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Experimental investigation and Analysis of Thrust Force in Drilling of Carbon Fibre Reinforced Plastic Composites using Response Surface Methodology

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ABSTRACT: *This paper reports the effect of thrust force during drilling of 10mm diameter holes in 20mm thick Carbon Fibre Reinforced Plastic composite laminate using HSS, Solid Carbide (K20) and Poly Crystalline Diamond insert drills. Experiments are conducted on a vertical machining centre using Taguchi design of experiments. A model is developed to correlate the drilling parameters with thrust force using Response surface Methodology (RSM).The results indicate that the developed model is suitable for prediction of thrust forces in drilling of CFRP composites. The influence of different parameters on thrust force of CFRP composites have been analyzed through contour graphs and 3D plots. The investigation has revealed that the type of drill geometry affects the thrust force significantly followed by the feed rate and the speed.*

Keywords: *Drilling, CFRP, response surface methodology, Thrust Force*

I. INTRODUCTION

CARBON FIBER REINFORCED PLASTIC (CFRP) composite materials are continuously replacing conventional metals and alloys in many applications such as automotives, aircraft etc. The combination of superior mechanical properties such as high specific strength, stiffness and fatigue strength, enable the structural design more reliable than conventional metals [1]. They can be easily fabricated to near net shapes by processes such as hand lay-up, filament winding, pultrusion; etc.Machining is required in places where composites are assembled by joining processes. Machining of composites has been recognized as a process different from that of conventional materials. A proper selection of cutting parameters facilitates good machinability since the coexistence of hard abrasive fibres and a soft matrix behave differently during machining [2].

Drilling is a frequently employed in industries owing to the need for component assembly in mechanical structures. Many researchers [3-5] reported that the quality of the drilled surfaces depend strongly on the tool geometry, drilling parameters and tool material. An inappropriate selection of these parameters can lead to material degradations, such as fiber pull-out, matrix cratering, thermal damage and delamination [3].

Tsao [6] reported that the feed rate and the drill diameter are recognized as the most significant factors affecting the thrust force. The radial basis function network is demonstrated more effective than multi-variable regression analysis for the evaluation of drilling-induced thrust force and surface roughness in drilling of composite material. Latha and Senthilkumar [10] used fuzzy logic technique to predict thrust force in drilling of composite materials. Davim [11] presented a study for selecting the cutting parameters for damage-free drilling in carbon fiber reinforced epoxy composite material which was based on a combination of Taguchi's techniques and on the analysis of variance (ANOVA).

Karnik et al., [12] carried out drilling as per full factorial design using cemented carbide (grade K20) twist drills that serve as input–output patterns for ANN training and reported that the developed ANN model shows a good correlation both for training and testing data sets, thus validating the model. Two-factor interaction effects were also analyzed by generating 3D surface plots. The interaction effects analysis demonstrates the advantages of employing a high spindle speed for drilling CFRP composite material which reduces the delamination at the entrance of the holes.

This paper investigates the effect of different drilling parameters on Thrust force in drilling CFRP composites. The experiments were conducted on a Vertical machining centre using HSS,Carbide(K20) and PCD drills of diameter 10mm. Response surface model is developed to correlate the thrust force with respect to different drilling parameters. The machining parameters considered for the experiments are spindle speed, feed rate, and type of drills. The results proved that the developed model can be effectively used for the prediction of Thrust forces in machining of CFRP laminates.

II. EXPERIMENTAL

2.1Materials and Methods

The CFRP laminates were fabricated using the hand lay-up technique. Carbon fibre (Zoltek, PANEX® 35)was used as a reinforcement in the Epoxy matrix(Huntsman, Warm curing epoxy system based on Araldite® LY 1564 SP/Hardener XB3486formulated amine hardener) and was cured at 220 deg Celsius for 90 minutes. This composite laminate was produced with a fiber orientation of 0/90 degrees with 20 layers of the fabric and resin used successively. The properties of the fibre are listed in Table 1.The different types of drill used in this study are shown in Fig 1.

Figure 1.a) HSS Ball Nose, b) Carbide Ball Nose, c) PCD Ball Nose

Table 1. Properties Carbon Fibre

TYPE OF FIBRE	TENSILE STRENGTH (MPa)	TENSILE MODULUS E (GPa)	ELECTRICAL RESISTIVITY Ω-cm	%CARBON CONTENT	DENSITY ρ (g/cc)	FIBRE DIAMETER d (microns)
Stitch Bonded Unidirectional	3800	228	0.00155	95	1.81	7.2

2.2Experimental Procedure:

The experimental setup is shown in Fig.2 Arix VMC 100 CNC drilling machining centre was used for making drills in the CFRP composites using different drill bits such as HSS, Solid Carbide and PCD.The experiments were conducted as per the L_{27} orthogonal array. The computer controlled data acquisition system was used to collect and record the data during experiments. The Kistler dynamometer was used to record the cutting forces.

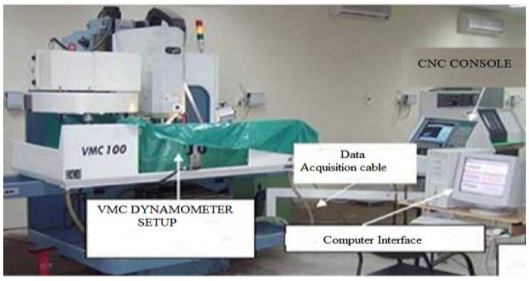

Figure 2.Experiment setup with dynamometer arrangement

2.3 Response Surface Modelling

Response surface methodology (RSM) is a collection of mathematical and statistical techniques that are useful for the modelling and analysis of problems in which a response of interest is influenced by several variables and the objective is to minimize this response [10].

The process parameters, their notations, and their ranges are given in Table 2.The experiments for the present work have been carried out using full factorial taguchi design of experiments. In the current investigation the number of variables considered for the response surface modelling is three and the numbers of experiments conducted are 27. The independently controllable process parameters identified for the experimentation are: Spindle speed (V) rpm, feed rate (f) in mm/min, and type of drills (d) used. The steps involved in the RSM technique [3] are as follows: (i) designing of a set of experiments for adequate and reliable measurement of the true mean response of interest, (ii) determination of mathematical model which best fits; (iii) finding the optimum set of experimental factors that produces maximum or minimum value of response; and (iv) representing the direct and interactive effects of process variables on the best parameters through two-dimensional and three-dimensional graphs.

Table 2.Process Parameters used for modelling

Control Parameters	Unit	Symbols	Levels		
			-1	0	1
Cutting Speed	rpm	v	2500	3000	3500
Feed Rate	mm/min	f	50	75	100
Drill Type	-	d	HSS	CARBIDE	PCD

In most RSM problems, the form of relationship between the response and the independent variable are unknown.When the experimenter is close to optimum, a model that incorporates curvature is usually required to approximate the response. Usually a second order model is utilized in response surface methodology.

$$y = \beta_0 + \sum_{i=1}^{k} \beta_i x_i + \sum_{i=1}^{k} \beta_{ii} x_i^2 + \sum_{i<j}\sum \beta_{ij} x_i x_j + \epsilon$$

Least square method is used to determine the β coefficients, in the model. Values of the controllable parameters that results in optimization of response or discover what values for the‘x’values will result in a product (process) satisfying several requirements or specifications can be determined by using RSM [8].A second-order model is normally used when the response function is not known or nonlinear. In the present study a second-order model has been utilized. The thrust force F is given by

Thrust Force = $81.56 - 25.56 * V + 55.22 * f + 202.5 * d + 12.67 * V * f - 54.58 * V * d + 9.58 * f * d - 5.33 * V^2 + 20 * f^2 + 442.83 * d^2 -$ *equation* (2)

R^2 is called coefficient of determination, is used to judge the capability of regression model developed, $0 \le R2 \le 1$.The R^2 value is the variability in the data accounted by the model in percentage [8].After estimating the sum of squares (SS) and mean squares

(MS), R^2 value can be used to check the adequacy of the model developed
R^2 = 1-SSerror /SS Total

There is good concurrence between the experimental and predicted values since the coefficient of determination calculated is 95.10%.The diagnostic checking of developed model can be checked by residual analysis. The normal probabilities of residuals are shown in Fig.3.The normal probability plot is used to verify the normality assumption.

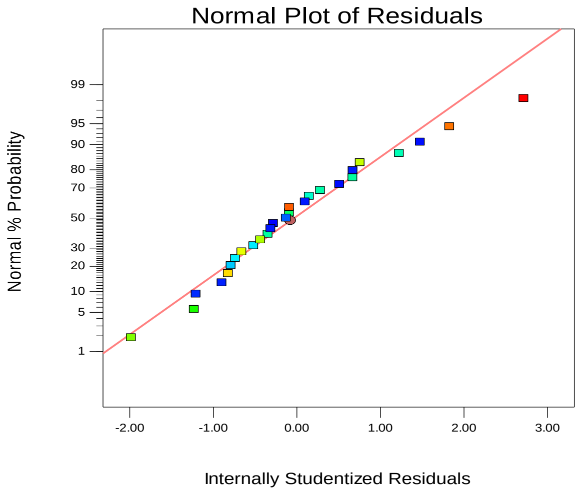

Figure .3 Normal residuals Plot

From the Fig.3 it is clear that the data are spread roughly along the straight line. Hence, it can be concluded that the data are normally distributed. Fig.4 shows predicted results against the actual results. It is understood that predicted results are very close to the experimental results so response surface models are suitable for predicting Thrust force of CFRP composites.

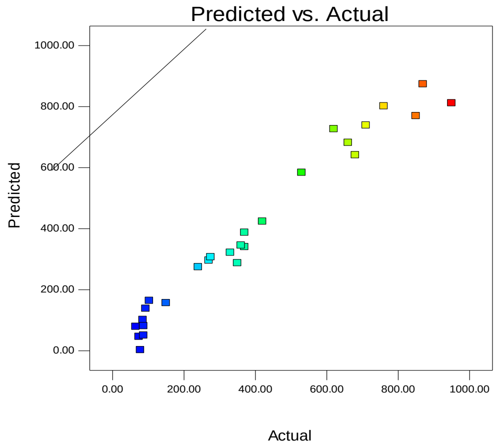

Figure.4 Graph showing variation of Experimental Values with predicted values

III. RESULTS AND DISCUSSION

It can be seen that effect of cutting speed on the cutting forces differs with various tool geometry and material. As expected, the type of drill used has a greater influence on thrust force. From Fig.5 it is observed that thrust force is high as feed rate increases due to the change in the shear area. There is tremendous increase in thrust force values for PCD because the amount of margin left after providing the flute is more. This reveals that drill geometry has significant effect on the thrust force. The thrust force generally increases as the speed increases but decreases further in the case of Carbide and PCD tool. On contrary to carbide, the cutting force observed during drilling using PCD is quite different. The value of cutting force is high as compared with the carbide. The analysis of response variable thrust force can be explained through contour and surface plots. The typical three-dimensional (3D) surface plots and two-dimensional (2D) contour plots for Thrust force in terms of the process variable are shown in Figures.6-11

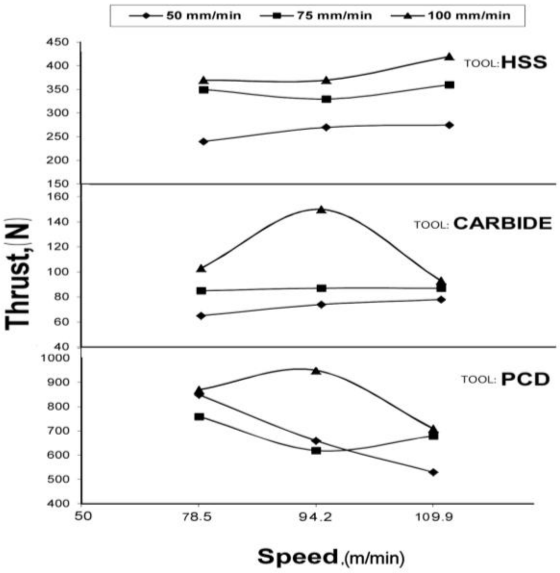

Figure 5.Measured thrust force at different speeds

Equation (2) is plotted in Fig.6-8 as contours for each of the response surfaces .These response contours can be used to predict of thrust force at any point of the experimental domain.

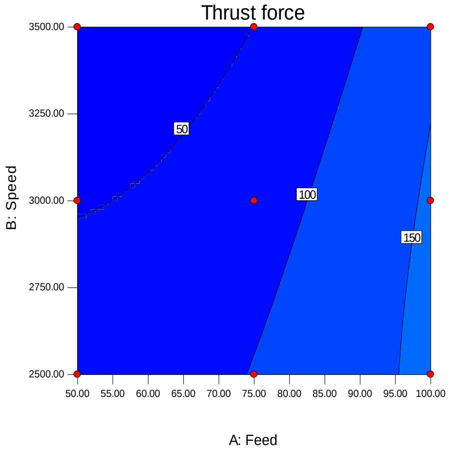

Figure.6 Estimated contour plots for Thrust force (Drill)

Fig.9 illustrates the surface plot for thrust force by varying the two variables Spindle speed and type of drill by keeping the feed as constant. It is found that the thrust force is high at lower speeds and found to decrease as speed increases.

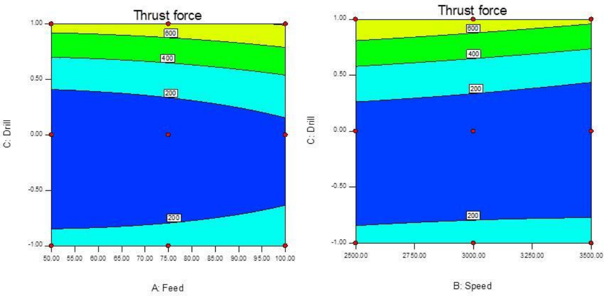

Figure.7 Estimated contour plots for Thrust force (Speed=3000rpm), Figure.8 (Feed=75mm/min)

PCD drill results in producing high forces. Thrust force increases as feed rate increases in the case of PCD.This effect is different in the case of Carbide drill.Fig.10 shows the 3D response surface plot for Thrust force with constant speed. Effect of keeping the type of drills constant can be witnessed from Fig.11.It can be seen that as feed increases and speed decreases the thrust force is found to increase.

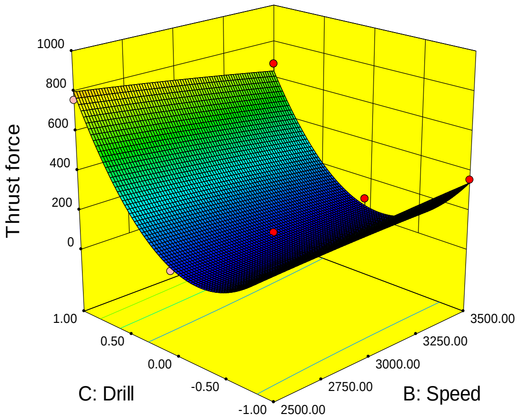

Figure .9 Estimated 3D response surface plot for Thrust force (Force vs. V and d).

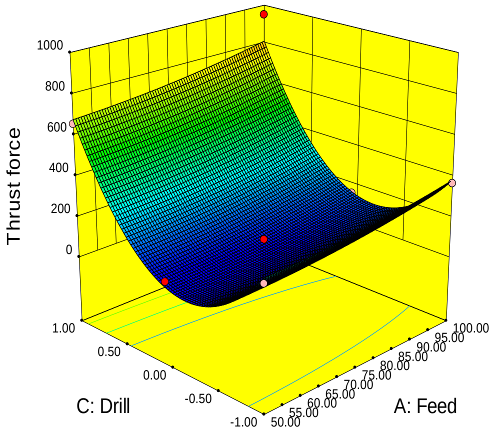

Figure .10 Estimated 3D response surface plot for Thrust force (Force vs. *d*)

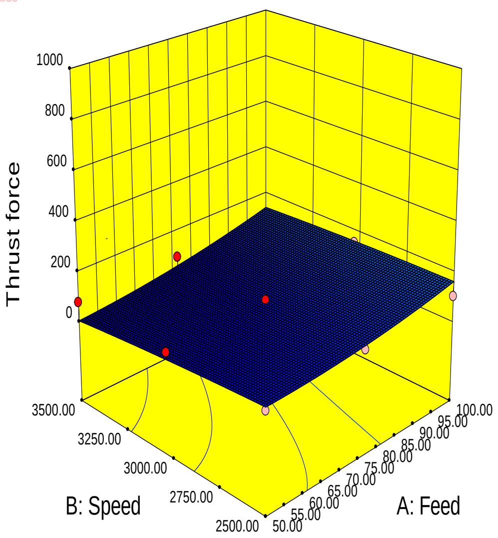

Figure.11 Estimated 3D response surface plot for Thrust force (Force vs. *V* and *f).*

IV. CONCLUSIONS

The following are the conclusions drawn from the experimental work

- For correlating the drilling parameters with respect to thrust force a second order response surface model has been developed. The developed model is significant at 95% confidence level, which shows that the developed model can be effectively used for drilling of CFRP composites within the range of the process parameters.
- Analysis of variance for the developed model revealed that the type of drill and the feed rate are the dominant factors that influence the thrust force. Thrust force recorded for HSS drill was high when compared to Carbide. Since the hardness of HSS tool is less than the Carbide drill.
- Medium cutting speed and feed rate provided optimum thrust forces irrespective of the drills used. Significant reduction in cost and timing can be achieved by using this response surface model

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REFERENCES

1. Ramesh.S, Karunamoorthy.L, Palanikumar.K Surface Roughness Analysis in Machining of Titanium Alloy,Materials and Manufacturing Processes, 2008,Vol.23,175-181
2. A.Riaz Ahamed & Paravasu Asokan & Sivanandam Aravindan & M. K. Prakash Drilling of hybrid Al-5%SiC-5%B4Cp metal matrix composites International journal of Adv.Manuf.Technol,2009,Vol.49,871-877
3. Bhattacharya,BandSorkhel,S.K.InvestigationforControlledElectrochemical Machining Through Response Surface Methodology Based Approach,Journal of Materials Processing Technology,1999,Vol 86,200-207
4. Palanikumar, K**.** Application of Taguchi and response surface methodologies for surface roughness in machining glass fiber reinforced plastics by PCD tooling. Int. J. Adv. Manuf. Technol,2008,Vol 30,19-27
5. S. Arul,D. Samuel Raj,L. Vijayaraghavan,S. K. Malhotra,R. Krishnamurthy Modeling and Optimization of Process Parameters for Defect Toleranced Drilling of GFRP Composites,Materials and Manufacturing Processes, 2006 Vol 21, 354-365
6. C.C. Tsao, H. Hocheng, Evaluation of thrust force and surface roughness in drillingcomposite material using Taguchi analysis and neural network,Journal of materials processing technology ,2008,Vol 2 0 3, 342–348
7. L. Krishnamurthy; B. K. Sridhar; D. Abdul Budan Comparative Study on the Machinability Aspects of Aluminium Silicon Carbide and Aluminium Graphite Composites,Materials and ManufacturingProcesses,2007,Vol.22, 903-908.
8. Montgomery, D.C**.** Design and Analysis of Experiments; 4th Ed.John Wiley and Sons: New York, 1997
9. D. Iliescu, D.Gehin, M.E.Gutierrez, F.Girot , Modeling and tool wear in drilling of CFRP, International Journal of Machine Tools & Manufacture,2010,50,204–213
10. B. Latha V. S. Senthilkumar Analysis of Thrust Force in Drilling Glass Fiber-Reinforced Plastic Composites Using Fuzzy Logic,Materials and Manufacturing Processes, 2009 ,Vol.24,509 – 516
11. J.P. Davim, Pedro Reis, Study of delamination in drilling carbon fiber reinforced plastics (CFRP) using design experiments, Composite Structures,2003,59 481–487
12. R.Thanigaivelan,RM.Arunachalam,Experimental Study on the Influence of Tool Electrode Tip Shape on Electrochemical Micromachining of 304 Stainless Steel, Materials and ManufacturingProcesses,2010,10,1166
13. V. N. Gaitonde S. R. Karnik J. Paulo Davim Prediction and Minimization ofDelamination in Drilling of Medium-Density Fiberboard (MDF) Using Response Surface Methodology and Taguchi Design,Materials and Manufacturing Processes, 2008, Vol.23, 377 – 384
14. S. Basavarajappa Tool Wear in Turning of Graphitic Hybrid Metal Matrix Composites,Materials and ManufacturingProcesses,2009,Vol.24, pages 484 – 487
15. Y. W. Seo, D. Ki,M. Ramulu ,Electrical Discharge Machining of Functionally Graded15–35 Vol% SiCp/Al Composites,Materials and Manufacturing Processes, 2006 ,Vol21,479 – 487
16. T. M. El-Hossainy, A. A. El-Zoghby, M. A. Badr, K. Y. Maalawi,, M. F. Nasr ,Cutting Parameter Optimization when Machining Different Materials,Materials and ManufacturingProcesses ,25,10,2010 ,1101
17. M. Dhananchezian, M. Pradeep Kumar, T. Sornakumar, Cryogenic Turning of AISI 304 Stainless Steel with Modified Tungsten Carbide Tool Inserts, Materials and ManufacturingProcesses,2011,26,5781
18. K.Palani Kumar,Modeling and Analysis of Delamination Factor and Surface Roughness in Drilling GFRP Composites, Materials and ManufacturingProcesses,2010,25,1059
19. Sundaravel Vijayan, R. Raju,S,R. K. Rao,Multiobjective Optimization of Friction Stir Welding Process Parameters on Aluminum Alloy AA 5083 Using Taguchi-Based Grey Relation Analysis, Materials and ManufacturingProcesses,2010,25,11,
20. S. Ranganathan,T. Senthilvelan,G. Sriram Evaluation of Machining Parameters of Hot Turning of Stainless Steel (Type 316) by Applying ANN and RSM,Materials andManufacturingProcesses,2010,10,1120
21. Erol Kilickap ,Mesut Huseyinoglu ,Selection of Optimum Drilling Parameters on Burr Height Using Response Surface Methodology and Genetic Algorithm in Drilling of AISI 304 Stainless Steel , Materials and Manufacturing Processes, 2010, 25, 10, 1068
22. A. M. El-Tamimi, M. S. Soliman, T. M. El-Hossainy, and J. A. Muzher ,Developed Models for Understanding and Predicting the Machinability of a Hardened Martensitic Stainless Steel, Materials andManufacturingProcesses,2010,25,8,758