An Investigation on Thrust Force and Circularity of GFRP Sheet by Applying Regression Analysis

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Abstract

Drilling is the most commonly applied method for hole making of fiber reinforced materials owing to the need for structure joining. This study, through a new approach present to optimize the thrust force and circularity through design of experiment by using full factorial design. The purpose of this study is to investigate the influence of drilling parameters, such as cutting speed, feed and point angle on thrust force and circularity produced when drilling GFRP composite. In this study, it will regression analysis and ANOVA to analyze and optimize the process parameter of drilling.
Keywords: GFRP, Regression analysis, ANOVA, Drilling

I. INTRODUCTION

Drilling is a cutting process that uses a drill bit to cut or enlarge a hole of circular cross-section in solid materials. The drill bit is a rotary cutting, often multipoint. The bit is pressed against the work piece and rotated at rates from hundreds to thousands of revolutions per minute. This forces the cutting edge against the work piece, cutting off chips from the hole as it is drilled.

Fig. 1: Drilling on GFRP Sheet

In drilling of composite laminates, the uncut thickness to withstand the drilling thrust force decreases as the drill approaches the exit plane. The laminate at the bottom can be separated from their interlaminar bond around the hole edge. At some point the loading exceeds the interlaminar bonding strength and delamination occurs.

II. LITERATURE REVIEW

The Literature review on GFRP is a new approach present to optimize the thrust force, delamination and circularity through design of experiment by using full factorial design. The purpose of this study is to investigate the influence of drilling parameters, such as cutting speed, feed and point angle on delamination, thrust force and circularity produced when drilling GFRP composite.

Reddy Sreenivasulu experiment on GFRP material during milling machining. He took the speed, feedrate and depth of cut as input parameter to influence the effect of surface roughness and delamination. Thus, he revealed that the application of desirability function analysis integrated with taguchi technique proves to be an effective tool for optimizing multi response characteristics of machining parameters during end milling of GFRP composites. Syed Altaf Hussain et all investigated focuses on the optimization of process parameters for surface roughness of glass fiber reinforced polymer (GFRP) composites using Genetic Algorithm (GA). They found that the optimized process parameters in turning of GFRP composite tubes with PCD cutting tool is: cutting speed range between 130 ~ 140 m/min, feed range is 0.048~ 0.05mm/rev, depth of cut range is 0.6 ~ 1.0mm and fiber orientation angle range is 300 ~ 450. Ali Mkaddem et all measured Wear resistance of CVD and PVD multi layer coatings when dry cutting fiber reinforced polymers (FRP). They revealed from the study that due to fiber abrasivness, the Cutting of galss/epoxy induces the deepest wear patterns occured, and develops the highest force and apparent friction values while cutting of carbon/epoxy generates the largest flank wear area. M.A.J.Bosco et all experiment on armour steel - GFRP composites to measured delamination with the various process parameter like Cutting feed, Cutting speed and Drill diameter. The spindle speed is having only limited effect on drilling of sandwich plates in which higher spindle is preferred. Rosario Domingo et all investigation on the dry drilling of PEEK GF30, a thermoplastic material, polyether-etherketone, reinforced with glass fiber. The results show that similar outcomes are obtained with two drills, one of them, wolfram carbide with coating of TiAlN y another of wolfram carbide with point of diamond. They found that with the drill of WC with point of diamond and under higher shear conditions (8000 rpm and 500 mm/min) are achieved better results, however the drill of WC with TiAlN coating shows similar results that is of interest due to its much lower cost. Also the energy required, assigned to the torques, is superior to 98%, in each case, question that could be taken in account in the tools design. Abhineet Saini et all conducted experiment for the dynamic behavior of GFRP under different cycle time of fatigue loading. During experiment. They did further investigation for properties of GFRP is done by measuring micro-hardness of the specimen which shows a slight decrease for the pre-fatigue load being applied but a much noticeable decrement for hygrothermally treated specimen and the minimum hardness is found to be of the specimen dipped in 55°C bath after two month time period. Hussein m ali et all conducted experiment on hole making in GFRP by drilling and milling machining. They also observed that the drilling process, average thrust force can be reduced by reducing the cutting speed while in milling, machining force can be reduced by reducing feed rate. They found that the both drilling and milling process, productivity can be increased by increasing speed and feed rate. Syed Altaf Hussain et all conducted experiment on GFRP composite tubes of different fiber orientation angle vary from 300 to 900 . They studied carried out on an all geared lathe using three different cutting tools: namely Carbide (K-20), Cubic Boron Nitride (CBN) and Poly-Crystalline Diamond (PCD). This is followed by cubic Boron Nitride (CBN) tool. They revealed that the Carbide (K-20) tool gave high surface roughness and high cutting forces hence, it is not at all desirable to use this tool for machining GFRP composites, While machining GFRP composites moderate cutting speed, low feed rate, moderate depth of cut and low fiber orientation angle are preferred. Luis Miguel P. Durao et all carried out a comparative study on different drill point geometries and feed rate for composite laminates drilling. They had measured thrust force, hole wall roughness and delamination using various a total of five tungsten carbide drills with 6 mm diameter and different geometries were used: a twist drill with a point angle of 1200, a twist drill with a point angle of 850, a Brad drill, a Dagger drill and a special step drill. Delamination is evaluated using enhanced radiography combined with a dedicated computational platform that integrates algorithms of image processing and analysis. They revealed from the research that a 1200 twist drill should be used for minimal delamination. Special step drill could present a good alternative, but is not commercially available yet. M. Vijaya Kini et all investigated to Effect of machining parameters on surface roughness and material removal rate in finish turning of glass fibre reinforced polymer pipes. They showed that the the depth of the cut is the main influencing factor on the roughness, followed by the tool nose radius. Among the interaction effects, cutting speed-tool nose radius has the highest influence. E. Kilickap et all investigation on delamination during drilling. The purpose of this paper was to investigate the influence of the cutting parameters, such as cutting speed and feed rate, and point angle on delamination produced when drilling a GFRP composite. They observed that the damage increases with both cutting parameters, which means that the composite damage is bigger for higher cutting speed and feed rate. They revealed from ANOVA that feed rate is the main cutting parameter, which has greater influence on the delamination factor for both drills (except point angle of 135_, at exit) and Low feed rates provided minimum damage. Roshan Mishra et all carried out experiment on drilling of fiber reinforced plastics (FRP) to analyze damage around the drilled hole. They generated predicted results will help the designers to specify accurate values while designing composite products with drilled holes. M. S. Ahmadi et all have been worked on a conventional textile braiding machine which modified and added to a pultrusion line in order to produce glass fiber reinforced composite rods by braiding-pultrusion technique. Braid-pultruded (BP) rods were produced with three braid roving linear densities and also with three different braid angles. They also concluded that increasing the braid roving linear density leads to an improvement in shear modulus, but a reduction in tensile modulus and flexural rigidity. Moreover, the rod with braid angle of 45° had higher shear modulus compared to those with braid angles of 30 and 55°. Tensile modulus and flexural rigidity were higher in BP rods with lower braid angles. G. Venu Gopala Rao et all experiment on UD-CFRP and UD-GFRP composites and measured cutting force and simulated using the finite element methods. They found that to failure of fiber is to be a combination of crushing and bending, with the bending effect becoming more significant as the fiber orientation changes from 900 to 150. K. Palanikumar et all conducted experiment on glass fiber reinforce polymers through investigation on surface roughness using response surface methodology. They developed Mathematical model for surface roughness to correlate the important machining parameters in machining of GFRP composites. They found that the surface roughness decreases with the increase of cutting speed and the increase of depth of cut. Also he revealed that the surface roughness increases with the increase of feed Rate and increase of fibre orientation angle. Now, It is concluded from above that no researcher has done on circularity. But circularity effected or directly related with surface roughness and thrust force, thus it has been decide to measure three output parameter like circularity, hole size and thrust force of GFRP material with response surface methodology for analysis purpose.

III. METHODOLOGY

The whole process of experimentation is discussed which is about the formation of design of experiment, application of RSM. Design of experiment is full factorial design L27 design. Total 27 experimental runs will be carried out in study. Responses measured will measure thrust force and Circularity.

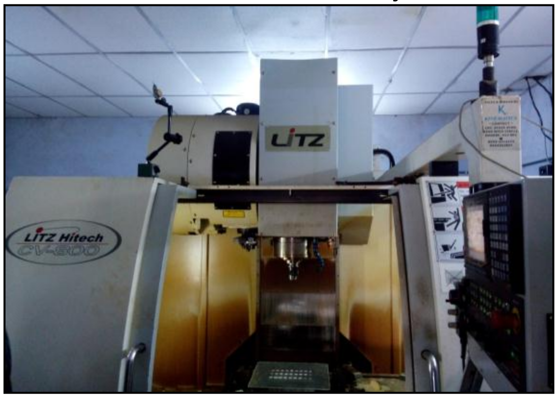

Fig. 2: Machine Tool and Work Table

A. Process Parameter:

1) Point angle.
2) Speed.
3) Feed rate

After literature review, the three main input parameters are Speed, Feed Rate and Point Angle will used for experimentation. The specimen is made of GFRP. The standard high-speed steel twist drill of 4 mm diameter with various point angles will used. Based on the literature it was decided to study the effect of point angle, speed and feed rate. This design models have been prepared by choosing three levels. Full factorial design design will for experimentation by applying L27 orthogonal array, taking three levels for each factor as depicted in Table

Table - 1
Proposed Ranges of Input Parameter

Parameter	*Unit*	*Level-1*	*Level-2*	*Level-3*
Speed	*RPM*	*400*	*700*	*1000*
Feed	*Mm/min*	*45*	*70*	*95*
Point angle	^{0}	*90*	*100*	*110*

IV. RESULT AND DISCUSSION

A. Main Effects Plot of Thrust Forces:

The main effects plot for S/N ratio of thrust force versus spindle speed, feed and point angle are shown in fig. 3, which is generate from the value of S/N ratio of thrust forces as per table 2 in minitab-15 statistical software is useful to find out optimum parameter value for response variable. Fig.3 shows that lower thrust force will meet at lower spindle speed 1000 RPM, lower feed 0.045 mm/rev and higher point angle 110^{0}. The graph generate by use of minitab-16 statistical software for thrust force is shown in fig.3.

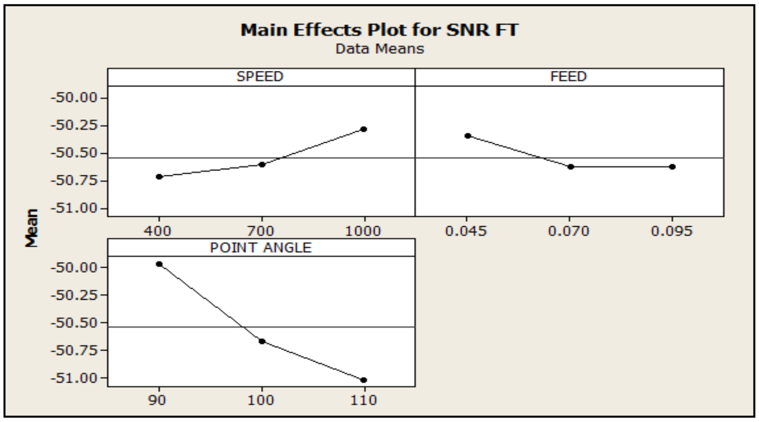

Fig. 3: Effect of Control Factor on Thrust Force

From the fig.3, it has been conclude that the optimum combination of each process parameter for lower thrust force is meeting at low spindle speed [A3], low feed [B1] and high point angle [C1].

B. Main Effects Plot of Circularity:

The main effects plot for S/N ratio of circularity versus spindle Speed, feed and point angle, which is generating from the value of S/N ratio of circularity as per table 2. MINITAB-16 statistical software is useful to find out optimum parameter value for response variable. Lower circularity meet at lower spindle speed 400 RPM, lower feed 0.045 mm/rev and highest point angle 1100. So that the level A3, B1, and C3 gives optimum result.

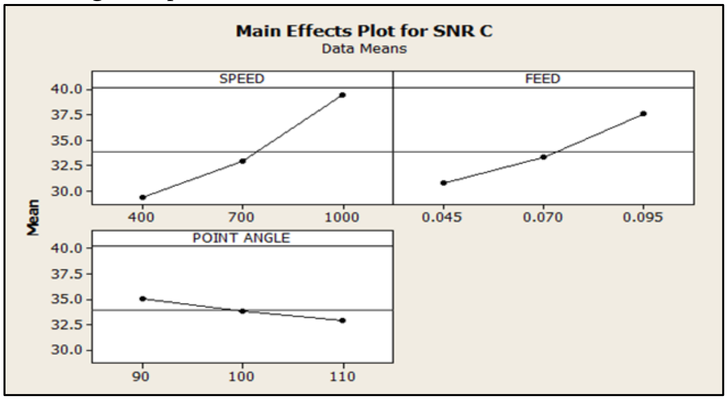

Fig. 4: Effect of Control Factor on Circularity

C. Analysis of Variance:

Analysis of variance (ANOVA) is a statistical model which can be used for find out effect of independent parameter on single dependent parameter and also it can be use full to find out the significant machining parameters and the percentage contribution of each parameter. MINITAB16 statistical software used to analyze the ANOVA analysis for thrust forces and circularity and their analyzed value is show in table 2.

1) *Analysis of Variance for Thrust force:*

According to the analysis done by the MINITAB software, if the values of probability are less than 0.05, it indicated that the factors are significant to the response parameters. Comparing the p-value to a commonly used α- level = 0.05, it is found that if the p- value is less than or equal to α, it can be concluded that the effect is significant, otherwise it is not significant.

Table - 3
ANOVA of Thrust force

Source	*DF*	*Seq SS*	*Adj SS*	*Adj MS*	*F*	*P*
Spindle Speed	*2*	*0.8896*	*0.8896*	*0.4448*	*30.93*	*0.000*
Feed	*2*	*0.4699*	*0.4699*	*0.2350*	*16.34*	*0.000*
Point angle	*2*	*5.1695*	*5.1695*	*2.5847*	*179.72*	*0.000*
Error	*20*	*0.2876*	*0.2876*	*0.0144*		
Total	*26*	*6.8167*				
R-Sq = 95.78				*R-Sq (adj) = 94.51%*		

From ANOVA result it is observed that the spindle speed, feed and point angle influencing parameter for thrust forces, because of p value of all process parameter has 0.000. thus its value indicated that the value of p for each parameter are 0.000 which is lower than 0.05 p value so they are all influencing parameter for thrust force.

The confidence level (CL) used for investigation is taken 95% for this investigation. The parameter R-Sq described the amount of variation observed in thrust forces is explained by the input factor. R-Sq= 95.78% which indicate that the model is able to predicate the response with high accuracy.

2) *Analysis of Variance for Circularity:*

From ANOVA result it is observed that the spindle speed and feed are influencing parameter for circularity, while the value of p for point angle is 0.171 which is greater than 0.05 p values. So, it is not influencing parameter for circularity.

Table - 4
ANOVA of Circularity

Source	*DF*	*Seq SS*	*Adj SS*	*Adj MS*	*F*	*P*
Spindle Speed	*2*	*474.24*	*474.24*	*237.12*	*45.67*	*0.000*
feed	*2*	*214.40*	*214.40*	*107.20*	*20.65*	*0.000*
Point angle	*2*	*20.03*	*20.03*	*10.02*	*1.93*	*0.71*
Error	*20*	*103.83*	*103.83*	*5.19*		
Total	*26*	*812.51*				
R-Sq = 87.22%				*R-Sq(adj) = 83.39%*		

The confidence level (CL) is taken 95% for this investigation. The parameter R-Sq described the amount of variation observed in thrust forces is explained by the input factor. R-Sq= 87.22 which indicate that the model is able to predicate the response with high accuracy.

V. REGRESSION MODEL

The Regression model for predicting the response parameters in turning can be derived using methods like Regression analysis. Regression analysis is often used to:

1) Determine how the response variable changes as particular predictor variable changes.
2) Predict the value of the response variable for any value of the predictor variable, or combination of values of the predictor variables.

Regression is method of estimating the conditional expected value of one variable, y, given the values of some other variable, x. The variable of interest, y, is called the dependent variable. The other variable, x, is called the independent variable. Regression analysis is a statistical tool for the investigation of relationships between variables. Usually, the investigator seeks to ascertain the casual effect of one variable upon another, for example, the effect of changes in cutting speed, feed and depth of cut on cutting forces. To explore such issue, the investigator assembles data on the underlying variables of interest and employs regression to estimate the quantitative effect of the casual variables upon the variable that they influence. The investigator also typically assesses the "statistical significance" of the estimated relationships, that is, the degree of confidence that the true relationship is close to the estimated relationship. The regression equation is an algebraic representation of the regression line and is used to describe the relationship between the response and predictor variables. The regression equation takes the form of:
Response= constant + coefficient (predictor) +… + coefficient (predictor)
Or

$$Y= b_0 + b_1x_1+b_2x_2+\ldots+b_kx$$

Where:

- Response (Y) is the value of the response.
- Constant (b0) is the value of the response variable when the predictor variable(s) is zero. The constant is also called the intercept because it determines where the regression line intercepts (meets) the Y-axis.
- Predictor (X) is the value of the predictor variable.

Coefficients (b1, b2… bk) represent the estimated change in mean response for each unit change in predictor value. In other words, it is the change in Y that occurs when X increase by one unit. The mathematical model using regression analysis is derived with the help of MINITAB software.

A. Regression Equation for Thrust Force:

The regression equation is
THRUST FORCE = 119 - 0.0278 SPEED + 213 FEED + 2.03 POINT ANGLE (1)

B. Regression Equation for Circularity:

The regression equation is
CIRCULARITY = 0.0494 - 0.000039 SPEED - 0.302 FEED + 0.000206 POINT ANGLE (2)

C. Confirmatory Test Result:

The final step is to confirm the validity of the optimization technique and verify the improvement of the performance characteristics by drilling same sample with predicted optimized level setting. Again considering the predicted optimized parameters and using Equation 1 and 2. The thrust force was calculated to 303.48 N and circularity 0.04497 mm.

Table - 5
Comparison of Result

Responses	*Actual value*	*Predicated value*	*Percentage error[%]*
Thrust force	*298*	*303.48*	*1.83*
circularity	*0.052*	*0.04497*	*13.51*

Analyzing actual result we found that actual circularity is the best among all the circularity. So circularity is actually maximized in the optimized levels. The thrust force is minimized at the optimized levels. Hence it is confirmed that the optimization technique applied is adequate and validate. Table 5 compares the predicted result and actual result of both the responses. The percentage error in predicted result for thrust force and cirularity was calculated to be 1.83% and 13.51% respectively.

VI. CONCLUSION

The objective of this experiment investigation is to find functional relationship between process parameters and output parameters using regression analysis involving interaction terms are studied and the reason behind the observed responses can be concluded as following.

1) The spindle speed, feed and point angle have significant effect on thrust force,
2) For minimizing thrust force, the optimum value of spindle speed, feed and point angle as 1000 RPM, 0.045 mm/rev and 900 respectively.
3) The spindle speed and feed have significant effect on circularity; however point angle has not significant effect on circularity.
4) For minimizing circularity, the optimum value of spindle speed, feed and point angle as 1000 RPM, 0.095 mm/rev and 920 respectively. From this experiment, it has been concluded that the thrust force and highest circularity meet lower at spindle speed, feed and point angle as 1000 RPM, 0.045 mm/rev and 900 respectively.
5) Experimental results are prediction by regression equation. The predicted an average percentage error is 1.83% and 13.51% respectively for all three responses

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