Artificial Intelligence Modelling of Process Parameters on Friction Drilling of Metal Matrix Composites

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ABSTRACT

Composites have a unique ability to incorporate the combined properties of different constituent materials. Metal matrix composites like Copper Silicon Carbide (CuSiC) have both the high thermal conductivity of Copper and strength of Silicon carbide and are a potential replacement for AlSiC in electronic packaging. Thermal drilling is a novel technique which results in high quality holes with no chip generation. In this study, the authors intend to develop an Artificial Intelligence model to predict thrust force and Torque using Fuzzy Logic .The model is to be built considering the process parameters such as Spindle speed, Feed rate, Thickness of the work piece and Cone Angle. The models are developed to predict Thrust Force and Torque. The effectiveness of the models are evaluated by comparing experimental values with the values from the model .The evaluation is done based on the parameter, Correlation coefficient (R). The models seems to be very effective with a correlation coefficient of around 90% approximately.

KEY WORDS: Thermal Drilling, Metal matrix composite, Fuzzy logic, Torque, Thrust Force.

1. INTRODUCTION

Composites are gaining increased popularity as an alternative to traditional materials due to their properties such as high specific strength, corrosion resistance, electrical and thermal insulation properties. Metal Matrix composites are finding increased applications due to their superior mechanical and other properties. They have even been proposed for making various components of IC engines (Rajmohan, 2012). Reinforced Metal matrix composites have an advantage over non reinforced MMC's in terms of structural efficiency, reliability, and mechanical performance, reliability and Structural efficiency (Khor, 1998). Reinforcing Ceramic particles like Silicon Carbide (SiC) which are known for their high Strength, increased wear resistance, rigidity modulus would impart these properties to the composites too. Aluminum matrix composites reinforced with SiC are mostly used in electronic packaging. Copper seems to be a better candidate for matrix than Aluminum as high thermal conductivity of Copper will lead to faster heat dissipation. Based on these properties, Copper matrix reinforced with Silicon carbide (CuSiC) is being considered for experimentation.

Drilling is one of the commonly used machining process which is almost unavoidable. Friction drilling also known as Thermal Drilling is a special drilling process with no chip generation. It employs the frictional heat between the rotating drill and the work piece to penetrate the work and a bush is created around the hole which strengthens it (Somasundaram, 2010). In Thermal drilling, Cone Angle along with Feed rate and Spindle speed are some of the important parameters considered. In addition, Thickness of the composite is also considered a significant parameter since thickness of the work piece is directly proportional to the drill depth. Analysis of the key response variables namely Thrust Force and Torque is important to study thermal degradation while drilling of composites. Thrust Force also has a direct impact on cutting of material, wear on the tool and quality of the hole. In this paper, an artificial intelligence model based on Fuzzy Logic is built for the prediction of Thrust force and Torque for friction drilling of CuSiC composite. The efficiency and correctness of model is evaluated by comparing the predicted values with the actual experimental ones. Artificial intelligence tools like Fuzzy logic play a crucial role in modeling and analysis. Latha (2009) had applied Fuzzy logic for determination of delamination while drilling GFRP composites. Vimal Sam Singh (2009) had also successfully applied Fuzzy logic modeling for prediction of Thrust force and torque for drilling of GFRP composites.

In this study, Fabrication of Copper Silicon Carbide was carried out using powder metallurgy process and a Flow drill machined with different cone angles from High Speed Steel was used. Friction drilling process was carried out and the experimental results were used for developing an Artificial intelligence model. The results showed that artificial intelligence tools such as Fuzzy logic can be successfully used for friction drilling of MMC composites.

2. EXPERIMENTAL SETUP

The ceramic particle reinforced Metal matrix composite Copper Silicon carbide (CuSiC) was made using powder metallurgy techniques. A mixture containing Pure Copper 95% with an average size of 30~40 μm and SiC particles 5% with a particle size of 20~25μm is mixed in a ball mill using Tungsten carbide balls. Then the mixture is compacted under 250 bar in a steel die (Cold Press). Finally, the mixture is sintered for 3 hours at 850˚C thus forming Copper Silicon carbide composite.

The Friction drill tool was machined from Tungsten High Speed steel. The tool can be divided into Conical region which is machined at an angle which is known as Cone angle (k) and is shorter in length, Cylindrical region which

is longer in length than the former and determines the diameter of the hole and Shank Area which is held by the tool holder. Tools were machined with cone angles 30˚, 45˚ and 60˚.

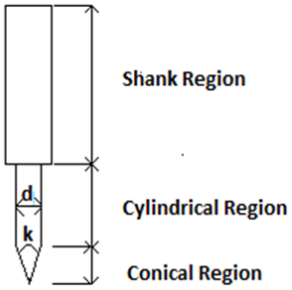


Figure.1. Regions in a Flow drill

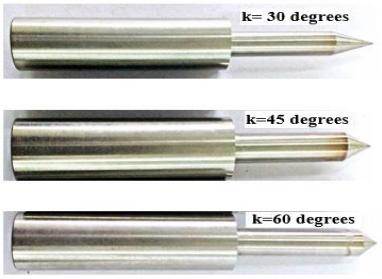


Figure.2. Flow drills of various cone angles used

Machining was done using a 3 axes CNC machining center with a maximum speed of 12000 rpm and a power of 22 kW. Work pieces of thickness 2, 4 and 6 mm were machined by changing the input parameters Spindle Speed and Feed rate using CNC programming. Three different flow drills of different cone angles were also used. The work piece was clamped to the table using suitable fixing. A Dynamometer was attached to the table which gives the Thrust Force and Torque readings.

Figure.3. Machining Setup

Figure.4. Dynamometer Readings

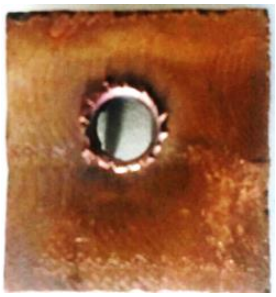


Figure.5. Drilled Work

The experimentation was done according to Taguchi's L9 orthogonal array. Taguchi's method helps in interpretation of the dependent parameters with minimum number of experiments. The parameters used are given below:

Table.1. 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 piece(mm)	2	3	4
Cone Angle(degrees)	30	45	60

Artificial intelligence modeling using fuzzy based logic in drilling of CUSIC: Fuzzy logic is a computing method used to create a relationship between the input parameters and their response.

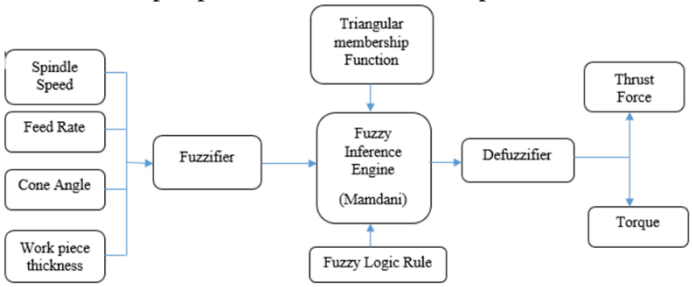


Figure.6. Outline of Basic Fuzzy Logic System Process

The first step involved in the computing process is Fuzzification where we convert crisp values to linguistic terms. Membership functions are allocated for both input and output parameters. Membership functions illustrate graphically the degree of contribution of each parameter. There are various membership functions present like triangular, trapezoidal etc…, out of which triangular functions are preferred as it had given good results previously. Triangular membership function can be evaluated by the expression given below:

$$f(y;p,q,r) = \begin{cases} 0 & y \le p \\ \frac{y-p}{q-p} & p \le y \le q \\ \frac{r-y}{r-q} & q \le y \le r \\ 0 & r \le y \end{cases} \dashrightarrow \quad [5]$$

Then, Fuzzy rules are defined which are in the form of IF-THEN statements with four inputs and two outputs.They are of the form:

Rule 1: If *p1* is A1 and *p2* is B1 and *p3* is C1 and *p4* is D1 then *q1* is E1 and *q2* is F1 else

Rule 2: if *p1* is A2 and *p2* is B2 and *p3* is C2 and *p4* is D2 then *q1* is E2 and *q2* is F2 else

Rule n: if *p1* is An and *p2* is Bn and *p3* is Cnand *p4* is Dnthen *q1* is En and *q2* is Fn. (1)The last step is Defuzzification which then converts the linguistic terms into values based on Centroid method. Fuzzy modeling is done with the help of Matlab software and Mamdani Fuzzy model is employed. The fuzzy logic employed is shown below:

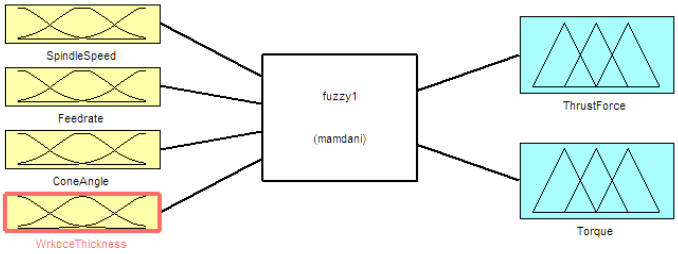
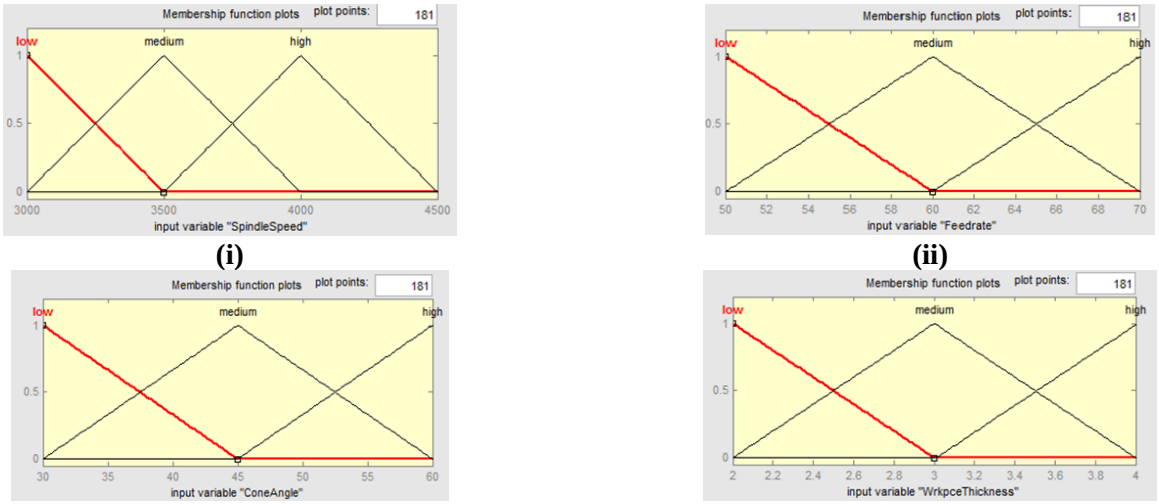


Figure.7. Fuzzy Logic System



(i) **(ii)**

(iii) **(iv)**

Figure.8. Membership Functions for (i) Spindle speed, (ii) Feed rate, (iii) Cone angle and (iv) Work piece thickness

The membership functions for input parameters for various input parameters are shown in Figure 7. Figure 8 shows the membership functions for Thrust Force and Torque which are the output parameters. The output is divided into nine membership functions namely Lowest, Lower, Low, Lower medium, medium, higher medium, High, Higher and Highest whereas Input parameters are divided only into three functions namely Low, Medium and High. The more the membership functions the higher the accuracy.

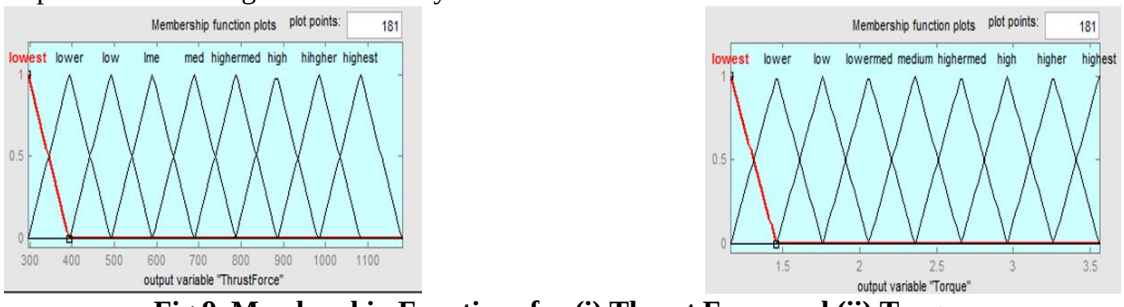


Fig.9. Membership Functions for (i) Thrust Force and (ii) Torque

3. RESULTS AND DISCUSSIONS

The Thrust produced during drilling can cause various problems such as Thermal degradation, Spalling and Irregular surface finish resulting in poor quality of holes. Hence Thrust Force and Torque are important parameters to be considered while drilling. The Artificial intelligence modeling of Thrust force and Torque is done using Fuzzy logic. Table.2, shows the Experimental and Fuzzy values for both Thrust Force and Torque. Figure 9 and 10 shows that the Fuzzy modeling values are very close with the Experimental values and there is very small difference between experimental and Modeled values.

Table.2. Experimental Results

Experiment No.	Spindle Speed	Feed rate	Cone angle	Thickness of plate	Thrust Force	Thrust Force Fuzzy	Torque	Torque Fuzzy
	(rpm)	(mm/min)	(degree)	(mm)	(N)	(N)	(Nm)	(Nm)
1	3000	50	30	2	295	325	1.33	1.46
2	3000	60	45	3	808	883	2.51	2.66
3	3000	70	60	4	1181	1080	3.56	3.47
4	3500	50	45	4	650	689	2.02	2.06
5	3500	60	60	2	375	394	1.51	1.76
6	3500	70	30	3	503	590	1.54	1.76
7	4000	50	60	3	650	689	1.47	1.46
8	4000	60	30	4	491	492	2.17	2.36
9	4000	70	45	2	320	394	1.16	1.25

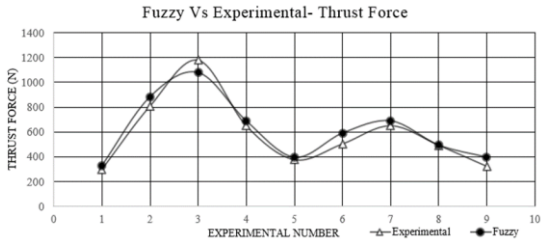


Figure.10. Fuzzy Values vs. Experimental values for Thrust Force

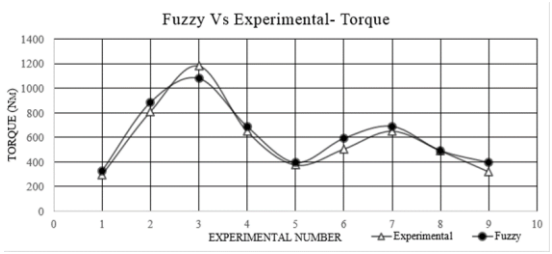


Figure.11. Fuzzy Values vs. Experimental values for Thrust Force

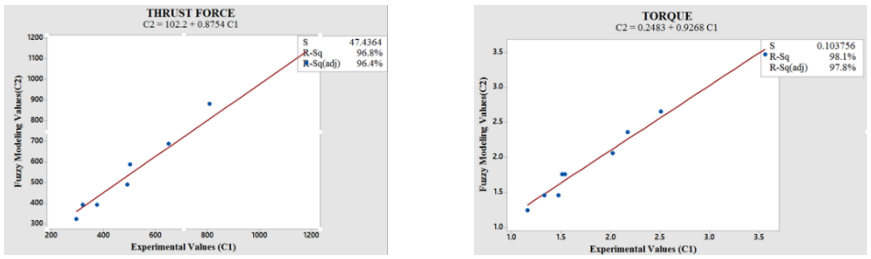
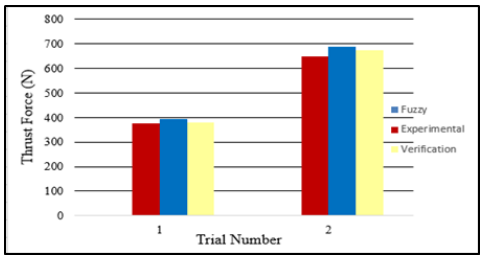


Figure 12: Model effectiveness evaluation for (i) Thrust Force and (ii) Torque

R-squared test is carried out to find the effectiveness of the Fuzzy model based on the formula

$$R - \text{sq} = 1 - \frac{S_{\text{Err}}}{S_{\text{T}}} \quad \text{[2]}$$

Where S_{Err} denotes total error and S_T is the total SS. Fig 12 shows the correlation graphs for Thrust force and Torque respectively. The R-squared value for Thrust force and Torque is 96.8% and 98.1% respectively. Hence, Fuzzy based Artificial Intelligence model can be used for prediction of Thrust Force and Torque in Friction drilling of Copper Silicon Composite.



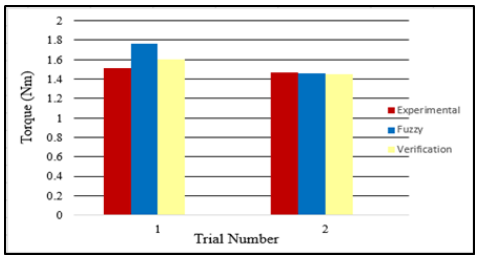


Figure.13. Verification Test results for ForceFigure.14. Verification Test results for Torque

Inorder to verify the effectiveness of model experiment was carried out for an existing parameter within the proces range and it was found that Fuzzy, Eperimental and Verification value was nearly same as shown in Figure 13 and 14.

4. CONCLUSION

The Thermal drilling of Metal matrix composite Copper Silicon Carbide has been performed in accordance with Taguchi's L9 orthogonal array and Thrust Force and Torque are noted down. Artificial intelligence modeling using Fuzzy logic is created to predict both Thrust force and Torque. From the comparison of Experimental Vs fuzzy values it can be concluded that

- The Fuzzy modeling values are very close to experimental values for Thrust Force with an R squared value of 96.8%.
- The modeled values for Thrust Force are also close to the experimental values with an R squared value of 98.1%.
- Hence Fuzzy based artificial modeling can be used for prediction of Force and Torque in thermal drilling of CuSiC composite.

In Future the work can be extended by investigating the machining of Composites for extended set of parameters with increased experimental runs.

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