

Experimental Investigation on the Influence of Process Parameters in Thermal Drilling of Metal Matrix Composites

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Friction Drilling is a special drilling technique that utilises the Frictional heat generated between the rotating conical drill bit and the stationary workpiece to soften and penetrate the work. The material which interests our study is the metal matrix composite Copper Silicon carbide (CuSiC) due to its high thermal conductivity which would accelerate the drilling process. Friction drill bits of various cone angles are made out of Tungsten High speed steel. Friction drill bits of various cone angles are made out of Tungsten High speed steel. The purpose of our study is to analyse the influence of the drilling parameters: Friction angle, Feed rate, Workpiece thickness and Spindle speed on Thrust force and Torque both graphically and by means of employing Taguchi's parametric design approach. Experimentation is to be conducted using Taguchi's orthogonal array and the results have to be assessed by analysis of variance (ANOVA).

Key Words: Friction drilling, CuSiC, Metal matrix composite, Thrust force, Torque.

1. INTRODUCTION

Drilling is one of the widely used machining processes. Almost 75% of the products need some sort of hole making process, hence drilling is inevitable. Unlike Conventional drilling where surface finish and dimensional accuracy is affected by the chips adhering to work piece friction drilling is a novel 'no chip' and dry hole making process where the friction between the rotating tool and the work piece softens the metal penetrating the tool inside the work piece. A bush is formed around the hole strengthening it and hole quality is on par when compared to the conventional drilling. It is also named as flow drilling, friction stir drilling or thermal drilling. [1]

Metal Matrix composites with various reinforcements are finding increased applications mainly in aerospace, automotive and non-structural industries as they provide better structural efficiency, reliability and strength. Metals like aluminium, copper, titanium are widely used as matrices. Reinforcing ceramic particles in the metal matrices result in better wear resistance, strength, rigidity modulus and make them reliable for high temperature applications. SiC reinforcements are widely used due to their high strength, hardness, stiffness, low density and easy availability [2]. Silicon Carbide (SiC) reinforced Aluminium matrix MMC's are mostly used for electronic packaging. Copper matrix MMC with SiC particles is a better candidate due to

high thermal conductivity of Copper which would accelerate the drilling process [3]. Although SiC is brittle in nature, high reinforcement rates and better bondage with ductile copper matrix increases the overall ductility, toughness of the composite [4].

As the drill rotating at high rpm with significant axial pressure comes in contact with the work piece [Figure 1: Stage 1] it softens the material thus penetrating it [Figure 1: Stage 2]. Meanwhile the displaced material forms a strong bush around the drill making it ideal where riveting is to be done [Figure 1: stage 4]. The softened material forms the bush hence there is no chip forming and material wastage. More ever coolant is not required, hence it is a dry process too.

There are various publications which are focussed only on friction drilling of various alloys of stainless steel. Copper Silicon carbide MMC is a high potential composite mainly used in electronic packaging with very little research done on it. Ching Yern Chee and Azida Azmi have mentioned a method of preparation of the above mentioned metal matrix composite [3]. In our study we are concerned with the influence of drilling parameters Friction tool angle, tool feed rate, work piece thickness and spindle speed on thrust force and torque. The material which interests our study is uncoated copper silicon carbide composite and the friction drill bit is made up of Tungsten High speed steel. Studying the thrust force and torque will help us in understanding the tool wear and in deciding the optimum conditions for smooth and efficient drilling. Thrust force generally increase with increasing feed rates and thickness of the sample and decrease with increasing spindle speeds[5] and torque also show the same trends[6]. Various graphs are drawn showing the effect of the drill parameters on the analysed factors and

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analysis is also done employing Taguchi's parametric design approach. Waleed [7] has deployed Fuzzy modeling for Thrust force and Torque analysis during flow drilling of CuSiC and has got good results. Regression Modeling is done in this study to predict the parameters Thrust Force and Torque and to evaluate the effectiveness of the model.

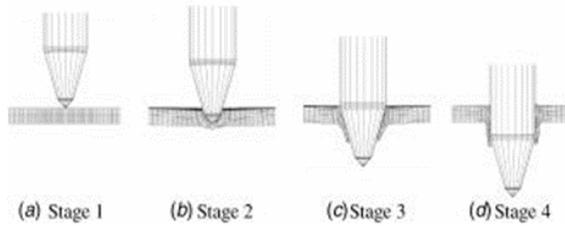


Figure 1. Stages in Friction drilling process [8]

2. EXPERIMENTAL DESIGN

2.1 Flow drill tool

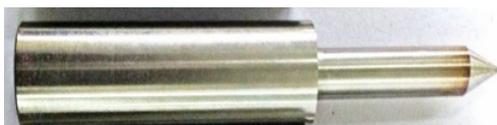
The flow drill bit was machined from a cylindrical Tungsten High speed steel work piece in a local industry here in Chennai. The Geometrical structure of the tool is shown in Figure 2. The Drill consists of four regions:

- (a) Conical Region: - It has a steeper angle k and is small in length. It is the region which enlarges the hole and pushes the plasticized work which was created due to friction between its surface and the work sideways.
- (b) Cylindrical Region: - This is a cylindrical region of diameter d which decides the diameter of the hole and it is relatively longer.
- (c) Shank region: - This is the curvature of the tool that is gripped by the tool holder [9].



Figure 2. Geometry of Flow drill

Although most flow drills have a shoulder region we neglected it as it does not interests our study. Tools with angle k as 30, 45 and 60 degrees were manufactured.



$k=30$ degrees



$k=45$ degrees



$k=60$ degrees

Figure 3. Top view of flow drills used

2.2 Work piece

Machining is done on the metal matrix composite Copper Silicon carbide (CuSiC). Here, Copper is the matrix and uncoated powdered silicon carbide is added as reinforcements. The work was made using powder metallurgy techniques. The steps involved in making the composite are:

- (a) Preparation of a powdered mixture of Cu and SiC containing 95% Cu and 5% SiC.
- (b) Mixing of the mixture via ball milling method using tungsten carbide ball. The drum was rotated at 300 rpm.
- (c) Compacting the mixture by cold pressing under 250 bar in a steel die.
- (d) Sintering under 850C for 3 hours.

2.3 Machine setup

A 3 axes, computer numerical controlled vertical machining centre Makino S33 with a maximum spindle speed of 12000 rpm and spindle motor of 22 kW was used for machining. The setup is shown in the Figure 4.



Figure 4. Vertical CNC machine



Figure 5. Setup for Drilling

The CuSiC composite work pieces of thickness 2, 3 and 4 mm is set on the table of the CNC machine with suitable holding devices as shown in Figure 5. The drilling operation is performed by changing the feed rate and spindle speed inputs in the CNC programming. A drilling tool dynamometer made by SYSCON was connected to the drilling machine which gave the Thrust force and Torque values for each drilling operation as seen from Figure 6.



Figure 6. Drill dynamometer

3. EXPERIMENTAL PROCEDURE

The Experiments are conducted in accordance with Taguchi's L9 array. Taguchi's unique method helps in easy understanding of the dependent parameters with minimum number of experiments and provides an ordered way to collect and analyse the data to satisfy the requirements of the experiment. Thus, saving both time and cost.

The machining parameters-Spindle Speed, feed Rate, thickness of work piece and Tool Cone angle are used in three levels. The three levels are denoted as Level 1, Level 2 and Level 3. The Parameters along with their values are given in Table 1.

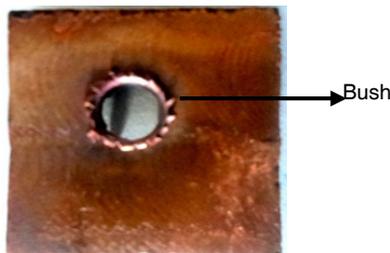


Figure 7. Work piece after drilling.

The work piece was rigidly fixed on the vertical machine bed using various fixtures. The digital dynamometer which directly gives the thrust and torque values was attached to the port in the table of the machine and machining was done was performed manipulated through CNC programming. Figure 7 shows the CuSiC work piece with a bush around the drilled hole after friction drilling.

Table 1. Values of Machining Parameters.

Parameters	Level 1	Level 2	Level 3
Spindle Speed(rpm)	3000	3500	4000
Feed Rate(mm/min)	50	60	70
Thickness of work (mm)	2	3	4
Cone Angle(degrees)	30	45	60

4. RESULTS AND DISCUSSIONS

4.1 Thrust Force

The variation of Thrust force during drilling operation under different machining conditions is shown in Figure 8. Thrust forces show an increasing trend with increase in feed rate as the tool must withstand vibrations which increase with the feed rate. It is observed that thickness of the work piece has a dominating effect on thrust force as greater forces are needed to penetrate thicker work. Work piece with thickness 2 mm has lowest thrust values. Further they depend on the cone angle. Greater the cone angle more is the thrust force due to the greater area that will be in frictional contact with the work. Thus tool with friction angle of 60 degrees show high thrust values.

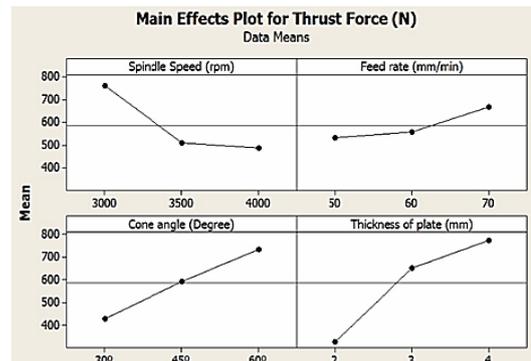


Figure 8. Thrust force variation with respect to different machining condition

High Spindle speeds give less thrust values as the high temperature due to friction between rotating tool and work melts the work faster near the drill area. Boopathi [10] has shown that with increasing spindle speed and depth of travel of the friction drill tool, Thrust force increases. Vimal [11] has also reported that with increasing Spindle speed during drilling of composites, material removal is high but Thrust Force is low. The highest values of thrust forces are obtained for the set with all the parameters having maximum values, while the spindle speed is having the lowest (3000) rpm. This is mainly due to uncomfortable combination of high thickness of work and low spindle speed.

4.2 Torque

The variation of Torque under different machining conditions is shown in Figure 9.

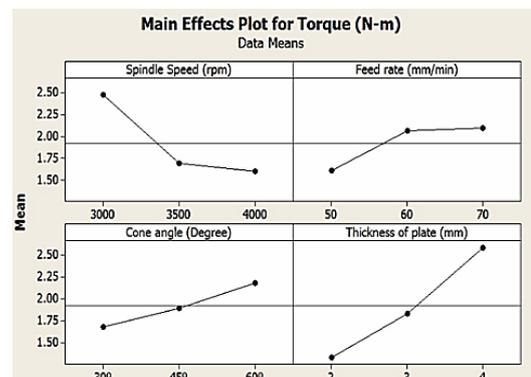


Figure 9. Torque variation with respect to different machining conditions

It is noted that Torque increases with feed rate but it seems to become saturated beyond a feed rate of 60mm/min. Increase of torque with tool angle is similar to the variation of torque force. The values of torque are seen increasing with the thickness of the work. Dependence of torque on spindle speed show same trend as thrust force.

4.3 ANOVA Table

Anova Table for Thrust Force is given in Table 2. It is noted from the Anova table that Feed rate contributes 50.92% amongst the various parameters to the thrust force Hence it is ranked at first position.

Table 2. ANOVA Table for variation of Thrust force

SOURCE	D O F	Sum of Squares	Mean of Variance	Percentage contribution	Rank
Tool cone angle (deg)	2	1.3734	0.6867	0.29822	2
Spindle speed(rpm)	2	0.44347	0.2217	0.096297	3
Feed rate (mm/min)	2	2.40007	1.20003	0.52116	1
Thickness of work (mm)	2	0.38827	0.19413	0.084311	4
Error	0				
Total	8	4.6052			

Thickness of the work piece also contributes for 22.37% of the thrust force. It is closely followed by Tool Cone angle which contributes 22.19% to the force. Spindle speed has a least contribution of 5%.

Anova Table for Torque is shown in Table 3. Feed rate contributes a maximum of 52.12% to the torque and is ranked at first position. While the tool angle contributes for 29.88% of the torque, Spindle speed and Thickness of the work contribute only 9.63% and 8.42% respectively to the torque.

Table 3. ANOVA Table for variation of Torque

SOURCE	D O F	Sum of Squares	Mean of Variance	Percentage contribution	Rank
Tool cone angle (degrees)	2	139262	69631	0.2219	3
Spindle speed(rpm)	2	31380	15690	0.05001	4
Feed rate (mm/min)	2	316376	158188	0.5042	1
Thickness of the work(mm)	2	140355	70177	0.22371	2
Error	0				
Total	8	627373			

4.4 Regression Modelling

For Prediction of Thrust Force and Torque for different parameter values, Regression Modeling is used. The Regression Equation was evaluated for Thrust force and Torque and is given by:

$$\text{ThrustForce}(N) = -86 - 0.253 * \text{SpindleSpeed}(rpm) + 7.23 * \text{Feedrate}\left(\frac{mm}{min}\right) + 11.32 * \text{Coneangle}(degrees) + 200.8 * \text{ThicknessofPlate}(mm)$$

$$\text{Torque}(Nm) = 2.53 - 0.000823 * \text{SpindleSpeed}(rpm) - 0.0065 * \text{Feedrate}\left(\frac{mm}{min}\right) + 0.111 * \text{Coneangle}(degrees)$$

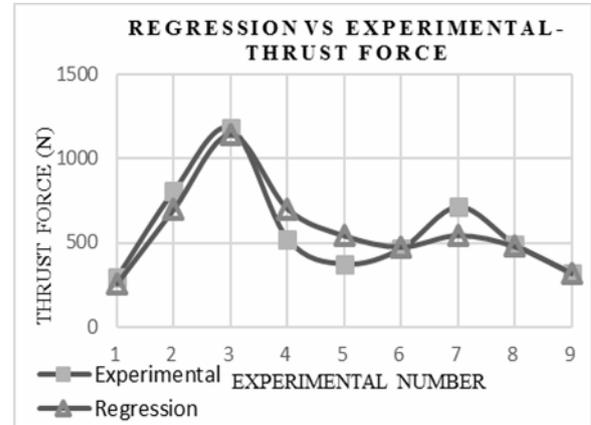


Figure 10. Regression V/s Experimental Values for Thrust Force

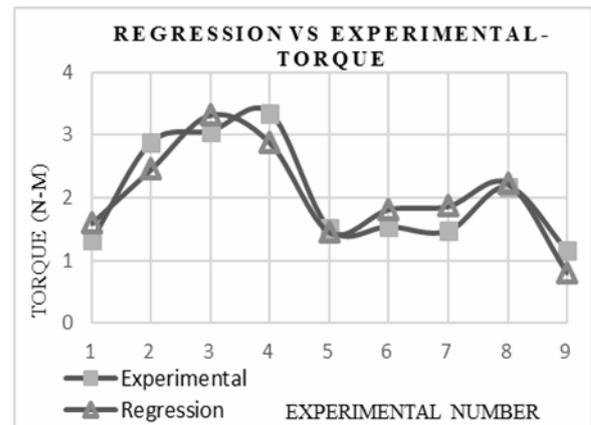


Figure 11. Regression V/s Experimental Values for Torque

The Graphs (Figure 10 and 11) shows the Regression modelled values and Experimental values of Thrust Force and Torque for each one of the experiment. Both the regression and the experimental values are close to each other for most of the experiment.

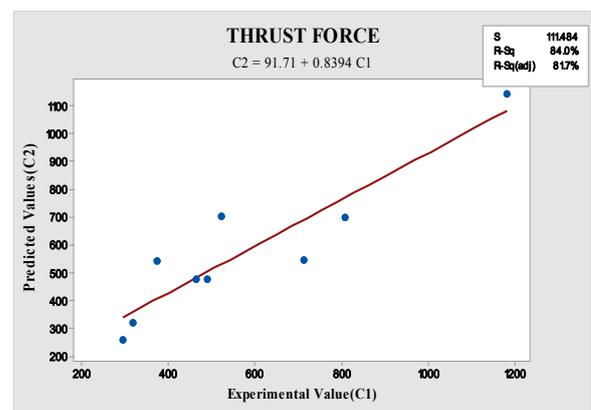


Figure 12. Evaluation of Model Effectiveness for Thrust Force

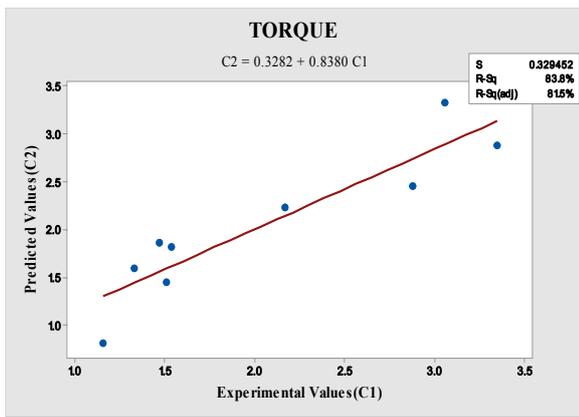


Figure 13. Evaluation of Model Effectiveness for Torque

Additionally, Graphs between Regression and Experimental values is drawn for both Thrust force and Torque (Figures 12 and 13) and R squared value is found for each of the graphs to find out the efficiency of the model.

The R-squared value for Thrust Force and Torque is 81.7% and 81.5% respectively.

5. CONCLUSION

Friction drilling was performed on Reinforced metal matrix composite Copper Silicon Carbide. Based on the experimental results the following conclusions were made:

- Thrust Force and Torque increase with increasing feed rate, thickness of the work piece and the tool conical angle.
- Thrust Force and Torque decrease with increase in spindle speed.
- The Regression Modelled values for both Thrust Force and Torque are in close agreement (R^2 value= 81.7 and 81.5%) with Experimental values and hence the model can be used for prediction.

Based on Anova table, the influence of drilling parameters on Thrust force and Torque are ranked as follows:

Table 4. Ranking of the parameters based on their effect

	Rank 1	Rank 2	Rank 3
Thrust Force	Feed rate	Thickness of the work piece	Tool cone angle
Torque	Feed rate	Tool cone angle	Spindle speed

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ЕКСПЕРИМЕНТАЛНО ИСТРАЖИВАЊЕ УТИЦАЈА ПАРАМЕТАРА ПРОЦЕСА ТЕРМИЧКОГ БУШЕЊА НА КОМПОЗИТЕ СА МЕТАЛНОМ МАТРИЦОМ

В.А.Валед, А.Чатријан, Р.С.С.Вимал

Фрикционо бушење је посебна техника бушења која користи топлоту генерисану трењем између ротационог конусног бит наставка бушилице и стационарног обратка да би се он омекао и у њега продрло. Предмет истраживања је композит са металном матрицом CuSiC због велике топлотне проводљивости која убрзава процес бушења. Наставци фриксионе бушилице различитог угла конуса су израђени од волфрамног брзорезног челика. Циљ истраживања је анализа утицаја параметара бушења:

угао трења, брзина помоћног кретања, дебљина обратка и брзина вретена, на аксијалну силу и обртни момент, како графичким приказивањем тако и

Тагучијевим приступом. Експеримент је изведен применом Тагучијеве орто-гоналне матрице а процена резултата анализом варијансе (ANOVA).