# Analysis and Optimization of Delamination Factor during Drilling of E-Glass/Epoxy Composite by Taguchi Method

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***Abstract*** *Composites are widely being used to replace the conventional metals in many industrial applications including Aircraft, Aerospace and defence due to its high strength to weight ratio. Delamination is the common problem that is faced during the drilling of composites. This paper presents the effect of Feed rate, Cutting speed and Drill Bit Material on delamination behaviour on composite material by conducting drilling experiments using* $L_9$ *orthogonal array. The output parameters considered here is Delamination factor the corresponding Material Removal rate (MRR), Thrust Force, Torque and Power are calculated. The effects of these parameters on Delamination will be studied based on the experimental results , also useful recommendations will be given in order to select the suitable process parameters in Drilling of a GFRP composite using Taguchi Technique.*

***Key words-*** *Composite, Delamination, Taguchi, GFRP.*

## I. INTRODUCTION

Delamination is defined as the separation of the layers of material in a laminate composite material. Delamination can occur at any time in the life of a laminate for various reasons and has various effects. It can affect the tensile strength performance depending on the region of delamination. Among the various defects that are caused by drilling, delamination is recognized as the most critical. Other defects are spalling and fiber pullout, but delamination can result in a reduction in the durability of the composite material and can cause a reduction in the bearing strength of the material and the structural integrity, resulting in performance issues. Hocheng and Tsao [4] have done a lot of work towards minimizing delamination during drilling. Their successful work includes studying various drill bits and developing mathematical equations to reduce delamination. Hocheng and Tsao [4] and Lachaud et al. [5] have successfully managed to drill holes without delamination, without back up at the exit, by clamping the plates and developing equations for the thrust force applied.

The main objective of this paper is to investigate the influence of the cutting parameters, such as Drill bit Material, feed rate and Cutting Speed on delamination produced when drilling a GFRP composite using Taguchi method design. The analysis of experimental results is carried out using main effect graphs. The constituents and their corresponding contents of a Eglass Epoxy were tabulated in the table below

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**Table 1:** Constituents of Eglass Epoxy

| SL No | Constituents | % by wt |
|---|---|---|
| 1 | $SiO_2$ | 53-55 % |
| 2 | $Al_2O_3$ | 14-15.5 % |
| 3 | CaO - MgO | 20-24 % |
| 4 | $B_2O_3$ | 6.5-9 % |
| 5 | $Fe_2O_3$ - $TiO_2$ | < 1 % |
| 6 | $Na_2O$-$H_2O$ | < 1 % |

**Table 2:** E-Glass Epoxy Composite Material Properties

| SL NO | Name of the Property | Values |
|---|---|---|
| 1 | Plate Dimension | 310 x 310 |
| 2 | Thickness | 5 mm |
| 3 | No of layers | 4 |
| 4 | Fiber Volume | 42.6% |
| 5 | Resin Volume | 57.34 |
| 6 | Mass of the Plate | 0.845 Kg |
| 7 | Density | 1750 Kg / mm$^3$ |
| 8 | Direction of the fiber | Unidirectional |

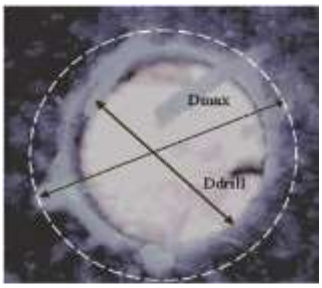


**Figure 1:** Delamination effect in drilling of GFRP composite

Where,

Delamination Factor = $\frac{DMax}{D}$

$D_{MAX}$ = Maximum diameter (mm), D = Drill diameter (mm)

## II. EXPERIMENTAL DESIGN

This method uses a special design of orthogonal arrays to study the entire parameter space with small number of experiments only. The experimental results are then transformed into signal-to-noise (S/N) ratio. Taguchi recommends the use of the S/N ratio to measure the quality characteristics deviating from the desired values. Usually there are three categories of quality characteristics deviating from the desired values i.e. the lower the better, the higher the better and the nominal is the better. The S/N ratio for each level of process parameter is computed based on S/N ratio analysis. A greater S/N ratio corresponds to the better quality characteristics. The s/n ratio are derived from quadratic loss function, three of them are considered to be standard and widely applicable.

Nominal is Best: $S/N = 10*\log (y_{avg}^2 / S^2)$

Smaller is Best: $S/ N = -10*\log ( 1/n\Sigma yi^2)$

Larger is Best: $S/ N = -10*\log( 1/n \Sigma 1/yi^2)$

Where $y_{avg}$ is average of observed data and $S_2$ is the variation of y, n is the no. of observation and y is the observed data.

**Table 3:** Factors and levels for the Experiments

| **Variables** | **Drill Bit** | **Feed Rate** | **Cutting Speed** |
|---|---|---|---|
| **Levels** | **Material (A)** | **(B)** | **(C)** |
| **unit** | **-** | **mm/rev** | **rpm** |
| 1. | HSS Tool | 0.01 | 900 |
| 2. | Carbide Tool | 0.03 | 1200 |
| 3. | HSSE Tool | 0.05 | 1500 |

The Experiments were carried out on SX XHMT vertical drilling machine with 3 factors and 3 levels and the experiments were conducted by using L9 orthogonal array and Smaller the Better is selected as a quality characteristics for Delamination. Figure 2 and 3 shows the VMC and workpiece with delamination after machining .

**Figure 2**: Vertical drilling Center

**Figure 3:** Delamination on the composite materials after drilling

**Table 4 :** S/N ratio's of the experiments

| | **Experiment condition Matrix** | | | **Delamination** | |
|---|---|---|---|---|---|
| | | | | **Mean(N)** | **S/N (dB)** |
| 1 | 1 | 1 | 1 | 1.0128 | -0.08869 |
| 2 | 1 | 2 | 2 | 1.0068 | 0.02296 |
| 3 | 1 | 3 | 3 | 1.0112 | -0.0211 |
| 4 | 2 | 1 | 2 | 1.0016 | -0.04348 |
| 5 | 2 | 2 | 3 | 0.998 | -0.02221 |
| 6 | 2 | 3 | 1 | 0.9925 | -0.02114 |
| 7 | 3 | 1 | 3 | 1.0007 | -0.02341 |
| 8 | 3 | 2 | 1 | 1.0029 | -0.03494 |
| 9 | 3 | 3 | 2 | 1.0037 | -0.02848 |

## III. EFFECT OF OUTPUT PARAMETERS

**Material Removal Rate**

Material removal rate in drilling is the volume of material removed by the drill per unit time. For the drill with diameter D, the cross sectional area of the drilled hole is $(\pi/4)*D^2$ the velocity of the drill perpendicular to the work piece is the product of the feed f (the distance the drill travels into the work piece per revolution) and the rotational speed N

**Thrust Force**

The thrust force in drilling acts perpendicular to the hole axis. If this force is excessive, it can cause the drill to bend or break. An excessive thrust force can also distort the work piece, particularly if it does not have sufficient stiffness or it can cause the work piece to slip into the work holding fixture.

**Torque**

The knowledge of the magnitude of the torque in drilling is essential for power requirements. The power dissipated during drilling is the product of torque and rotational speed. The torque during drilling is difficult to calculate.

Power P = $\frac{2\pi NT}{60}$ T = Torque in (Nm)

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**Table 5:** Values of MRR, Power, torque and Thrust Force

| **Mrr** | **Power** | **Torque** | **Thrust force** |
|---|---|---|---|
| $mm^3$ / s | Watts | N_m | N |
| 12.56 | 6.28 | 0.04 | 7.56 |
| 22.61 | 11.30 | 0.12 | 23.99 |
| 50.26 | 25.13 | 0.2 | 39.24 |
| 7.53 | 3.76 | 0.04 | 7.91 |
| 62.83 | 31.41 | 0.2 | 39.36 |
| 30.15 | 15.07 | 0.12 | 23.65 |
| 37.69 | 18.84 | 0.12 | 39.14 |
| 10.05 | 5.02 | 0.04 | 7.06 |
| 37.69 | 18.84 | 0.12 | 23.64 |

From the table it is found that The Metal Removal Rate ranges from a minimum of 7.53 $mm^3$/S and a maximum of 62.83 $mm^3$/S, Power varies from 3.76 W to 31.41 W, Torque ranges from 0.04 N-m to 0.2 N-m and the Trust force Ranges from 7.06 N to 39.36 N

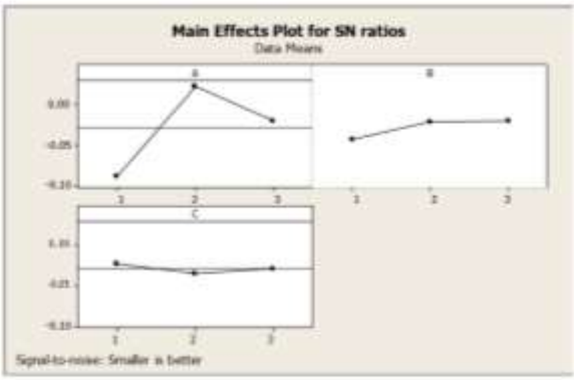


**Fig:4**

From the above S/N ratio plot it is found that the optimum values with Drill bit as Carbide tool, Speed as 900 RPM and Feed rate of 0.05mm/rev

## IV. CONCLUSION

The Drilling of GFRP (Unidirectional) Composite has been investigated by the Taguchi method. Three important parameters that is the drill bit material, cutting speed and feed rate have been studied. The following conclusions are drawn from the investigation. The optimum levels of the drill bit material, cutting speed and feed rate have been established for making damage free holes in GFRP (Unidirectional) Composite. The optimum delamination damage is recorded with Carbide Tool at cutting speed of 900 rpm and feed rate 0.05 mm/rev. corresponding Metal removal rate, Power, Torque and Thrust Force were Recorded and it s found that The Metal Removal Rate ranges of 7.53 $mm^3$/S to 62.83 $mm^3$/S, Power varies from 3.76 W to 31.41 W, Torque ranges from 0.04 N-m to 0.2 N-m and the Trust force Ranges from 7.06 N to 39.36 N.

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