Scientific Journal of Impact Factor (SJIF): 4.72
e-ISSN (O): 2348-4470
p-ISSN (P): 2348-6406

International Journal of Advance Engineering and Research Development

Volume 4, Issue 11, November -2017

Investigation of the Machinability Characteristics on Delamination during Drilling of Hybrid Reinforced Epoxy Polymer using Taguchi Approach

[1]Balamurugan M, [2]Boobalakrishnan P

[1]*Assistat Professor, Government College of Engineering, Bodinayakanur, Tamilnadu, India*
[2]*PG Scholar, Government College of Technology, Coimbatore, Tamilnadu, India*

Abstract: *Nowadays quality plays a vital role in all the products. Hence, the development in manufacturing process focuses on the fabrication of composite with high dimensional accuracy and also incurring low manufacturing cost. The composites, especially epoxy polymer composites have important advantages because of its superior mechanical properties such as high strength to weight ratio, high wear resistance, corrosion resistance, electrical resistance, and etc. It can replace the traditional materials for manufacturing different components with required properties. The major applications of these composites are in electronic industry, automobile industry and aerospace industry. But machining of these composites is dissimilar to conventional metals due to their isotropic nature and in-homogeneity. Major drawbacks of these composites in machining are fiber pull out, delaminating and burring of fibers. So, appropriate selection of process parameters is an important concern in machining of GFRP composites. So, appropriate selection of process parameters is an important concern in machining of GFRP composites. This work mainly focuses on assessing the effects of process parameters i.e. spindle speed, feed on Delamination factor in drilling of GFRP composites.*

KEYWORDS: *Taguchi method, Epoxy polymer composites, E-glass fiber, GFRP, Delamination factor*

I INDRODUCTION

Composite is a combination of two or more material having individual chemical, mechanical and physical properties. After combining these materials, the property of the particular material change and a better single material is obtained, as a composite. Now this composite have many advantages of being used in fields like shipping, aerospace, and aircraft industries. A composite has enough specific stiffness, high specific strength ,less thermal expansion coefficient, high moisture absorption ability with time and a real ability for corrosion protection.

. Mankind was aware of and using composite materials from ancient times in improving the quality of life. In recent times the development and application of composite materials in all branches of engineering are occurring at an increasingly fast pace. Contemporary composites are the results of research and innovations during the last few decades when these progressed from glass fibre for automobiles to particulate composites for aerospace. Some define composite as "materials composed of two or more distinctly identifiable constituents". But modern composites developed for specific purposes like flake, particulate and laminar composites defy such definitions. Fibres or particles embedded in matrix of another material which are mostly structural are latest developments. Glass fibre reinforced polymer (GFRP) is one such composite developed for structural applications.

GFRP composites are used in fairings, passenger compartments, storage room doors due to their high mechanical properties. Drilling using twist drill is the most common operation of secondary machining for fiber-reinforced materials. However, composite laminates are regarded as hard-to-machine materials, which results in low drilling efficiency and undesirable drilling-induced Delamination.

For rivets and bolted joints, damage-free and precise holes must be drilled in the components to ensure high joint strength and precision. However, composite laminates are non-homogeneous, anisotropic, and highly abrasive and have hard reinforcement fibers, which make them difficult to machine. Among the problems caused by drilling, Delamination is considered the major damage. It was reported that, in aircraft industry, the rejection of parts consist of composite laminates due to drilling-induced Delamination damages during final assembly was as high as 60%; Wong T.L et.al, (1982)

Defu Liu, Yongjun Tang and W.L Cong. (2012) mentioned that amongst all machining operations, drilling using twist drill is the most commonly applied method for generating holes. A large number of experiments were conducted by Lee SC, Park J N, Chen W C,(1995), Wang X, Davim JP(2004), Tsao CC, Hocheng H(2004, 2005) to research the influence of input variables (spindle speed, feed rate, and drill bit geometry) on output variables (Delamination & thrust force). Park KY, Choi JH & Lee DG (1995) firstly introduces grinding drilling to reduce Delamination by improving drilling performance. Tsao CC & Hocheng H(2004) investigated that Delamination generally resulted from excessive thrust force and smaller Delamination holes could be obtained when grinding drilling composite laminates .

A low (<1000 Hz) or high (>1000 Hz) frequency and low amplitude vibration if superimposed on a twist drill bit along the feed direction during drilling could reduce the Delamination. Ramkumar J, Malhothra SK, Krishnamurthy R (2004) found that the thrust by (vibration-assisted twist drill) VATD was reduced by 20–30%, compared with conventional drilling. Therefore, VATD used to reduce the Delamination damage during drilling of composite laminates.

Unlike conventional drilling operation, high speed drilling operation of composite laminates has to be conducted in a high speed drilling machine system which is very expensive. Investigators revealed that the Delamination tendency decrease with increased in cutting speed and the combination of low feed rate and point angle was also essential in minimizing Delamination during high speed drilling of composite laminates. H. Hochenga, C.C. Tsao(2006) studied effects of special drill bits on Delamination of composite materials and found that core drill was able to with stand the highest feed rate with reduced Delamination. From literature it is clear that twist drill bits made of HSS or carbides are the primary attraction in drilling of composite laminates among various drill bits. However, the applications of other drill bits in drilling of composite laminates are also very extensive to improve machinability of composite laminates.

Most of investigators found that using drill bits with different geometry and materials in drilling of composite laminates gave more advantages & benefits. For practical machining of GFRP, it is necessary to determine the optimal machining parameters to achieve less Delamination etc. Optimization of process parameters is the important criterion in the machining process to achieve high quality. Most of the studies on GFRP show that eliminating Delamination is very difficult. K Palanikumar.K. (2011) conducted experiments on GFRP composites using Brad & Spur drill and optimized drilling parameters by using two input variables with four levels and concluded that low feed rate and high spindle speeds were beneficial to reduce Delamination. Previous researchers carried out the experiments with three or four levels for optimisation of input parameters.

In the present study the experiments are carried out using Twist drill (Carbide drill with point angle 90^0 and diameter10 mm) to find the optimum drilling parameters using Taguchi's L_9 orthogonal array.

II. FABRICATION OF GFRP COMPOSITE

2.1 Material Selection

The material selection for the component is selected as composite material which has high specific density and high impact resistance over the conventional material.

The study of composite materials is carried out and the selection of material for matrix and fibers was done. The matrix material is selected as Epoxy resin and reinforcement as E-glass fibber. Epoxy based composites provide good performance at room temperature and elevated temperatures. Epoxies can operate well up to temperatures of 200 to 250°F. Epoxy is a versatile resin system, which exhibits low shrinkage as well as excellent adhesion to a variety of substrate materials. Glass is found in abundance and glass fibers are cheapest among all other types of fibers. Three major types of glass fibers are E-glass, S-glass and S2-glass. When the cost factor is taken into consideration, E-glass fiber is selected.

2.2 Material Properties

Table 1 Material Properties of the Composite components

Material	Elastic Modulus in GPa	Density in g/cm^3
Epoxy (Matrix)	(2.5 - 5.0)	(1.2 - 1.4)
E - Glass fibre (Reinforcement-I)	72.35	2.54
Kevlar fibre (Reinforcement-II)	129	1.44

2.3 Die Preparation For Test Specimen

The die is prepared as per ASTM standards. The dimension of test specimen is 150 x 85 x1 5 mm.

Figure 1 Photographic view of die for specimen

2.4 Manufacturing of test Specimen

The manufacturing of test specimen is done **by** Hand lay-up process. The process is performed with the following materials.

i. Matrix- Epoxy resin
ii. Reinforcement -Glass fiber, Kevlar fiber
iii. Polyvinyl Acetate- Releasing Agent
iv. Hardener –ARADUR HY 951

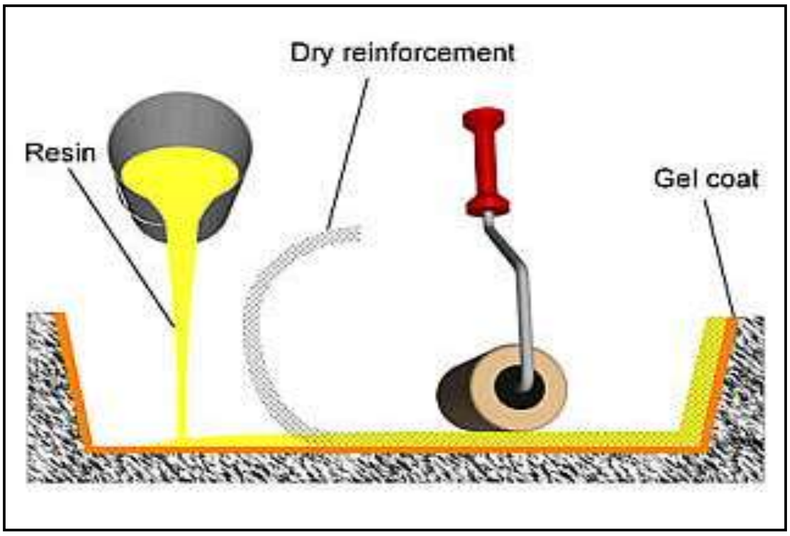

Fig 2 Hand lay-up process

Initially, the releasing agent is applied to the inner sides of the die where the composite material is in contact. The hardener and epoxy resin are mixed in a separate beaker according to the volume fraction. The glass and kevlar fibers are cut into the shape of die and the weight of fibers is measured based on the volume fraction. The process is started by applying the mixture hardener and resin as 1^{st} layer and glass and Kevlar fibers are alternatively applied. The process is continued until the thickness gets covered. After applying up to the thickness of mold, the material is allowed to cure for 1 day in room temperature. The composite material is then cut into pieces according to the dimensions of standard test specimen.

The composite material is manufactured with three different volume fractions is shown in the table.

Table 2 Volume fraction of samples

S.No	Matrix %	Reinforcement 70%	
		Fiber 1- Kevlar	Fiber 2- E glass
1	30	55	45

Figure 3 Test Specimen

III DRILLING PROCESS AND DELAMINATION MECHANISM

The two mechanisms associated with delamination during drilling of polymer matrix composites are known as peel-up at the drill entrance and push-down at the drill exit.

3.1 Peel-up Delamination

As the drill bit touches the composite workpiece, the cutting edge of the drill abrades the laminate. As the tool further penetrates, this abraded material is pulled along flute and spirals up. This action peels up the upper laminae from the uncut portion under the tool and is known as Peel-up Delamination.

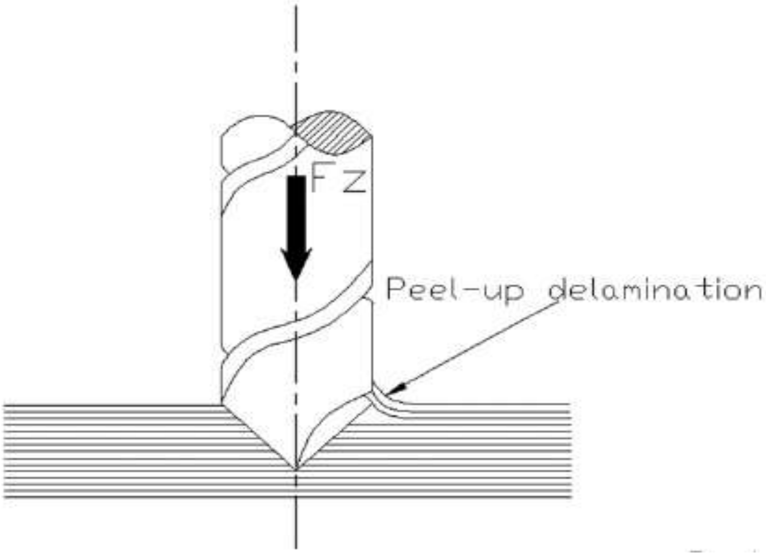

Figure 4 Peel-up delamination

3.2 Push – down Delamination

At the exit, as the uncut thickness becomes smaller and resistance to deformation decreases, the inter-lamina bonding failure produces Push-down Delamination.

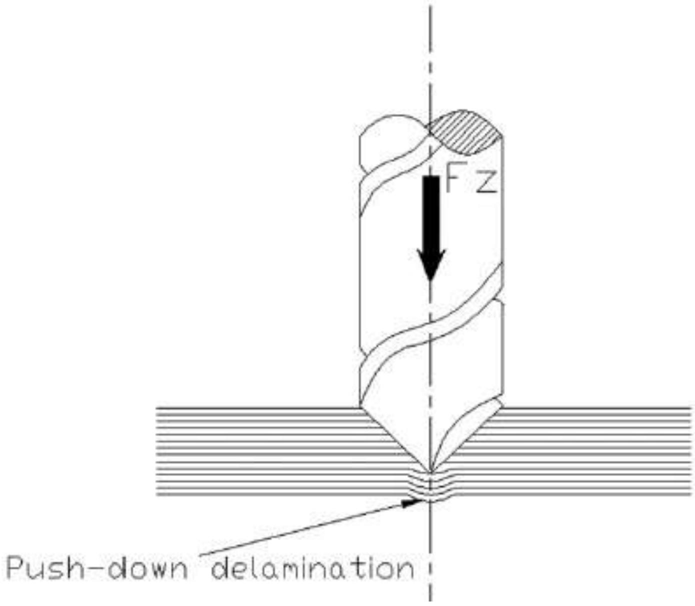

Figure 5 Push - down delamination

Delamination factor was taken as the measure of performances for this material & spindle speed (N) and feed rate (f) were chosen as drilling parameters.

Experiments were conducted based on Taguchi L-9 orthogonal array design.

3.3 Delamination factor (F_d)

An index or factor called delamination factor (F d),

Fd = (Dmax/D) is used to determinate the extent of delamination.

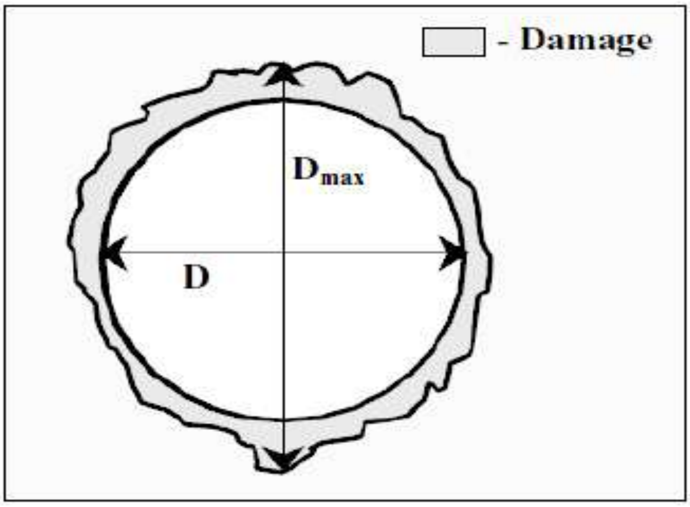

Figure 6 Delamination factor

Alternatively the ratio of delaminated area to the hole area has been used to determine the extent of delamination by D_{max} is the maximum diameter created due to delamination around the hole and D is the hole or drill diameter.

3.4 Drilling Tool and CNC Milling Machine

The tools used for drilling in the present experiment is carbide drill. The drill has point angle 90 degree and diameter of 10 mm was used for the drilling operation. Drilling was carried out on a CNC milling machine. In modern CNC systems, end to end component design is highly automated using computer aided design (CAD) and computer aided manufacturing (CAM) programs. The Profile Projector was used to measure the maximum diameter due to delamination around the hole.

IV EXPERIMENTAL DESIGN USING TAGUCHI METHOD

4.1 Design of Experiments (DOE)

DOE is an important tool for designing processes and products. DOE is a method for quantitatively identifying the correct inputs and parameter levels for making a high quality product. A proper design of experiments is conducted to perform more accurate, less costly and more efficient experiments.

4.2 Taguchi Experimental Design Method

In order to minimize the number of tests required, Taguchi experimental design method which is a powerful tool for designing a high quality system was developed by Taguchi. This method uses a special design of orthogonal arrays to study the entire parameter space with a small number of experiments. In this study, two machining parameters were used as control factors and each parameter was designed to have three levels (Table 3). Minitab software was used for Taguchi analysis.

Table 3 Drilling parameters and levels

Parameters	Level 1	Level 2	Level 3
Speed (rpm)	800	1200	1600
Feed (mm/rev)	100	150	200

Delamination factor is taken as the measure of performances for this material. The feed rate (f) and spindle speed (N) were chosen as drilling parameters.

The experimental design was according to an L_9orthogonal array based on Taguchi method (table 4).

Table 4 Taguchi L_9 orthogonal array

Experiment No	Feed rate (mm/min)	Spindle speed (rpm)
1	800	100

2	800	150
3	800	200
4	1200	100
5	1200	150
6	1200	200
7	1600	100
8	1600	150
9	1600	200

Figure 7 Drilled work piece based on Taguchi L_9 Orthogonal Array

V RESULTS AND DISCUSSIONS

5.1 Experimental Results

The Delamination factor is used to determine the extent of Delamination. The Delamination factor is also called as Index factor. Table 3 illustrates the influence of cutting parameters on the Delamination factor.

Table 5 Experimental results

Experiment No	Spindle Speed (rpm)	Feed rate (mm/min)	Delamination Factor
1	800	100	1.1777
2	800	150	1.1881
3	800	200	1.2097
4	1200	100	1.1709
5	1200	150	1.1791
6	1200	200	1.2595
7	1600	100	1.1963
8	1600	150	1.2203
	1600	200	1.1867

From the result it can be observed that the delamination is increasing with feed rate and decreasing with the spindle speed.

5.2 Signal to Noise ratio (S/N)

In the Taguchi method, Signal to Noise ratio (S/N) is the measure of quality characteristics and deviation from the desired value.

By applying equation given below, the S/N values for these experiments of L_9 were calculated and tabulated in Table 7.2. The signal to noise ratio were calculated using the condition lower is the better (LB).

$$LB : S/N\_ratio = -10 \cdot \log_{10}\left[\frac{1}{r}\sum_{i=1}^{r} y^2\right]$$

The highest S/N ratio always yields the optimum quality with minimum variance. Therefore, the level with a higher value reveals the optimum level of each factor. So the optimal cutting parameters for the delamination were obtained as based on the response value from Table 6.

Delta:

Measures the size of the effect by taking the difference between the highest and lowest value for each characteristic response.

Rank:

Orders the factors from the greatest effect (based in the Delta values) to the least effect on the characteristic response.

Table 6 S/N response table for delamination factor (F_d)

Level	Spindle speed	Feed
1	-1.524	-1.449
2	-1.602	-1.552
3	-1.591	-1.715
Delta	0.078	0.265
Rank	2	1

5.3 Main Effects Plot for S/N Ratio

Based on the graph 7.1 of the S/N ratios, the optimal cutting parameters for the delamination were obtained as feed rate at Level 1 (100 mm/rev) and the cutting speed at Level 1 (800 rpm), where S/N values are high.

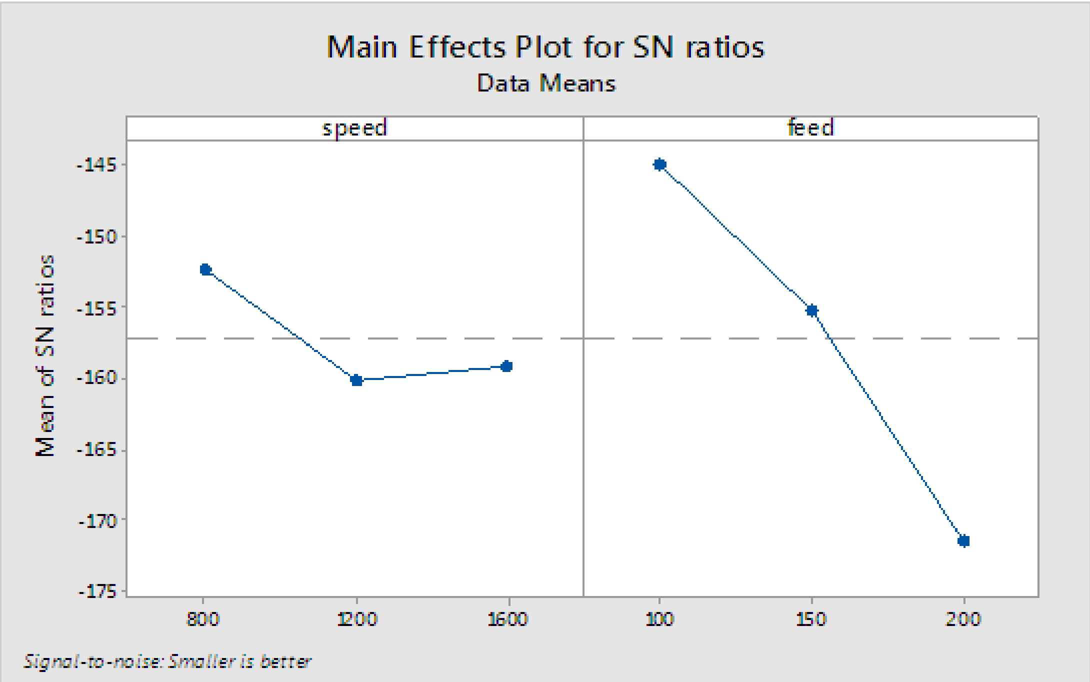

Figure 8 S/N ratios Feed (mm/rev) Vs. Speed (rpm)

5.4 Main Effects Plot for Means

The main effect plot for means of feed rate and spindle speed on delamination factor are shown in Figure 9 From these graphs, it can be observed that the at 1200 rpm there is a sudden increase in the delamination factor against excepted lower value, This is due to the reason that when the drill speed increases so consequent severe heat generation in drilling area leads to softening of the fiber and matrix. It can also be observed that the feed rate increases from 100 mm/rev to 150 mm/rev, the delamination factor increases. Further it can be observed that the lowest delamination is at the spindle speed 800 rpm and feed rate of 100 mm/rev.

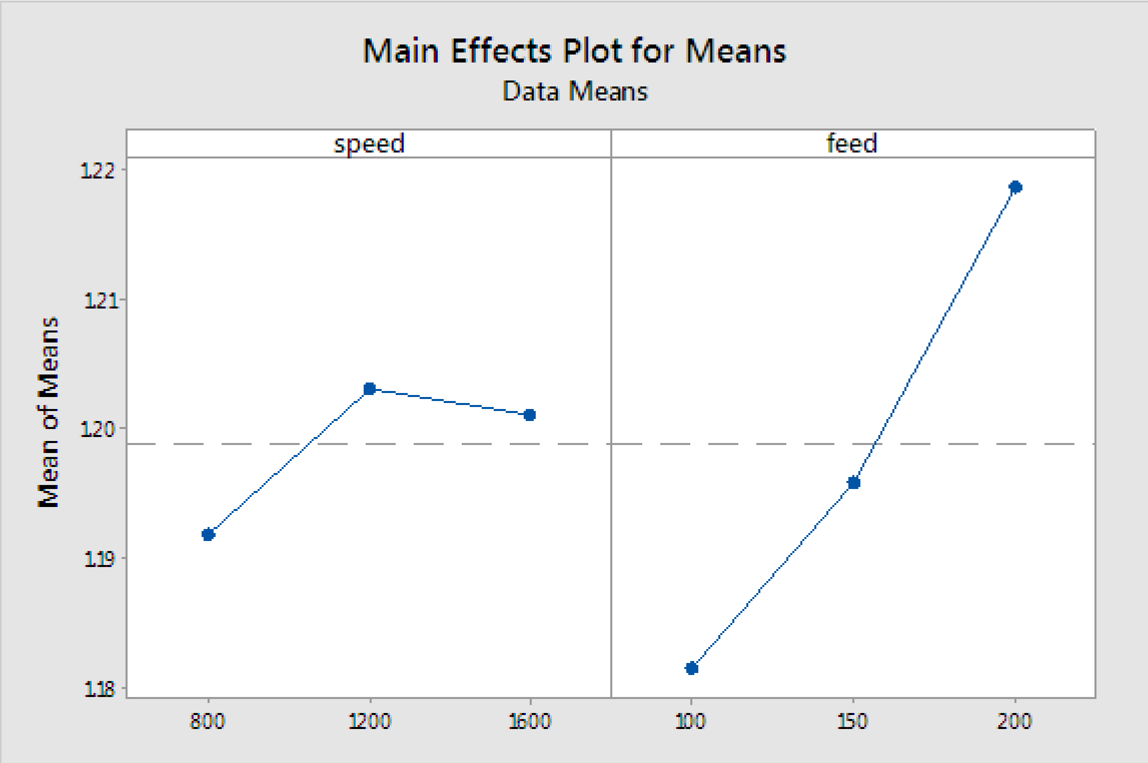

Figure 9 Main effect plot for means

5.5 Response table for Means

From the table 7, the Delta values for feed rate are more compared to the delta values of spindle speed. The Rank for feed rate is 1 and that of spindle speed is 2. So the feed rate affects the delamination factor more than spindle speed.

The optimal cutting parameters for the delamination were obtained as feed rate at Level 1 (100 mm/rev) and the cutting speed at Level 1 (800 rpm) based on response table for means in Table.

Table 7 Response table for means

Level	**Spindle speed**	**Feed**
1	1.192	1.182
2	1.203	1.196
3	1.201	1.219
Delta	0.011	0.037
Rank	2	1

VI PREDICTION FOR OPTIMIZED VALUE AND CONFIRMATION TEST

From S/N analysis and mean response characteristics, the optimum levels of Delamination factors were calculated as Level 1 for feed rate and Level 1 for spindle speed. The predicted value is calculated using below equation

$$F_{d\ opt} = y + (A_1 - y) + (B_1 - y)$$

Where,

Y is the average of Delamination factor to all the readings. A_1 and B1 are the average values of the delamination factor with input parameters at their respective optimal levels.

Y=1.1987, A_1=1.1918 and B_1=1.1816, Substituting these values in above equation the mean optimum value of Delamination factor has been predicted as

$F_{d\ opt}$=1.1747

In Taguchi optimization technique confirmation experiment was required to be conducted for validating of the optimized condition.

Table 8 Results of confirmation experiments and predicted values of Delamination factor

Trial 1	Trial 2	Mean	Predicted
1.1731	1.1702	1.1716	1.1747

Table 8.1 shows the result obtained and compared with the predicted values. The experimental values are less than 5%error with the predicted values.

VII CONCLUSION

The hybrid composites were prepared by using Kevlar and Eglass reinforced Epoxy hybrid composites by hand-lay-up technique. The application of Taguchi method for the Delamination study of drilling this hybrid composite was done.

The analysis of experimental results is carried out using Taguchi L_9orthogonal array. The reason for higher Delamination at spindle speed 1200 rpm, when the drill speed increases so severe heat generation in the drilling area leads to softening of the fiber and matrix.

The results reveal that feed rate is the main cutting parameter than spindle speed, which has greater influence on the Delamination factor.

From the S/N ratio, optimal parameters for the minimum Delamination are the feed rate at Level 1 (100 mm/rev) and the spindle speed at Level 1 (800 rpm).

The predicted values of Delamination at optimized process parameters were good condition where the experimental values pose are than 5% error with the predicted values.

The predicted values of Delamination at optimized process parameters were good condition where the experimental values pose are than 5% error with the predicted values

REFERENCE

[1]. Silvio Leonardo Valença a, SandroGriza a, Vandalucia Gomes de Oliveira a, Eliana Midori Sussuchi b, FredericoGuilherme de Carvalho Cunha c, 2014, "Evaluation of the mechanical behavior of epoxy composite reinforced with kevlar plain fabric and glass/kevlar hybrid fabric", part b.

[2]. V. Fiore and A. VAlenzA, 2008, "Epoxy resins as a matrix material in advanced fiber-reinforced polymer (FRP) composites", University of Palermo, Italy.

[3]. P.B.N.Reis, J.A.M.Ferreira, P.Santos, M.O.W.Richardson, J.B.Santos, 28 May 2012, "Impact response of Kevlar composites filled with epoxy matrix", Composite Structure 94(2012) 3520-3528.

[4]. Chensong Dong, Ian J. Davis, "Optimal design for the flexural behavior of glass and carbon fibre reinforced polymer hybrid composite", 25 January 2012, Materials and design 37 (2012) 450-457.

[5]. M.T.Isa, A.S.Ahmed, B.O.Aderemi, R.M.Taib, I.A.Mohammad-Dabo, "Effect of fibre type and combinations on the mechanical, physical and thermal stability properties of polyster hybrid composites", 17 April 2013, Composites: Part B 52 (2013) 217-223.

[6]. M.Jawaid, H.P.S.Abdhul Khalil, "Cellulosic/synthetic fibre reinforced polymer hybrid composites: A review", 28 April 2011, Carbohydrate polymers 86 (2011) 1-18.

[7]. Yangoli Zhang, Yan Li, Hao Ma, Tao Yu, "Tensile and interfacial properties of unidirectional flax/glass fibre reinforced hybrid composites", 11 September 2013, Composites Science and Technology 88 (2013) 172-177.

[8]. Chensong Dong, Ian J. Davies, "Flexural and Tensile Moduli of Unidirectional Hybrid Epoxy Composites Reinforced by S-2 Glass and T700S Carbon Fibres".

[9]. L. C. Hollaway, "Advanced fibre-reinforced polymer (FRP) composite materials in bridge engineering: materials, properties and applications in bridge enclosures, reinforced and prestressed concrete beams and columns ", 2013, Woodhead Publishing Limited.