ANALYSIS OF DELAMINATION AND SPECIFIC CUTTING ENERGY OF A COMPOSITE MADE OF VINYL ESTER RESIN AND CHOPPED GLASS FIBERS DURING DRILLING

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ABSTRACT

Composites are being used as most interesting group of materials. Drilling is frequently used as secondary machining operation for building assemblies. The material anisotropy resulting from fiber reinforcement influences material removal rate and power consumption during drilling. A proper selection of tool geometry, drilling parameters like speed, feed can influence these parameters. In this paper, effect of three cutting speeds, three feed rates, three tool geometries on two chemically different structures of composite made up of thermosetting vinyl ester resin and one fourth inch long glass fiber by compression molding were compared for specific cutting energy and delamination. A plan of experiments, based on the techniques of Taguchi was established. The analysis of variance, signal-to-noise ratio and regression analysis were performed to investigate the specific cutting energy. Conclusions showed that the influence of proper selection of tool and cutting parameters on material removal rate, structure of composite and power consumption. It was observed that the highest specific cutting energy was achieved by using smallest point angle at high speed. The main contributing factor for highest specific cutting energy was observed to be feed followed by speed and point angle of the drill. For all combination of the point angle, speed and feed, the delamination factor was found to be zero.

KEYWORDS: *Delamination, Specific cutting energy, compression molding, taguchi, ANOVA.*

I. INTRODUCTION

A composite material can be defined as amalgamation of a matrix and a reinforcement, which when combined gives properties superior to the properties of the individual components. In the case of a composite, the reinforcement is the fibers and is used to fortify the matrix in terms of strength and stiffness. The reinforcement fibers can be cut, aligned, placed in different angles to affect the properties of the resulting composite. They have shown a promising future in areas such as automotive, aeronautical, railways, and nautical industries, sport goods like motor sports, cycling, tennis or golf. They have unique properties such as higher specific strength, low weight, stiffness and fatigue characteristics, high damping capacity, good dimensional stability, a low coefficient of thermal expansion and good corrosion resistance [1-3]. They are intensively used in the new Airbus A380 or Boeing 787 airplanes. 50% of the weight of its primary structure in airplane is made of composite materials [4]. Engineers now have total freedom in the design of new parts because of composite properties can be tailored for use due to availability of variety of reinforcements such as glass fiber, carbon fiber, kevlar, boron fibers, their alignment and fiber-resin fraction. For assembling purposes drilling, turning, trimming, sawing, and slitting etc. operations are prerequisite between composite parts and other structural parts [5]. Drilling is widely used operation for the generation of holes required for assembly using rivets, screws and various types of bolts. Unlike other engineering materials, composites are characterized by anisotropy, structural in homogeneity and lack of plastic deformation behavior [6-7]. Hence it is observed that drilling is the root cause of several damages whose consequence can be the rejection of manufactured part. It has been pointed that in aeronautical industry 60% of part rejections are due to drilling associated damages [8]. These associated damages are due to fibers used as reinforcement, their abrasiveness which causes fast tool wear and deterioration of machined surfaces. Besides that, machining of composites can cause several damages such as push-out delamination/peel-up delamination, fiber/matrix debonding, intralaminar cracking, thermal damages, micro cracking etc. Consequence of delamination is the loss of mechanical strength and stiffness of the parts [9]. These damages are difficult to detect in a visual inspection and reduce the load carrying capacity of the composite part under compression loading, loss of material durability affecting the service life under fatigue loads, results in poor assembly tolerance [10].

Researchers have investigated the composites drilling process and reported the factors that affect the quality of the finished part. Davim and Reis [11], studied the effect of cutting parameters on specific cutting pressure, delamination and cutting power in carbon fiber reinforced plastics. The authors concluded that feed rate has the greater influence on thrust force, so damage increases with feed.

Mishra et al. [12] has used artificial neural network (ANN) to predict the drilling induced damage on unidirectional glass fiber reinforced plastic. A neural network is used in predicting the presence of embedded delamination in FRP composite laminates in terms of size, shape, and location. Natural frequencies are used as indicative parameters, in modeling the mechanical behavior of fiber-reinforced polymeric composite materials.

Luis Miguel P. Durão et al. [13] did a comparative study of different drill point angles and feed rate on composite laminates during drilling. For this goal, thrust force monitoring during drilling, hole wall roughness measurement and delamination extension assessment after drilling is accomplished. Delamination is evaluated using enhanced radiography combined with a dedicated computational platform that integrates algorithms of image processing and analysis. An experimental procedure was planned and consequences were evaluated. Results show that a cautious combination of the factors involved, like drill point angle geometry and feed rate, affect delamination damage.

Larry Adams [14] observed that drilling holes in laminated composites requires special tools and techniques. Their highly abrasive nature quickly dulls conventional steel and carbide tools, and their low inter laminar strength often results in splintering and delamination of the hole. There have been many innovative drill designs, but none have been able to produce clean repeatable holes without some kind of backside support or frequent sharpening. For applications where backside support or backing material is not cost effective, a new diamond coated drill has been developed. Even when operated at non-optimum speeds and feed rates, a hole free of delamination is produced. These drills were evaluated for durability, and hole quality over a six month period.

Rosario Domingo et al. [15] studied the energy required during the dry drilling of PEEK GF30, a thermoplastic material, polyether-ether-ketone, reinforced with glass fiber. Three different types of drills were used with reference to materials and geometry. Nine cutting conditions were selected based on cutting speeds of 6000, 7000 and 8000 rpm, and feed rates of 300, 400 and 500 mm/min. Similar results were obtained for two types of drills namely wolfram carbide with coating of TiAlNy and wolfram carbide with diamond point. First type of drill has economic advantages over the second one. An analysis of variance, ANOVA, shows that the type of drill is more influential factor and the optimum conditions are with the tool made of WC with diamond point under the higher cutting conditions of speed & feed rate.

Hocheng H. et al. [16] studied the machinability aspects for thermoset-based and thermoplastic-based composites with high and low fiber loading. The experimental observations are discussed with reference to chip characteristics and specific cutting energy to reveal the mechanism of removal of material. It is concluded that the material fracture due to the brittle reinforcement as well as the level of fiber loading and the deformation behavior of matrix polymer determine the extent of plasticity in chip formation and the chip length. The discussions of machinability are based on drilling force, surface roughness and edge integrity affected by cutting conditions (feed rate and cutting speed), drill geometry and lay-up system. An optimal domain of cutting parameters is suggested for secured machinability.

The emergence of new high-performance thermoplastics to replace thermoset in fiber-reinforced polymers puts up a new challenge i.e. their machining [17]. In this study, carbon fiber-reinforced poly-cyclic butylenes terephthalate laminates were manufactured, drilled, and inspected. Different commercial drill geometries and machining conditions were compared. Roughness, microscopy, and non-destructive tests were used to determine the hole quality as well as delamination. The surface tests showed that better results were obtained at the cutting speed of 3000 rpm which was commonly used than at high speed (15,000 rpm) with a constant feed rate. The result is explained on the basis of viscoelastic properties of the matrix that becomes fragile at high cutting speeds. The Delamination factor obtained by means of Ultrasonic and X-ray Computed Tomography also confirmed that the best results were achieved with a Twist drill bit at 3000 rpm. In contrast to carbon fiber-reinforced thermoset, the detected delamination at high cutting speeds was not as remarkable as expected. These results were used to conclude that the new composite would certainly increase production rate without delamination damage. Chip formation also plays a special role. The chips can be recovered and reused as reinforcement in manufacturing processes due to the recyclability of the thermoplastic matrix.

Titanium/graphite hybrid composites TiGr exhibit a potentially enabling technology which satisfies the low structural weight fraction and long operational lifetime required for the high-speed civil transport. TiGr composites are made of thermoplastic polymer matrix composite plies sandwiched with titanium foils as the outer plies [18]. The two materials are assembled by bonding the polymer matrix composite plies and titanium foils to form a hybrid composite laminate. Both experimental and analytical work were performed to characterize major hole quality parameters and cutting mechanisms encountered in drilling of TiGr composites. The effects of consolidation processing, such as induction heating press and autoclave processes, on drilling characteristics of TiGr composites were examined. The hole quality parameters and hole exit damage were investigated and discussed.

A thermoplastics-based composite material possesses better machinability. The work done by Hocheng H and Puw HY reveals the machinability of carbon fiber-reinforced ABS (Acrylonitrile Butadiene Styrene) in drilling compared to representative metals and thermoset-based composites [19]. The observation of chips reveals that considerable plastic deformation is involved. Compared to the chip formation of thermoset plastics, it contributes to the improved edge quality in drilling. The edge quality is generally fine except in the case of concentrated heat accumulation at tool lips. Heat is generated by high cutting speed with low feed rate. Plastics tend to be extruded out of the edge rather than neatly cut. The average surface roughness along hole walls is commonly below one micron for all sets of conditions. In the experiment, the values between 0.3 to 0.6 microns were typically observed. The high speed steel drill showed minor tool wear during the tests. Based on these results, it was concluded that the carbon fiber- reinforced ABS demonstrated good machinability in drilling.

A composition and method for selectively increasing the resin flow and gel time of an epoxy resin that fills the capillary region between filaments in fiberglass yarns making up a woven fabric [20]. The composition and method are used in the lamination of fiberglass reinforced composites such as copper clad laminates for circuit boards and reduces the occurrence of voids in the capillary region.

A center or non-center cutting end mill for orbital drilling of fiber reinforced plastic (FRP) materials includes a shank, a neck, a cutting head and two or more flutes [21]. The end mill has a tool geometry with the following features: a dish angle between about 2 degrees to about 6 degrees; a helix angle between about 5 degrees to about 18 degrees; an end teeth radial rake angle between about 0 degrees and about 15 degrees; a peripheral teeth radial rake angle between about 8 degrees and about 16 degrees; a gashing axial rake angle between about 3 degrees to about 10 degrees; and a primary clearance angle between about 10 degrees to about 18 degrees. The end mill is made from a tungsten carbide substrate with cemented cobalt in a range between about 3 to 10 wt. % and a diamond coating having a thickness in a range between about 8 to 20 μm.

This paper analyses the effect of the three cutting speeds, three feed rates and three point angle of the drill geometries on mechanical grade of composite made up of vinyl ester resin and glass fiber manufactured by the process of compression molding.

II. EXPERIMENTAL WORK

2.1Composite specimen preparation

Using vinyl ester resin, mechanical grade dough molding compound is prepared. The composition, their parts by weight and actual composition for producing this grade with the help of Sigma mixer is shown in Table 1 [22]. The Sigma mixer consists of two counter rotating tangential blades in a W shaped trough, curved at the bottom to form two longitudinal half cylinders. Close clearance is maintained between the blades and the walls of the mixer resulting in a perfectly homogenous mix. The tangential action of mixing obtained by two ‘Z’ shaped kneading blades, which rotates in opposite direction to each other causes the product to be transferred from one blade to the other. It is then followed by feeding calcium stearate as lubricating agent and benzyl peroxide as catalyst. The dough so formed is then mixed with calcium carbonate filler and vinyl ester resin respectively. The dough is allowed to remain in a rotating mixture for 15-20 minutes till thorough mixing is achieved. A semi positive compression mould is designed to manufacture square composite plates of size 100mm and 8mm thick. It is designed with means of heating the mold by cartridge heater, cooling circuits for water and ejection arrangement from core side.

Table 1. Chemicals for Mechanical Grade composition-M.

Sr. No.	Description	Parts by weight	Composition-M (gms)
1	Vinyl Ester resin	100	48.0
2	E-glass fiber	85	40.8
3	Calcium carbonate	150	72.0
4	Benzyl peroxide	1	0.5
5	Calcium stearate	2	1.0
6	Pigment	2	1.0
7	Coupling agent	2	2.0

Before mixing the dough in sigma mixer, the compression molding machine is set at a temperature of 200^0C and is left to reach the set temperature. The thoroughly mixed dough from sigma mixer is then placed in the cavity of a heated compression mould and the core is brought slowly towards cavity to avoid spillage of material and then the mould is closed. The mould is opened and closed 2-3 times for degassing and then the packing pressure of 145 kg/cm^2 is applied. Due to heat and pressure, the composite dough is cured in the mould. As a result of cooling circuits laid in the mold, the moulding reaches the room temperature. The composite plate is removed by the ejector pin provided in the core-half. In this way, a composite plate of mechanical grade is prepared. The tonnage of compression molding machine used is 10 ton from Machinefabrik. The sigma mixer and compression mold mounted on compression molding machine are shown in Figure 1, Figure 2 respectively.

Figure 1. Sigma mixer

Figure 2. Compression mold

2.2 Description of chemicals used

The matrix for the composite used is Vinyl ester resin espol™ 38.00 from Satyen Polymers. It has excellent resistance to corrosive chemical environments at room and elevated temperature. Its typical applications include fabrication of tanks, pipes, chemical equipments, ladder, sewerage &effluents equipments etc. exposed to stringent conditions at elevated temperature. The vinyl ester resin is widely used for applications inlayup / spray up, filament winding, pultrusion and can be used with glass fiber, pigment, fillers and other additives as per requirement. The reinforcement used is chopped E-glass fibers strands from Owens Corning having specification EC 146 mm 979. The letter E in the specification stands for electrical grade, C for continuous glass fibers, 146 stands for 14 micron diameter, 6 mm in length and 979 stands for company's code for sizing system. Crystal structured fine precipitated calcium carbonate is used as filler. It has 99.9% purity and 95-99 % Hunter brightness. The coupling agent used is Silquest A174NT having a methacryloxy functional trimethoxy silane from Momentive Performance Materials Inc. Benzyl peroxide is used as a curing agent and calcium stearate is used as a mould lubricating agent in the formulation.

2.3 Drilling set-up

To analyze the effect of delamination and specific cutting energy on mechanical grade vinyl ester composite plates produced by compression molding, each plate is drilled at 6 places on a CNC milling machine with a drill bit size of 10 mm. The drill is having flute length of 60 mm, overall length of 100 mm and helix angle of 30^0. The drill material is solid carbide. Three drill tools having point angles as 80^0, 100^0 and 118^0 are selected for experimentation. The CNC milling machine used is ARGO 2S vertical milling machine. The composite plate is kept on parallel block on two opposite faces and is clamped with the help of strap clamp with the machine bed. The CNC milling machine is shown in Figure 3. During drilling, no coolant is used in the entire experimentation.

Figure 3. ARGO 2S vertical CNC milling machine

2.4 Specific cutting energy, Delamination factor and its measurement

Drilling in composite plate induces damages like peel-up at entrance, push-out delamination, intra laminar cracking, fiber/matrix debonding, chipping and matrix burning etc. Delamination is observed to be more damaging among these as it affects structural integrity, tensile strength of material, and deterioration of properties in long term performance. Delamination is defined as the separation of the layers of a material in a laminate. Chen [23] proposed a comparing factor called as Delamination Factor that enables the evaluation and analysis of delamination extent in composites after drilling. It was defined as ratio of maximum diameter of the damaged zone around the hole to actual diameter of the hole as shown in Figure 4. Delamination occurs at the entry and at the exit of the drill into the plate.

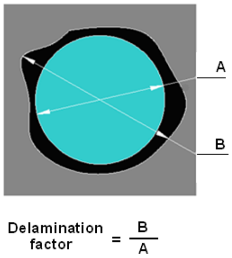


Figure 4. Delamination factor

Specific cutting Energy is defined as the total energy input divided by material removal rate and depends on the material, chip cross section and tool geometry. The best drilling process would be one which consumes minimum energy and yields high metal removal rate. Energy required to drill a hole can be measured by energy meter. For this, an energy meter is coupled to CNC machine. The energy meter used is NANOVIP PLUS from company called as Decontroland is a widely used hand held portable instrument in power transmission systems. It is used to measure power in the range of 7 W to 150 KW accurately. It gives the values of voltage (V rms), current (A rms), P.F.cosø, active power (W), reactive power (var), apparent power (VA), frequency (Hz). The NANOVIP energy meter used is shown in Figure 5.

Figure 5. Nanovip energy meter

The material removal rate (MRR) in drilling is the volume of material removed by the drill per unit time. For a drill with a diameter D, the cross-sectional area of the drilled hole is $(\pi D^2/4)$. The velocity of the drill perpendicular to the work piece f (mm/s) is the product of the feed fr and the rotational speed N where N = (V) / (π D).

Conversion of feed rate fr (mmrev^{-1}) to feed rate f (mmsec^{-1}) is f = (N x fr)(mmmin^{-1}).

Thus MRR = $[(\pi/4) \times (D^2 f / 60)]\text{mm}^3\,\text{sec}^{-1}$.

Therefore specific cutting energy (SCE) in Jmm^{-3} is given by following equation,

SCE = [(Power in watts or J Sec^{-1}) / (material removal rate MRR in $\text{mm}^3\,\text{sec}^{-1}$)] ---------------Eq.(1)

The power consumed is measured with energy meter for each drilling and results are recorded. The average reading of the 6 drilled holes is considered as a final result. The specific cutting energy SCE is then calculated using equation 1.

Carton stereo microscope made in Japan with model no. SPZ-50PFM and having zoom range of 6X-50X and illumination source of 9Watt fluorescent light is used to measure the delamination of the drilled holes at the entry and exit surfaces. A typical delaminated hole and the actual hole as observed through the Carton stereo microscope is shown in Figure 6.Out of the six holes drilled, the image of the maximum damaged hole at entry and the exit surface is captured. This damaged hole image in .tiff format is then imported in a CAD software and control points are located on the image.

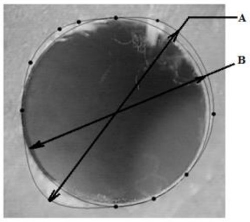


Figure 6. Delaminated hole

A spline is drawn by joining all these control points to get the maximum damaged zone and the image is enlarged in the software so that actual diameter hole size is equal to 10 mm. Thus the diameter around maximum damaged zone is automatically enlarged and is then noted. The delamination factor is calculated as the ratio of maximum diameter of the damaged zone around the hole to actual diameter of the hole. The Carton stereo microscope used for experimentation is shown in Figure 7.

Figure 7. Carton stereo microscope

2.5 Taguchi Method and Design of Experiments

To analyze the influence of known process variables over unknown process variables, DOE-Design of experiment a statistical tool, is widely used. The features of DOE can be harnessed for process optimization in drilling of composites. Design of experiments is selected in identifying the best set of parameters among the effective factors. The Taguchi method involves reducing the variation in a process by effectively utilizing design of experiments. It aims in producing high quality product at low cost to the industry. It investigates how different parameters affect the mean and variance of a process performance characteristic which in turn defines how well the process is functioning. It involves using orthogonal arrays to organize the parameters affecting the process and the levels at which they varies. Like the factorial design which tests all possible combinations, the Taguchi method tests pairs of combinations. This saves time and resources and determines which factors grossly affect product quality with a less amount of experimentation [24-26]. The orthogonal array (OA) and the signal to noise (S/N) ratio are the major tools used in experimentation. Orthogonal array is a matrix of numbers arranged in rows and columns. Each row represents the levels of factor in each run and each column represents a specific level for a factor which can be changed for each run. The quality is best judged by S/N ratio. The design of experiments as defined by Taguchi is used to get best level for each operating parameter to maximize or minimize the S/N ratio. The S/N ratio characteristics are divided into three following groups:

1) Smaller the better characteristics:

$S/N = \{(-10) \times \log [(1/n) \times (\sum y^2)]\}$

2) Larger the better characteristics:

$S/N = \{(-10) \times \log [(1/n) \times (\sum 1/y^2)]\}$

3) Nominal the best characteristics:

$S/N = [(10) \times \log (\bar{y}^2/s^2_y)]$

Where $\bar{\mathbf{y}}$ is the average of observed data, s^2_y isthe variation of y, n is number of observation and y is the observed data.

The general steps used in Taguchi method are as given below:

Step 1) In this step, the process objective is defined. The process objective in this case is to have minimum delamination factor and least specific cutting energy. Ideal target values would be unity for the delamination factor and zero for specific cutting energy. Hence smaller the better characteristics of S/N ratio are selected for both these process objectives.

Step 2) In this step, the variables that affect these process objectives and their levels are determined. Point angle of drill, cutting speed and feed are the variables which affect Specific cutting energy and delamination. For these variables, three levels are selected as shown in Table 2.

Table 2. Variables and their different levels.

Sr. No.	Variables	Level 1	Level 2	Level 3
1	Point angle (degree) (A)	80	100	118
2	Speed (RPM) (B)	980	1560	2355
3	Feed (mm/min) (C)	39.2	124.8	353.25

The degrees of freedom for these variables are calculated as below:

Degree of Freedom (DOF) = (number of levels - 1)

For point angle, DOF = (3–1) = 2;

For speed, DOF = (3–1) = 2;

For feed, DOF = (3–1) = 2.

Step 3) In this step, based on number of variables and their levels suitable orthogonal array is selected. L9 orthogonal array (OA) is selected which has nine rows which correspond to number of tests. L9 orthogonal array has eight DOF, of which 6 are assigned to three factors and 2 DOF are assigned to the error. Table 3, shows tabulated L9 orthogonal array with its variable levels for nine experiments. Hence in all nine experiments are to be carried out at different speed, feed and point angle with the variation in these variables.

Steps 4)In this step, all experiments are conducted as per the variable levels indicated in the table 3. The process objectives, delamination factor at entry and exit of the composite plate and specific cutting energy are noted. Table 4 shows the measured experimental results for specific cutting energy, delamination at entry and exit and S/N ratio calculations. Corresponding response table for signal to noise ratio is shown in Table 5 and the analysis of variance ANOVA calculations are shown in Table 6. The main effect plots for S/N ratio are shown in Graph 1.

Table 3. Taguchi Orthogonal Array for the variables.

Sr. No.	Experiment No.	A	B	C	Trial condition
1	1	1	1	1	A1B1C1
2	2	1	2	2	A1B2C2
3	3	1	3	3	A1B3C3
4	4	2	1	2	A2B1C2
5	5	2	2	3	A2B2C3
6	6	2	3	1	A2B3C1
7	7	3	1	3	A3B1C3
8	8	3	2	1	A3B2C1
9	9	3	3	2	A3B3C2

Table 4. Specific cutting energy (SCE), S/N ratio and delamination factor table for Composition-M.

Expt. No.	Trial	Point angle in °	Speed (RPM)	Feed (mm per min)	Power (watt)	MRR (mm^3 per sec)	SCE (J per sec^3)2	S/N ratio for SCE	Delamination factor	
									At entry	At exit
1	A1B1C1	80	980	39.2	186.2	51.35	3.6	11.1	0.0	0.0
2	A1B2C2	80	1560	124.8	442.7	163.4	2.7	8.63	0.0	0.0
3	A1B3C3	80	2355	353.3	275.0	462.7	0.6	-4.4	0.0	0.0
4	A2B1C2	100	980	124.8	157.6	102.7	1.5	3.52	0.0	0.0

5	A2B2C3	100	1560	353.3	444.0	306.5	1.4	2.92	0.0	0.0
6	A2B3C1	100	2355	39.2	269.7	123.4	2.2	6.84	0.0	0.0
7	A3B1C3	118	980	353.3	156.9	192.5	0.8	-1.9	0.0	0.0
8	A3B2C1	118	1560	39.2	571.1	81.7	7.0	16.9	0.0	0.0
9	A3B3C2	118	2355	124.8	275.5	246.8	1.1	0.82	0.0	0.0

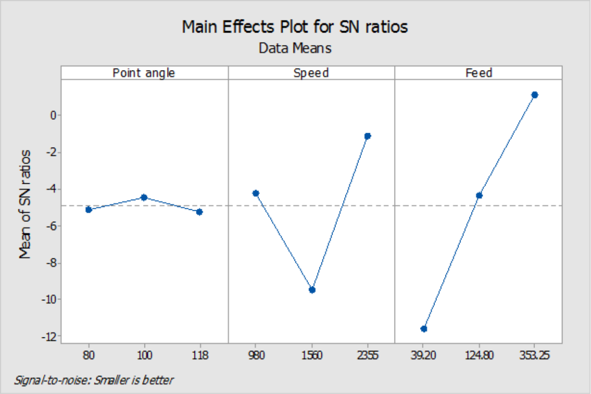
Table 5. Response Table for Signal to Noise ratio for Composition-M. (Smaller is better).

Sr. No.	Level	Point angle	Speed	Feed
1	1	-5.105	-4.237	-11.625
2	2	-4.431	-9.484	-4.326
3	3	-5.264	-1.080	-1.51
4	Delta	0.833	8.404	12.776
5	Rank	3	2	1

Table 6. ANOVA Table for Composition-M.

Sr. No.	Source of variation	Degree of freedom	Sum of squares	Variance	F ratio	P value	% Contribution
1	Point Angle	2	2.41	1.205	1.05	0.489	7.53%
2	Speed	2	9.21	4.605	4.00	0.20	28.8%
3	Feed	2	18.05	9.025	7.84	0.113	56.44%
4	Residual Error	2	2.31	1.155	---	---	7.23%
5	Total	8	31.98	---	---	---	100%

Graph 1. Main effects plots for S/N ratio for Composition-M.



Minitab version 16 software is used for S/N ratio, ANOVA and response for signal to noise ratio calculations. Regardless of the category of the performance characteristics, a greater S/N value corresponds to a better performance.

Step 5) Multiple linear regression model: Using statistical software Minitab version 16, a multiple linear regression model is developed. Multiple linear regression models give the relationship between an independent / predicted variable & a response variable by fitting a linear equation to observe data. It gives correlation between point angle of drill, speed and feed obtained from ANOVA analysis.

The regression equation developed for mechanical grade with S/N ratio as output variable is:

S/N = {(-15.6)-[(0.003) x(Point angle)] + [(0.00279) x (Speed)] + [(0.0372) x (Feed)]} -----Eq. (2)

Step 6) Confirmation Test: The experimental confirmation test is the last step in verifying the results drawn based on Taguchi's design. The confirmation experiment is a most important step as recommended by Taguchi to verify the experimental results. It is worth noting that the optimum run may not be necessarily among the many experiments that were carried out. Confirmation experiment is carried out by utilizing levels of initial and optimum process parameters. Optimum process parameters correspond to greater S/N value as obtained in the main effect plot for S/N ratio graph. These are then compared with initial run for determining difference in gain. These parameters are shown in Table 7.

Table7. Confirmation experiment parameter for Composition-M

Type of composite	Condition	Point Angle (degree)	Speed (rpm)	Feed (mm/min.)
Composition -M	Initial	80	980	39.20
	Optimum	100	2355	353.25

III. CONCLUSIONS

Using Taguchi technique, mechanical grade composition has been investigated for drilling parameters. The effect of three drill angle, three speeds and three feed of drilling process parameter has been studied. The following conclusions can be drawn from the investigations:

a) The power consumed is observed to be minimal for point angle of 118°, speed of 980 RPM and feed of 353.25 mm/min. Using smallest point angle of 80°, highest speed of 2355 RPM and feed of 353.25 mm/min, highest material removal rate is observed. The efficient drilling process is the one which consumes less power and at the same time achieves higher material removal rate as indicated by SCE i.e. specific cutting energy. This is achieved by using smallest point angle of 80°, highest speed of 2355 RPM and feed of 353.25 mm/min. The lowest specific cutting energy recorded is 0.6 J/mm^3. The variable feed has contributed to 56.44% followed by speed 28.80% and point angle 7.53% and is seen from response for signal to noise S/N ratio (Table 5) and the ANOVA calculations (Table 6). For all combination of the point angle, speed and feed, the delamination factor is found to be zero.

b) As per parameters listed in Table 7, confirmation experiment is carried out. Results of experiment for the optimum condition for mechanical grade composite which is not covered under the Taguchi Table are indicated in Table 8.

Table 8. Confirmation experiment results of experiment for the optimum condition of Composition-M

Point angle in °	Speed (RPM)	Feed (mm per min)	Power (watt)	MRR (mm^3 per sec)	SCE (J per sec^3)	S/N ratio for SCE	Delamination factor	
							At entry	At exit
100	2355	353.2	265.7	462.2	0.58	4.73	0.0	0.0

From the derived equations (2), results of confirmation experiments and linear regression model are compared and are tabulated in Table 9.

Table 9. Confirmation experiment result comparison for Composition-M

Type of composite	Condition	S/N ratio by Experimentation	S/N ratio by regression equation
Composite-M	Initial	-11.13	-11.65
	Optimum	4.73	3.81
	Gain	6.40	7.84

Signal to noise ratio gain by experimental method and regression analysis method are observed to be very close to each other. Hence design of experiments by Taguchi method was successfully implemented to predict the specific cutting energy.

c) For a thermoset composite made of vinyl ester and reinforced by glass fiber, a platform is laid out by experimental results established as a part of this investigation, to determine effect of drilling process variable namely drill angle geometry, speed and feed on specific cutting energy and delamination. These results could be a starting guideline factor for engineers in composite fabrication field and will help them in determining optimum machining process parameters.

IV. FUTURE WORK

This research approach can be extended in studying glass fiber reinforced thermoplastic composites. Thermoplastic composite behave altogether differently in machining over thermoset composite due to large variation in visco-elastic properties. Thermoplastics exhibits greater plastic deformation capability under loads, while thermoset are brittle. Such behavior influences material response to machining.

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