Evaluation of Machining Parameters Influencing Thrust Force in Drilling of Al–SiC–Gr Metal Matrix Composites using RSM

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ABSTRACT- This paper focused on evaluation of machining parameters influencing thrust force during drilling of Al–SiC–Gr metal matrix composites using multifaceted carbide drills. There are three machining parameters i.e. Spindle speed, Feed rate, Drill diameter. Experiments are conducted on a vertical machining centre using Taguchi design of experiments. Taguchi orthogonal array is designed with three levels of drilling parameters with the help of software Minitab 15. 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 Al/SiC/Gr composites. The influences of different machining parameters on thrust force of Al/SiC/Gr composites have been analyzed through contour graphs and 3D plots. The investigation has revealed that the type of spindle speed affects the thrust force significantly followed by the feed rate and drill diameter.

Keywords*:* Drilling, Al-SiC-Gr MMC, multifaceted carbide drill, response surface methodology, Thrust force\\

1 Introduction

Metal matrix composites (MMCs) have become a large leading material in composite materials, and particle reinforced aluminium MMCs have received considerable attention due to their excellent engineering properties. These materials are known as the difficult-to-machine materials, because of the hardness and abrasive nature of reinforcement element like silicon carbide (SiC) particles [1].The matrix is usually a lighter metal such as aluminium, magnesium or titanium. The reinforcement material is embedded into the matrix [2]. The reinforcement does not always serve a purely structural task, which is, reinforcing the compound, but is also used to change physical properties. Such new classes of materials are characterized by light weight, high strength and wear resistance than those of conventional materials. Due to such attractive properties coupled with the ability to operate at high temperatures. [3]. Hybrid MMCs were obtained by reinforcing the matrix alloy with more than one type of reinforcements having different properties [4]. The application fields of MMCs include aerospace and automotive industries the increase in demand for light weight materials with high strength to weight ratio has led to the development and use of aluminum alloy based composites [5].

The Al-based hybrid composites, with 20% SiC whiskers and 0, 2%, 5%, 7% SiC nano particles, were fabricated by squeeze casting route [6]. In the view of the growing engineering applications of these composites, a need for detailed and systematic study of their machining characteristics is envisaged. The efficient and economic machining of these materials is required for the desired dimensions and surface finish [7]. Drilling is a frequently employed in industries owing to the need for component assembly in mechanical structures.

Many researchers [8-10] 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 [10]. Latha and Senthilkumar [11] used fuzzy logic technique to predict thrust force in drilling of composite materials. Taguchi technique is a powerful tool in experiment design. It provides a simple, efficient and systematic approach for optimization, quality and cost [12]. The methodology is valuable when the design parameters are qualitative and discrete [13].

The clustering of the particulate reinforcement during Metal Matrix Composite production has an important influence on MMC properties. By avoiding this, it gives better micromechanical properties [14] Silicon Carbide (SiC) ceramics are the promising candidates in the field of high temperature structural materials due to their excellent oxidation, corrosion, and creep resistance [15].SiC particulates affect the micro structural properties of MMC by increasing its density, sintering temperature and hardness. Best characteristics are obtained at 10 to 15 Weight percentage in the presence of SiC [16].

This paper investigates the effect of different drilling parameters on Thrust force in drilling Al/SiC/Graphite hybrid metal matrix composites. The experiments were conducted on a CNC Vertical machining centre using Multifaceted drills of diameter 4mm,8mm and 12mm. 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 drill diameters. The results proved that the developed model can be effectively used for the prediction of Thrust forces in machining of Al/SiC/Graphite hybrid metal matrix composites.

2 EXPERIMENTAL WORK

2.1 Materials and Methods

The Al/SiC/Graphite metal matrix composites were fabricated by stirring casting method. Silicon carbide and graphite was used as reinforcement in the metal matrix. The melting was carried out in the electrical resistance furnace. The aluminium scraps of 6061 were first preheated at 600°C before melting. The SiC and graphite were also preheated at the required temperature. The preheated aluminum scraps were first heated above the liquidus temperature to melt them completely. They were then slightly cooled below the liquidus temperature to maintain the slurry in semi-solid state. The pre-heated reinforcement were mixed manually then composite slurry were heated to a liquid state, The final temperature was controlled to be within 800° C and pouring temperature was controlled to be around 820° C. The melt was poured in to steel moulds and allowed to cool to obtain 110 mm × 110 mm × 5 mm size of plate.

The microstructure of the 15% volume fraction SiC and 4% volume fraction of Graphite composites is shown in Fig.1. Table 1 shows the chemical composition of Al-15% SiC-4% Gr metal matrix composite. The brief summary of the experimental conditions was shown in Table 2. The Multifaceted carbide drill bits used in this study are shown in Fig.2.

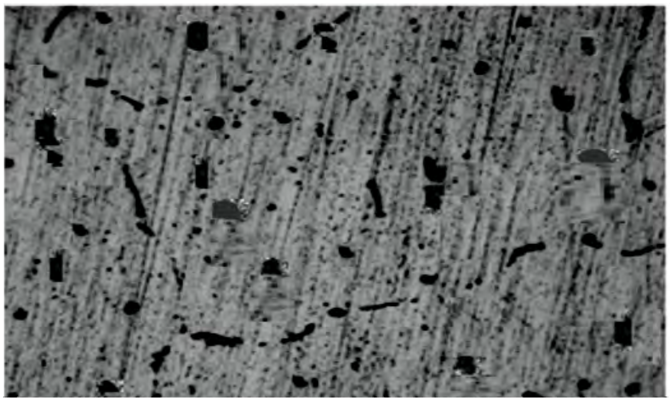

Fig. 1. Microstructure of Al alloy 6061 reinforced with SiC and Gr size of 50 microns.

Table 1 Chemical composition of Al -15% SiC-4%Gr

Fe	Si	Mn	Cu	Cr	Ti	V	Pb	Mg	Al
0.05	0.781	0.305	0.207	0.03	0.018	0.005	0.019	0.749	Remainder

Table 2 Processes Parameter used for modeling

Machine	**Arix Vertical CNC Machining Center**
Drills	Multifaceted carbide drills
Diameter of the drills	4 mm, 8 mm and 12 mm
Work piece	Al alloy 6061/15%SiC/4% Graphite
Machining conditions	Spindle speed : 1000, 2000 and 3000 rpm; feed rate : 0.05, 0.10 and 0.15 mm/rev

Fig. 2. Multifaceted drill bits used for the experiments

2.2 Experimental Procedure

The experimental setup is shown in Fig.3. Arix VMC 100 CNC drilling machining centre was used for making drills in the Al/SiC/Graphite composites using multifaceted drill bits. 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.

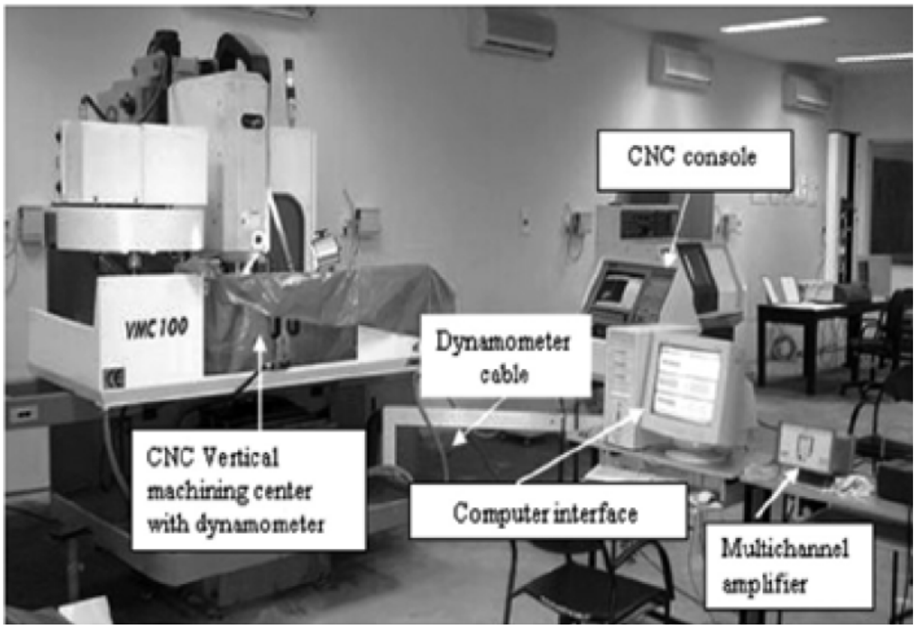

Fig.3. Experiment setup with dynamometer arrangement

2.3 Experimental Results

There are two measurable components to be considered during the drilling operation - thrust force and torque. They are the main two important responses used in the drilling process. Thrust force (F_Z) is the necessary force to maintain a given feed rate into the material

In addition the thrust force is responsible for the effects of tool wear, plowing in the drill center chisel edge and chip generation in the main cutting edge. These two forces are affected by cutting parameters like spindle speed, feed rate, and drill geometry and work piece material. Thrust forces (F_Z) have been measured using a Kistler dynamometer with suitable amplifier and stored by using a data acquisition system.

The responses thrust forces are obtained from experiments by varying input machining parameters such as spindle speed, feed rate and drill diameter by using Multifaceted carbide drills are listed down in Table 4.

Table 4 Drilling parameters and their Thrust forces for multifaceted drill

Trial No	**Spindle speed, *V* (rpm)**	**Feed rate, *f* (m/rev)**	**Diameter *d* (mm)**	**Thrust force F_Z , (N)**
1	1000	0.05	4	76.34
2	1000	0.05	8	98.11
3	1000	0.05	12	103.00
4	1000	0.10	4	125.90
5	1000	0.10	8	140.20
6	1000	0.10	12	128.87
7	1000	0.15	4	164.20
8	1000	0.15	8	182.20
9	1000	0.15	12	220.12
10	2000	0.05	4	51.00
11	2000	0.05	8	89.43
12	2000	0.05	12	139.20
13	2000	0.10	4	97.00
14	2000	0.10	8	119.10
15	2000	0.10	12	140.00
16	2000	0.15	4	127.10
17	2000	0.15	8	165.00
18	2000	0.15	12	177.00
19	3000	0.05	4	49.32
20	3000	0.05	8	58.00
21	3000	0.05	12	73.21
22	3000	0.10	4	56.20
23	3000	0.10	8	68.00
24	3000	0.10	12	97.20
25	3000	0.15	4	42.00
26	3000	0.15	8	103.00
27	3000	0.15	12	113.00

2.4 Optimization of Drilling Parameters for Al/Sic/Gr Metal Matrix Composites

The data preprocessing is carried out for each of the performance characteristics of the research interest. The performance characteristics are thrust forces with respect to the independent machining parameters such as spindle speed, feed rate and drill diameter. Processed data for all performance characteristics in drilling operation performed using multifaceted drill. The thrust force values measured from the experiments and their corresponding S/N ratio values of the multifaceted drills are listed in Table 5.

Table 5 Effect of machining parameters on the thrust force and S/N ratio

Trial No	**Spindle speed, *V* (rpm)**	**Feed rate, *f* (m/rev)**	**Diameter *d* (mm)**	**Thrust force F_Z , (N)**	**dB (S/N ratio)**
1	1000	0.05	4	76.34	-3.76
2	1000	0.05	8	98.11	-3.98
3	1000	0.05	12	103.00	-4.02
4	1000	0.10	4	125.90	-4.20
5	1000	0.10	8	140.20	-4.29
6	1000	0.10	12	128.87	-4.22
7	1000	0.15	4	164.20	-4.44
8	1000	0.15	8	182.20	-4.52
9	1000	0.15	12	220.12	-4.68
10	2000	0.05	4	51.00	-3.41
11	2000	0.05	8	89.43	-3.90
12	2000	0.05	12	139.20	-4.29
13	2000	0.10	4	97.00	-3.97
14	2000	0.10	8	119.10	-4.15
15	2000	0.10	12	140.00	-4.29
16	2000	0.15	4	127.10	-4.21
17	2000	0.15	8	165.00	-4.43
18	2000	0.15	12	177.00	-4.49
19	3000	0.05	4	49.32	-3.39
20	3000	0.05	8	58.00	-3.53
21	3000	0.05	12	73.21	-3.73
22	3000	0.10	4	56.20	-3.50
23	3000	0.10	8	68.00	-3.66
24	3000	0.10	12	97.20	-3.97
25	3000	0.15	4	42.00	-3.25
26	3000	0.15	8	103.00	-4.02
27	3000	0.15	12	113.00	-4.11

the η response table for each level of the process parameters (spindle speed, feed rate, and diameter) of the Multifaceted drill was created in the integrated manner and the results are given in Table 6.

Table 6 η values for thrust force by factor level (dB) (S/N)

Level	**Thrust force (N)**		
	Spindle speed (A)	**Feed rate (B)**	**Diameter (C)**
1	- 41.95	- 37.38*	- 37.45*
2	- 40.94	- 39.98	- 40.57
3	- 36.94*	- 42.46	- 41.80
Delta	5.02	5.08	4.35
Rank	2	1	3

2.5 Response Surface Modeling

Response surface methodology (RSM) is a collection of mathematical and statistical techniques that are useful for the modeling and analysis of problems in which a response of interest is influenced by several variables and the objective is to minimize this response [11].

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.

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

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 [14]. 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:

$$\text{Thrust Force} = -5.6752+0.0637739*V+812.711*f+5.54153*d-1.72661E-005*V^2 +1917.56*f^2-0.227153*d^2-0.352667*V*f-1.04875E-0.003*V*d+15.8625\,f*d \quad (2)$$

R^2 is called coefficient of determination, is used to judge the capability of regression model developed, $0 \leq R^2 \leq 1$.The R^2 value is the variability in the data accounted by the model in percentage [14]. 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 $R^2 = 1 - \frac{\text{SS error}}{SS\ Total}$.

The adequacy of the model is checked by using the co-efficient of correlation. The co-efficient of correlation (R-Sq = 93.6%) indicates that the model is adequate at 95% confidence level. Further the analysis of variance is carried out for thrust force in drilling hybrid metal matrix composites. The analysis of variance (ANOVA) method is used to evaluate the confidence interval and adequacy of the model. Analysis of variance essentially consists of partitioning the total variation in an experiment into components ascribable to the controlled factors and error. Table 3 shows the analysis of variance for thrust force. In this table, F-ratio is an index used to check the adequacy of the model in which calculated F-value should be greater than the F-table value. The model is adequate at 95% confidence level since the calculated F-value is greater than the F-table value. From the table (Table 3), the model F-value of 23.85 indicates that the model is significant. The results also indicate that the factors *V*, *f*, *d* and the interaction between the factors *V* * *f* are highly significant in drilling of composite materials.

Table 5 Analysis of Variance for Thrust force model

Source	Degree of freedom	Sum of square	Mean square	F-Value	P (%)
V	2	2	16174.8	8087.4	19.66
f	2	2	19625.1	9812.5	23.85
d	2	2	9002.1	4501.0	10.94
V *f	4	4	4731.2	1182.8	2.88
V *d	4	4	793.2	198.3	0.48
f *d	4	4	420.8	105.2	0.26
Error	8	8	3290.8	411.35	
Total	26	26	54038.0		100

When compared to other interactions and square effects considered.

3 RESULTS AND DISCUSSION

In the present work the drilling is carried out for Al/SiC/Graphite metal matrix composites. Reduction of thrust force is the important concern in machining of these materials. For prediction of thrust force in drilling Al/SiC/Graphite metal matrix composites, response surface model is developed. The model prediction ability is analysed by using residual analysis.

Figs.4-6 shows the residual graphs for thrust force in drilling Al/SiC/Graphite metal matrix composites. Figure 4 shows the normal probability plot for residuals. The plot shows that all the residuals are almost formed in a straight line which indicates the high correlation that exists between the predicted and measured values.

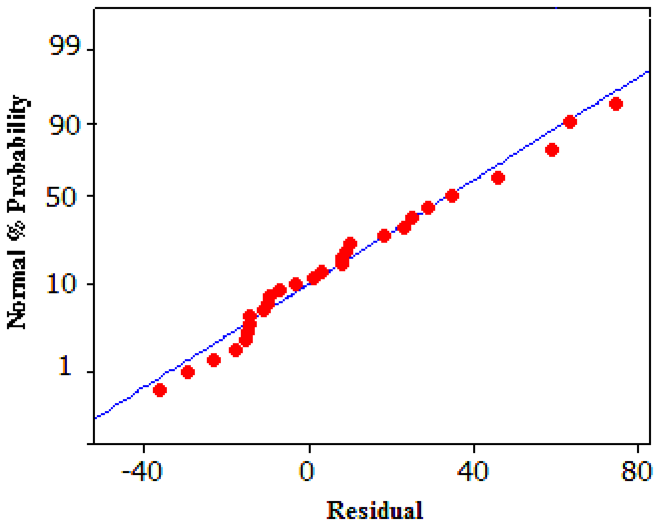

Fig. 5. Plot of normal percent probability Vs residual

Fig.5. shows the statistics about the residuals. From the analysis of residuals, it has been asserted that the response surface model developed for predicting thrust force in drilling is very much suitable for predicting thrust force in drilling hybrid metal matrix composites. In addition, the plot of the residues verse predicted SR illustrates that there is no noticeable pattern or unusual structure present in the data as depicted in Fig.6.

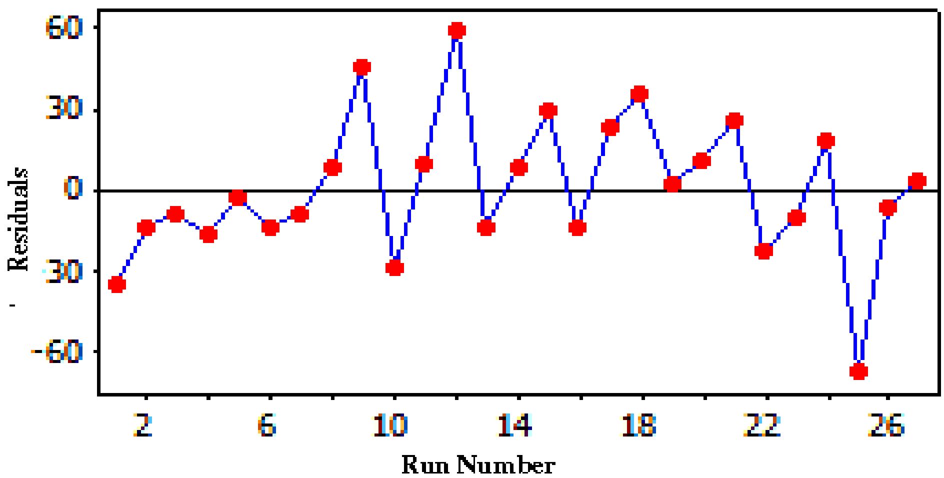

Fig.5. Plot of residual Vs predicating value

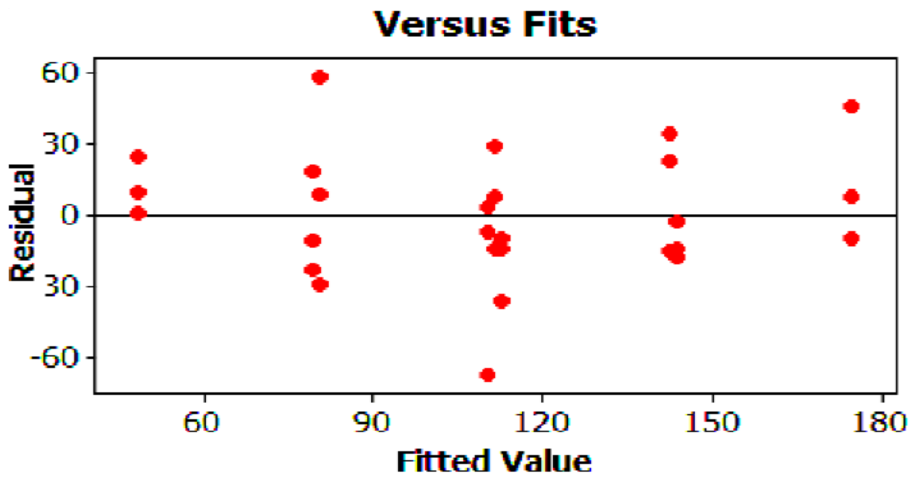

Fig. 6. Plot of residual Vs Fitted value

The major focus of research is to find optimum machining conditions for which desired thrust force can be achieved. Hence, the contour plots of the thrust force in spindle speed, feed rate and drill diameters are shown in Figs. 7-9 respectively.

Fig.7. shows the estimated response surface for thrust force in relation to the process parameters of drill diameter and spindle speed while feed rate remain constant. It can be seen from the figure, the thrust force tends to increase significantly with the increase in diameter for any value of spindle speed. However, the thrust force tends to decrease with increase in spindle speed, especially at higher spindle speed.

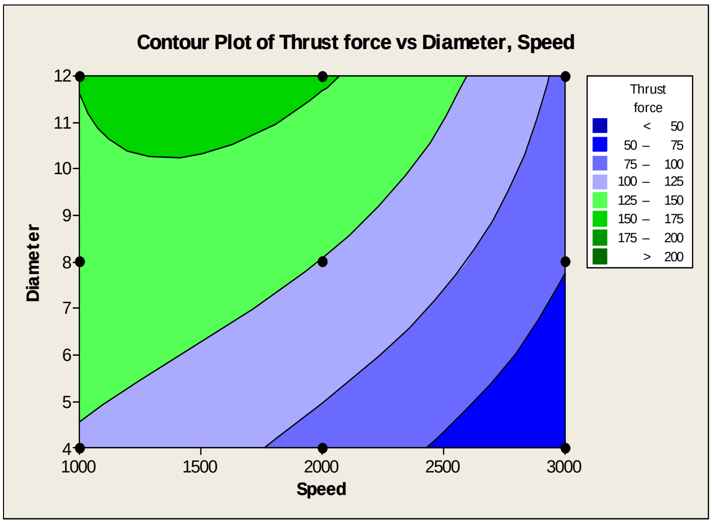

Fig.7. Effect of Diameter & Spindle Speed on Thrust force

Fig.8. shows the estimated response surface for thrust force in relation to the process parameters of diameter and feed rate while spindle speed remains constant. It can be seen from the figure, the thrust force tends to increase significantly with the increase in Feed rate for any value of drill diameter.

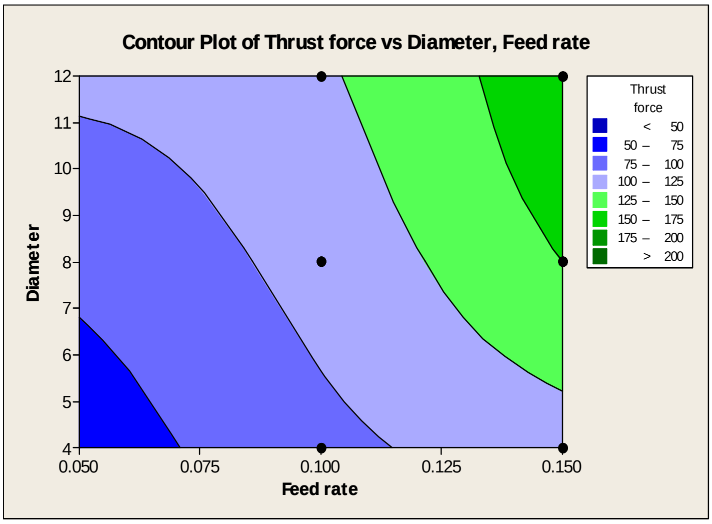

Fig.8. Effect of Diameter & Feed rate on Thrust force

Fig.9. shows the best thrust force is achieved with the combination of lowest feed rate and highest spindle speed, as reported by earlier investigators. The thrust force does not vary much with feed rate at low spindle speed ranges, but tends to increase almost linearly with increasing feed rate at higher spindle speed.

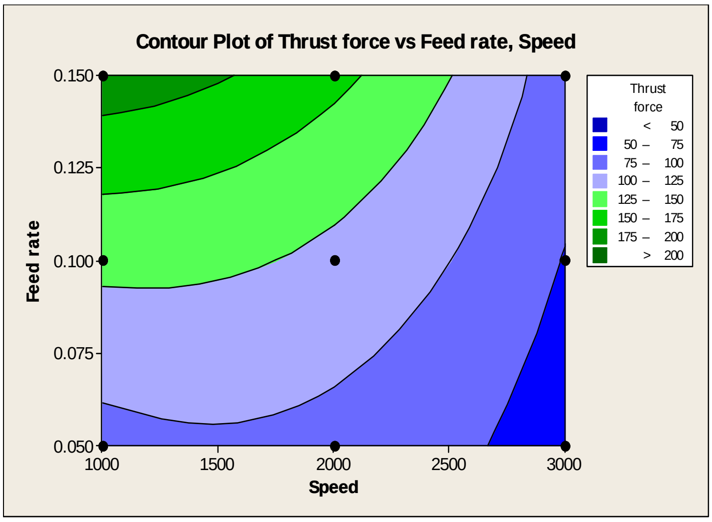

Fig .8. Effect of Spindle Speed & Feed rate on Thrust force

4 CONCLUSIONS

The following conclusions can be drawn from the present investigation on drilling of Al–SiC–Gr reinforced composites using Multi-faceted carbide drills at different machining parameters

- ❖ Thrust forces vary with feed, feed rate affects drilling forces but spindle speed has comparatively less influence than feed rate.
- ❖ Feed rate is the main factor, which influence the thrust force in drilling of composite and as the feed rate increases the thrust force also increases.
- ❖ Lower speed shows comparatively more thrust force than higher spindle speed.
- ❖ Thrust forces decreases with increase in cutting speed and vice versa.
- ❖ The model used in the work is able to predict the thrust force in drilling of hybrid metal matrix composites, within the ranges of machining parameters studied.
- ❖ The accuracy of the model can be improved further by adopting more cutting conditions and more variables.

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