EXPERIMENTAL ANALYSIS IN DRILLING OF GLASS FIBER REINFORCED PLASTIC (GFRP) COMPOSITE MATERIALS USING TAGUCHI METHOD

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ABSTRACT

Glass fiber reinforced plastic (GFRP) composite materials are increased application in aeronautical, automobile and structural applications. Most of fiber reinforced composite (GFRP) material parts are processed to a near net shape, machining is often like finishing, trimming, drilling, grinding, etc. Among the several research processes, drilling of composite materials causes several damage modes, such as: de-lamination, fiber pull out, edge chipping, spalling, uncut fibers, surface roughness and dimensional errors and others. During machining, the reduction of tool wear is an important aspect. The objective of this study was an optimization technique has been developed to predict the de-lamination on the machining of GFRP composites using Taguchi method in order to study the main and interaction effects of machining parameters, viz., cutting speed, feed rate, spindle speed. Drilling test is carried out on E- glass fibre composites using two different HSS twist drills with same tool geometry.

KEYWORDS: Glassfiber reinforced plastic (GFRP), High speed steel (HSS), Electrical resistance glass fiber (E-Glass)

1.INTRODUCTION

Drilling Process

Drilling is the operation of producing circular hole in the work-piece by using a rotating cutter called DRILL..

De-lamination

Among the several research processes, drilling of composite materials causes several damage modes, such as: de-lamination, fiber-pull out, swelling, edge chipping, uncut fibres, surface roughness and dimensional errors and others. De-lamination is considered as the major concern.

A. Peel up de-lamination

Peel-up is caused by the cutting force pushing the abraded and cut materials to the flute surface.

The cutting edge of the drill will first abrade the laminate initially. It then, by moving forward, tends to pull the abraded material away along the flute.

Before material is machined completely it spirals are up. This action introduces a peeling force upwards to separate the upper laminas from the uncut portion held by the downward acting thrust force.

B. Push down de-lamination

The laminar under the drill thus tend to be drawn away from the inter-laminar bond around the hole. At the end of the drill, the uncut thickness becomes smaller and the resistance to deformation decreases. In particular point, the loading exceeds the inter-laminar bond strength and de-lamination occurs.

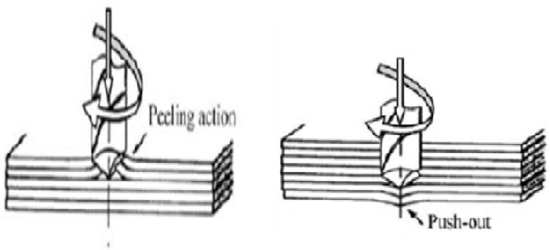

Fig. 1.1 peel-up and push down de-lamination

C. De-lamination Factor (F_d)

An index or factor called de-lamination factor (F_d) is used to determinate the extent of de-lamination

$F_d = D_{max}/D$

D_{max} is the maximum diameter created due to de-lamination around the hole and D is the hole or drill diameter. At a critical thickness, the bending stress becomes greater than the inter-laminar strength between the plies and an inter-laminar crack is initiated around the hole.

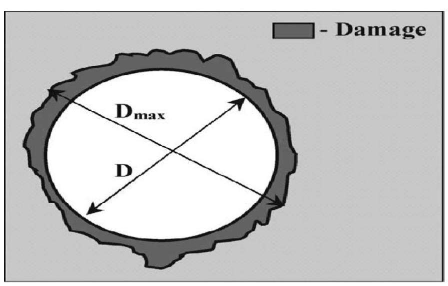

Fig 1.2 de-lamination factor

Further pushing down by the drill point causes the crack to propagate and the flexural rigidity of the supporting plies becomes weaker. This leads to fracturing the material below the drill point as the chisel edge proceeds to exit the laminate. The damage at exit plies is shown as spalling that extends beyond the diameter of the hole.

2.EXPERIMENTAL SETUP

The following processes are following. The experiment flow chart is shown in Fig. 2.1

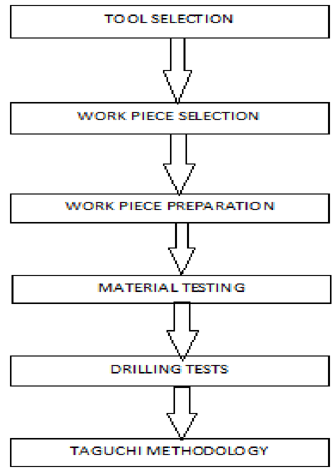

Fig 2.1 Experimental Flow Chart

3. MATERIALS AND EXPERIMENTAL SETUP

A. TOOL MATERIAL SELECTION

From this experiment, the analysis is mostly depending on the tool (drill bit) selection. The uncoated and diamond coated drill bits are used in the experiments to drilling the GFRP composite materials.

3.1 Uncoated HSS Twist Drill Bit

The twist drill bit was invented by Steven A. Morse of East Bridgewater, Massachusetts in 1861.The original method of manufacture was to cut two grooves in opposite sides of a round bar, then to twist the bar (giving the tool its name) to produce the helical flutes. Twist drill bits range in diameter from 0.002 to 3.5 in (0.051 to 88.900 mm) and can be as long as 25.5 in (650 mm)

Twist drill bits are available in the widest choice of tooling materials. However, even for industrial users, most holes are drilled with standard high speed steels bits.The most common twist drill bit (sold in general hardware stores) has a point angle of 118 degrees, acceptable for use in wood, metal, plastic, and most other materials.

Fig 3.1 Uncoated HSS Twist Drill Bit

3.2 Diamond Coated HSS Twist Drill Bit

Fig 3.2Diamond Coated HSS Twist Drill Bit

Diamond drill bits will machine hardest material, including those materials that other conventional types of abrasives, carbide and high speed steel will not. Diamond drills/ bits will drill materials faster, produces smoothes surface finish quality, provide consistent performance & yield (cost per part) possible.

B. Work Piece Material

E-Glass is a low alkali glass with a typical nominal composition of SiO2 54wt%, Al2O3 14wt%, CaO+MgO 22wt%, B2O3 10wt% and Na2O+K2O less then 2wt%. Some other materials may also be present at impurity levels

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Fig 3.3 E-Glass Fiber Mate

C. Work Piece Preparation

In this study, bi-directional glass fiber reinforced plastic composite laminate specimens with 40% fiber volume ratio were prepared with E-glass fiber using epoxy resin by hand lay-up process. The work piece material specimen size of 120 × 120 × 5 mm was cut from a laminate.

The laminates were composed of 4layers; fibers were unidirectional (UD) E-Glass. The applied resin was epoxy, araldite Ly 556 with hardener HY (anhydride hardener). The thickness of the laminate was 5mm.

D. Hand-Layup Process

Fig 3.4Hand Layup Process

Four layered UD-GFRP specimens of 5mm thickness were prepared using the hand lay-up process. The reinforcement was in the form of unidirectional E-glass fiber mat and the matrix was epoxy, araldite Ly 556 with hardener HY (anhydride hardener).

A gel coat was applied on the mould prior to the lay-up process to facilitate easy removal of the laminate. Specimens were cured at room temperature for 24 hr in ambient conditions

Fig 3.5 E-glass fiber

F. Material Testing

The material testinglike,tensile molding and impact testing to be conducted.The testing results are carried out in below table.

SPECIMEN (E- GLASS FIBRE)	TENSILE STRENGTH (Mpa)	IMPACT STRENGTH (J)
100*100*3MM	49.98	22.250
100*100*4MM	54.08	22.354
100*100*5MM	59.36	22.434

Table 3.2 Material Testing of E-Glass Fiber

G. Drilling Tests

De-lamination in drilling is an important concern, it affects the work piece quality consequently the joint conditions in the composite structures. During drilling many factors affect the de-lamination. Feed rate is an important factor, which affects the quality of drilled holes. The spindle speed also has some effect on de-lamination.

Fig.3.6 experimental setup

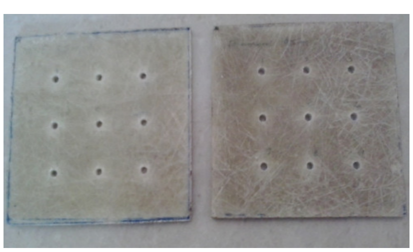

Fig 3.7View of Entrance Side of Drilled Holes for Different Cutting Parameters by Both Drills

Design of Experiments

Taguchi method is a powerful tool in quality optimization makes use of a special design of orthogonal array (OA) to examine. Number of experiments used to design the orthogonal array for 2 parameters and 3 levels of drilling parameters.

This technique is based on orthogonal arrays to reduce the number of experiment to be executed. An L_9 orthogonal array is chosen to conduct de-lamination test an L_9 design of experiments would be the full factor test. Table shows the factors with their levels.

Experiment No	Spindle Speed	Feed Rate
1	1	1
2	1	2
3	1	3
4	2	1
5	2	2
6	2	3
7	3	1
8	3	2
9	3	3

Table 3.3 Design of Experiment

H. Analysis Of Variance(ANOVA)

The reason for doing an ANOVA is to see if there is any difference between groups on some variable.For example, you might have data on student performance in non-assessed tutorial exercises as well as their final grading. You are interested in seeing if tutorial performance is related to final grade.

4. DE-LAMINATION FACTOR

A drilling test was conducted to evaluate the effect of cutting parameters on the damage at work piece. The damage around the work piece was measured using a toolmaker micros scope.

After measuring the maximum diameter D_{max} in the damage around each hole, the de-lamination factor is determined by utilizing equation as mentioned in the section II for both

drills. Table IV illustrates the influence of cutting parameters on the de-lamination factor.
From the table 3.3 it was observed that the de-lamination factor was vary with feed rate and spindle speed for both uncoated and diamond coated HSS twist drill.

Test no	Spindle speed	Feed rate	De-lamination factor	
			Uncoated	Diamond coated
1	2000	25	1.064	1.056
2	2000	30	1.084	1.052
3	2000	35	1.162	1.066
4	2400	25	1.106	1.060
5	2400	30	1.090	1.049
6	2400	35	1.092	1.062
7	2800	25	1.150	1.041
8	2800	30	1.128	1.062
9	2800	35	1.126	1.087

Table 4.1 Orthogonal Array and Experimental Results

The highest value of de-lamination factor was observed from the table 2 is 1.162 for uncoated and 1.087 for diamond coated drill bit. The lowest value of de-lamination factor was 1.064 for uncoated and 1.041 for diamond coated drill bit.

The formula used for calculating S/N ratio is given below.

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

S/N ratio (η) = $-10 \log_{10} 1/n \sum_{i=1}^{n}(yi\^2)$

Where,

y_i= observed response value and

n = number of replications.

Nominal the best: It is used where the nominal or target value and variation about that value is minimum.

S/N ratio (η) = $-10 \log_{10} (\mu^2/\sigma^2)$

Where,

μ = mean and

σ = variance.

Higher the better: It is used where the larger value is desired.

S/N ratio (η) = $-10 \log_{10} 1/n \sum_{i=1}^{n} 1/(yi\^2)$

Where,

y_i= *observed* response value and

n = number of replications.

Here, I prefer

Lower-the-better

n = -10 Log$_{10}$ [mean of sum of squares of {measured - ideal}]

Test number	Feed rate	Spindle speed	De-lamination factor	S/N ratio
1	25	2000	1.064	23.8764
2	30	2000	1.084	21.5144
3	35	2000	1.162	15.8097
4	25	2400	1.106	19.4939
5	30	2400	1.090	20.9151
6	35	2400	1.092	20.7242
7	25	2800	1.150	16.4782
8	30	2800	1.128	17.8558
9	35	2800	1.126	17.9926

Table 4.2S/N Response Table for De-lamination Factor (Uncoated)

From the above table we can clearly seen that the de-lamination factor is indirectly proportional to the S/N ratio. It is also vary with the varying feed rates and spindle speeds. For smaller de-lamination factor we get the higher S/N ratio for both the drill bits.

The highest value of S/N ratio is 23.8764 for uncoated and 27.7443 for diamond coated drill bit. The lowest value of S/N ratio was 15.8097 for uncoated and 23.6091 for diamond coated drill bit.

Test number	Feed rate	Spindle speed	De-lamination factor	S/N ratio
1	25	2000	1.056	25.0368
2	30	2000	1.052	25.6799
3	35	2000	1.066	23.6091
4	25	2400	1.060	24.4370
5	30	2400	1.049	26.1961
6	35	2400	1.062	24.1522
7	25	2800	1.041	27.7443
8	30	2800	1.062	24.1522
9	35	2800	1.087	27.2096

Table 4.3 S/N Response Table for De-lamination Factor (Diamond Coated)

From the table 4.2 the lowest de-lamination factor occurs at the feed rate 25 mm/min and spindle speed 2000 rpm for drilling E-glass fiber by uncoated HSS twist drill bit.

From the table 4.3 the lowest de-lamination factor occurs at the feed rate 25 mm/min and spindle speed 2800 rpm for drilling E-glass fiber by diamond coated HSS twist drill bit.

5. RESULTS AND DISCUSSIONS

5.1 Effects of De-Lamination Factor

After finding the de-lamination factor and S/N ratio, the mean values are predicted and the graphs are plotted between the de-lamination factor and varying parameters like feed rate and spindle speed for both drills called main effects for means shown in fig 5.1 to 5.4.

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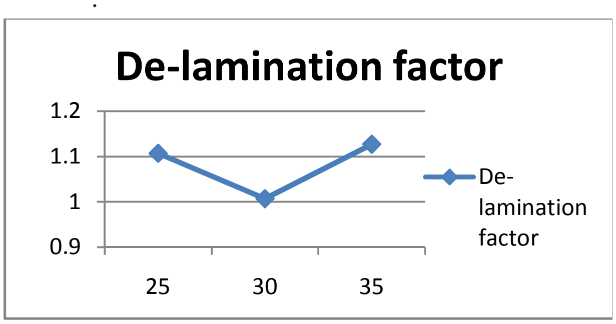

Fig 5.1 Feed rate Vs de-lamination factor for uncoated drill bit

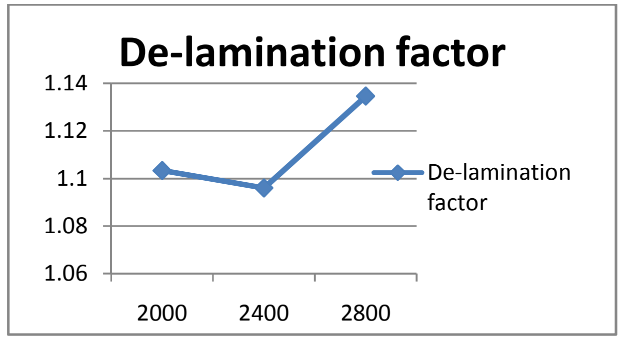

Fig 5.2 Spindle speed Vs de-lamination factor for uncoated drill bit

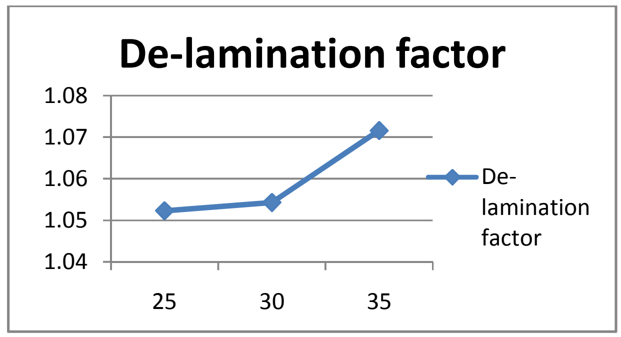

Fig 5.3 Feed rate Vs de-lamination factor for diamond coated drill bit

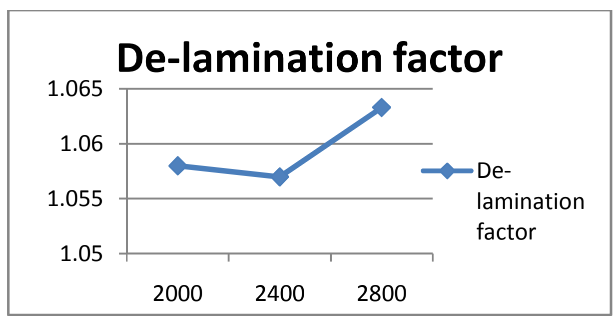

Fig 5.4 Spindle speed Vs de-lamination factor for diamond coated drill bit

At the same time the graphs plotted between the de-lamination factor, feed rate and spindle speed called interaction effects for means for both uncoated and diamond coated HSS twist drill bits shown in fig 8.6 and 8.7It is clearly indicate the path of de-lamination factor for varying feed rate and spindle speed. Path I- de-lamination factor for varying feed rate (25mm/min, 30mm/min and 35mm/min) at constant spindle speed (2000rpm).

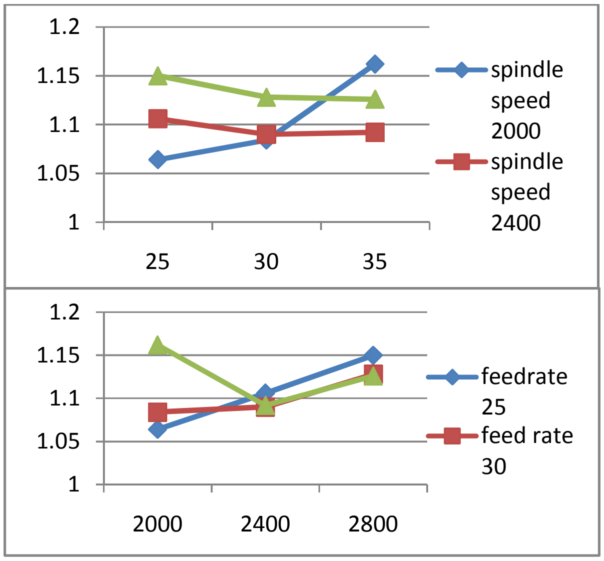

Fig 5.5 Interaction effects for means (uncoated)

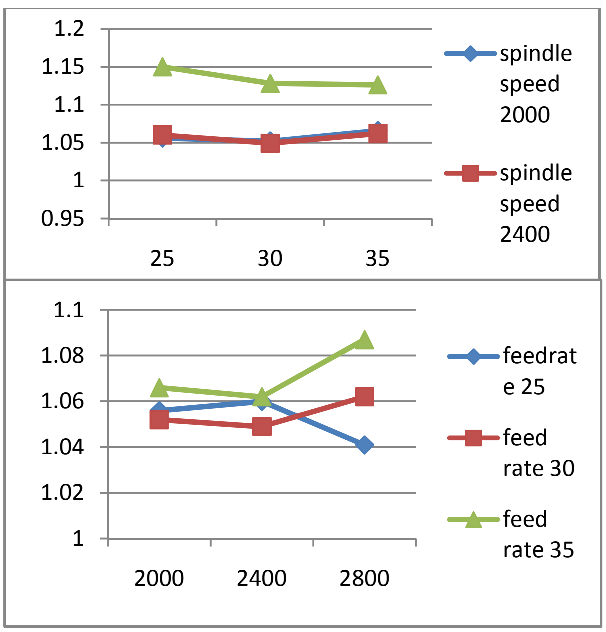

Fig 5.6 Interaction effects for means (diamond coated)

It is clearly indicate the path of de-lamination factor for varying feed rate and spindle speed.

From the graphs it is seen that the spindle speed decreased from 2800rpm to 2400rpm, the de-lamination factor decreases for uncoated drill bit. And also the feed rate decreased from 35mm/min to 30mm/min, the de-lamination factor decreases for diamond coated drill bit.

6. CONCLUSION

The optimization of cutting process parameters namely speed and feed rate in drilling glass fiber reinforced polymer (GFRP) composites using the application of Taguchi and ANOVA analysis the conclusion drawn from this work are as follows:

The optimum process parameters in the drilling of GFRP composites are

- **Uncoated** drill bit **-** Speed of **2000 rpm,** feed rate at **25 mm/min** for the de-lamination are found to be optimum parameters.
- **Diamond coated** drill bit**-** Speed of **2800 rpm,** feed rate **25 mm/min** and for the de-lamination are found to be optimum parameters.
- The **ANOVA** results reveal that's that **spindle speed** is most significant influencing on the de-lamination factor for the **uncoated** drill bit.
- **Speed** is the most significant influencing on the de-lamination factor for the **diamond coated** drill bit.

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