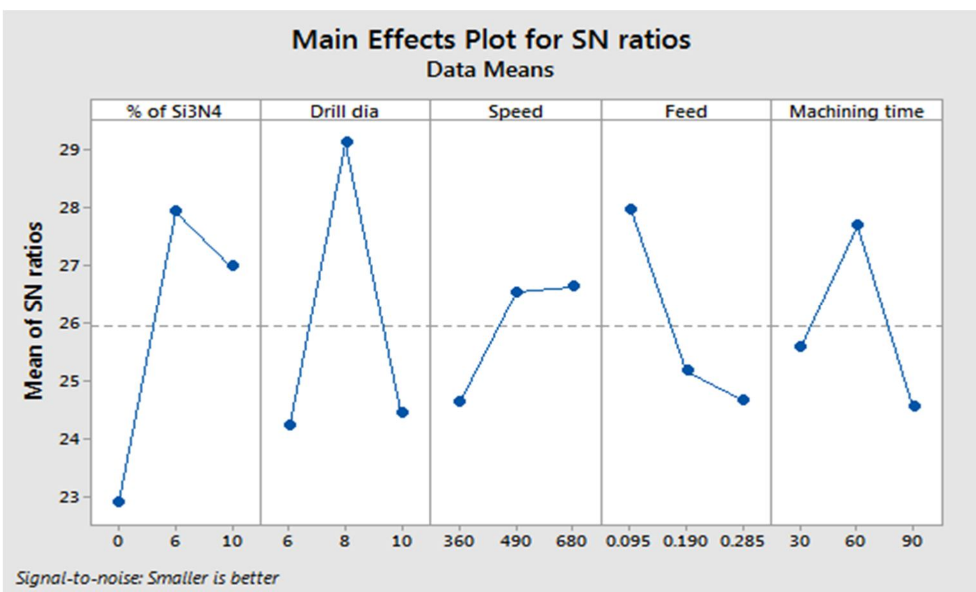


Fig 6: Main effects Plot for Cylindricity

Therefore the optimum levels of the control factors which give good Cylindricity are summarized in the Table 5 for CFRP composite material.

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*ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.177*
*Volume 7 Issue VI, June 2019- Available at www.ijraset.com*

Table 5: Optimized parameters

| Control Factors | | Optimum level | Unit |
|---|---|---|---|
| A | % weight of $Si_3N_4$ | 6 | % |
| B | Speed | 680 | Rpm |
| C | Feed | 0.095 | mm/rev |
| D | Diameter of drill bit | 8 | mm |
| E | M/T | 60 | Sec |

### *C. Observations On Delamination*

Typical monitored response plots on Delamination (Fd) based on S/N ratio are shown in Fig 7.

From the Figure 7 the main effect plots for CFRP composite material that, the factor % of $Si_3N_4$has largest effect on the Delamination (Fd) as the response variable. The optimum level for a factor is the level that gives the highest value of η in the experimental region.

From the below Figure 7 it is clear that:

1) The Delamination (Fd) of the material increases with the increase in % weight of $Si_3N_4$ from 0 to 6%, further it decrease with increases in % weight of $Si_3N_4$ from 6 to 10%.
2) The Delamination (Fd) of the material decreases with the increases in the speed from 360 to 490RPM further it increases with increase in speed from 490 to 680 RPM.
3) The Delamination (Fd) increases with the increase in feed rate from 0.095 to 0.190mm/rev, further it decreases with increase in feed rate from 0.190 to 0.285mm/rev.
4) As the drill diameter increases from 6 to 8mm the delamination decreases and it increases on further increase in drill diameter from 8 to 10mm.
5) Machining time appears to have lesser effect comparatively and it comes around the average line.

The optimum levels of the control factors for reduced Delamination (Fd) are summarized in the Table 6 for CFRP composite material.

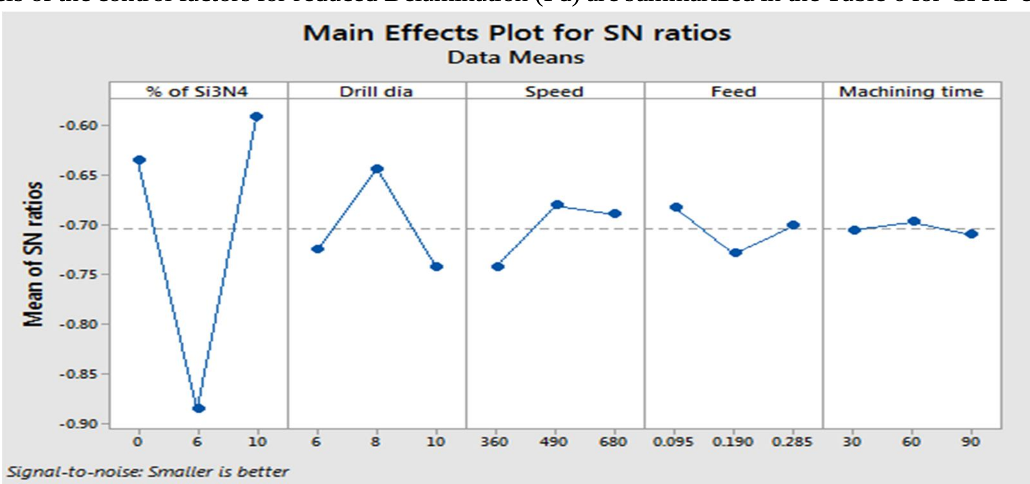


Fig 7: Main effects Plot for Delamination

Table 6: Optimized parameters

| Control Factors | | Optimum level | Unit |
|---|---|---|---|
| A | % weight of $Si_3N_4$ | 10 | % |
| B | Speed | 490 | Rpm |
| C | Feed | 0.095 | mm/rev |
| D | Diameter of drill bit | 8 | mm |
| E | M/T | 60 | Sec |

### *D. Observations On Surface Roughness*

The typically monitored response plots on surface roughness (Ra) based on S/N ratio are shown in below Fig 8

From the Figure 8 the main effect plots for CFRP composite material that, the factor weight % of $Si_3N_4$ has larger effect on the Surface Roughness (Ra) of the material as a response variable. Therefore the optimum level for a factor is the level that gives the highest value of η in the experimental region.

From the below Figure 8 it can be seen that:

*1)* The surface roughness (Ra) increases with the increase in % weight of $Si_3N_4$ from 0 to 10%.
*2)* The surface roughness (Ra) decreases with the increase in drill diameter from 6 to 10mm.
*3)* The surface roughness (Ra) of the material increases with the increase in the speed from 360 to 680rpm.
*4)* The surface roughness (Ra) increases with the increase in feed rate from 0.095 to 0.190mm/rev, further it decreases with increases in feed rate from 0.190 to 0.285mm/rev. There by having mixed effect over it.
*5)* The surface roughness (Ra) decreases initially with increase in machining time from 30 to 60 seconds and then increases with further increase in machining time from 60 to 90 seconds.

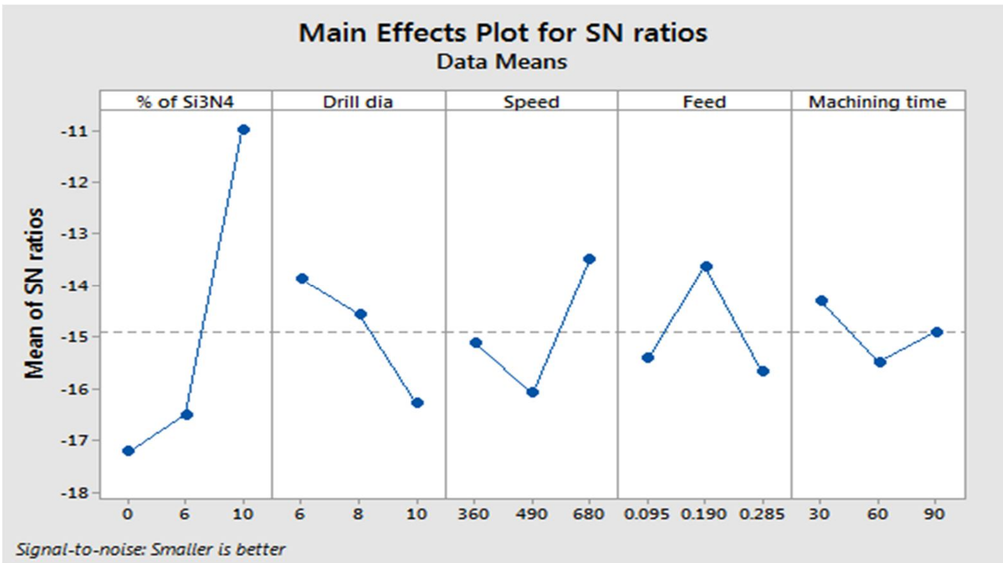


Fig 8: Main effects Plot for Surface roughness

Therefore the optimum levels of the control factors which give good surface finish (Ra) are summarized in the Table 7 for CFRP composite material

Table 7: Optimized parameters for CFRP composite material

| Control Factors | | Optimum level | Unit |
|---|---|---|---|
| A | % weight of $Si_3N_4$ | 10 | % |
| B | Speed | 680 | Rpm |
| C | Feed | 0.190 | mm/rev |
| D | Diameter of drill bit | 6 | mm |
| E | Machining time | 30 | sec |

## V. CONCLUSION

In this study, it was all about the optimization of effect of process parameters on the quality of drilled holes and the results fairly shows the improvement in the quality of holes and the major effect of the weight % of $Si_3N_4$ in the material, which increases as the increase in the weight % of $Si_3N_4$ from 0 to 10% and the quality of holes fairly increase in terms of circularity, Cylindricity and surface finish. The feed rate and speed had the next major impact as the speed increases to some extent the productivity decreases same with the feed rate and the drill dia had the converse effect as the diameter of drill increases the error kept decreasing, and the optimum value of these variables for better results is as shown in the above table. So therefore from the results these levels of each parameters makes the better quality holes.

## VI. ACKNOWLEDGEMENT

Centre for Excellence in Mechanical Machine Design, Department of Mechanical Engineering P.E.S.C.E, Mandya. I would like to thank my Guides Dr H V Ravindra and Mr. Rakshith Gowda D.S and also our beloved HOD Dr. H.P Raju who rendered me the opportunity work on this project, optimization of process parameters in drilling of CFRP reinforced with different percentage of silicon nitride using Taguchi method.

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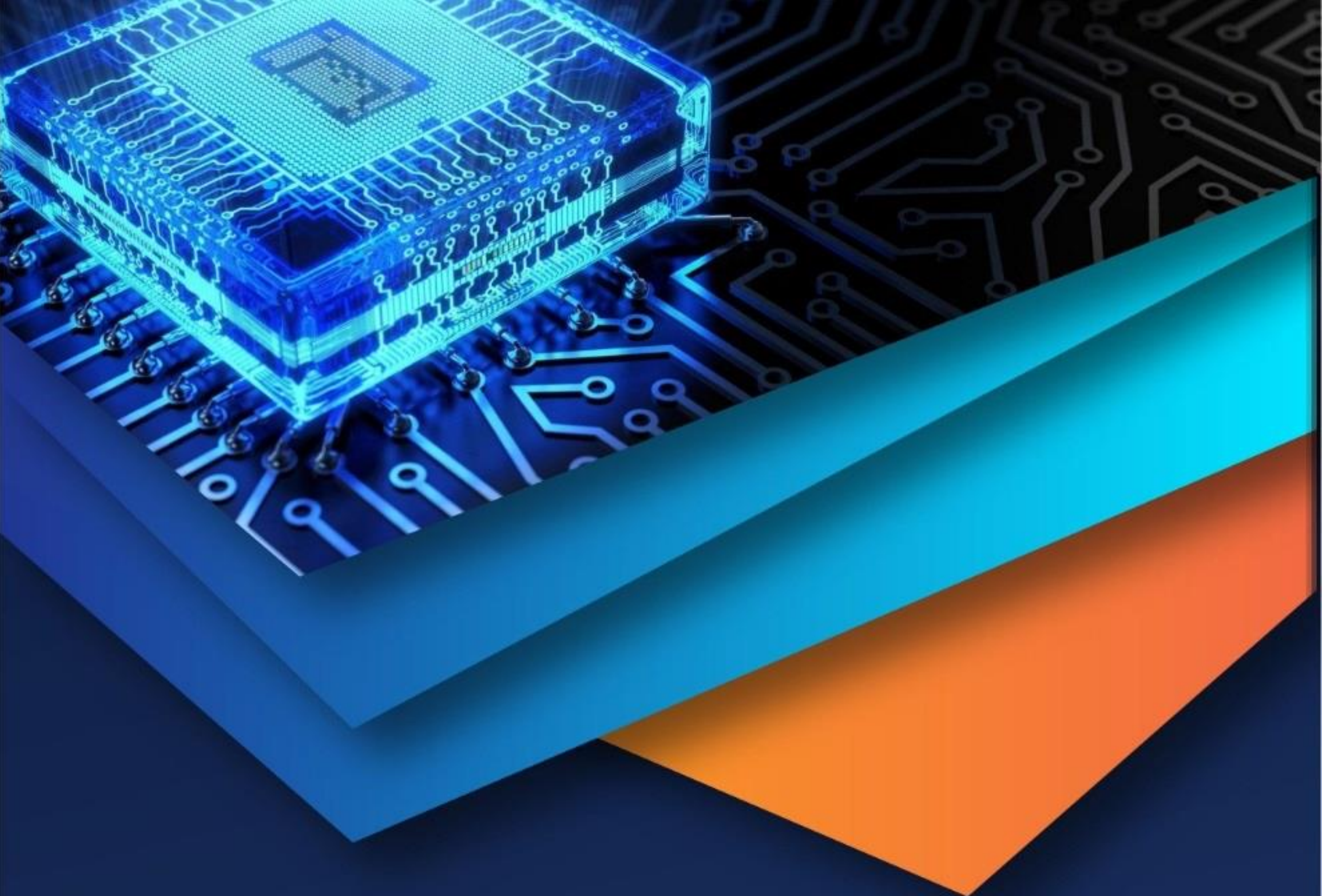


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