

Fuzzy Rule based Modeling of Drilling Parameters for Tool Wear in Drilling GFRP Composites

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Abstract

The most recent development of high performance fibers has led to the availability of composites which can compete and indeed replace metals. Just like any other engineering material GFRP's have to be machined as well. Amongst the three machining operations of turning, milling and drilling, the latter is the most important. Drilling of GFRP is different from traditional metal machining because of the following concerns. In machining of GFRP the drill bit experiences variable thrust forces that produces excess vibration results in poor tool life. Apart from force fluctuations, cutting tools also experience severe abrasion on the flank surface, due to encounter with hard glass fiber. In this work, experiments were conducted in CNC milling machine for carbide drill bit based on L9 orthogonal array. The process parameters investigated are spindle speed, feed rate, and drill diameter. Fuzzy rule based model is developed to predict the thrust force in drilling GFRP. The results indicated that the model can be effectively used for predicting the response variable by means of which tool wear can be controlled.

Keywords: Drilling, Fuzzy Logic, GFRP Composites, Thrust Force, Toolwear

1. Introduction

Glass fiber reinforced composites are perhaps the most commonly used ranging in application from helmets, fishing boats, automobiles body and aircraft structures due to their high strength, high stiffness, low weight, low thermal expansion and good dimensional stability. GFRP composites are characterized by high strength and rigidity coupled with low weight and, in many respects, they are superior to metals Davim (2004). However, the glass fiber constituent often renders the machining of GFRP difficult. Drilling operations involve cutting holes in the raw materials using rotating cutters called drilling machines or drilling presses. It includes drilling holes which enables the GFRP composites to be incorporated and assembled

in structural elements. Drilling of GFRP is essential for assembly or fabrication process. During drilling GFRP the tool continuously encounters alternate matrix and fiber materials, whose response to machining can vary greatly, experiencing force fluctuations and consequent deterioration in tool performance stated by Velayudham (2005).

Thrust force is an important parameter related to the drilling tool that is found life of the tool. It also affects the extent of delamination suffered by the composite material. Abrate et al (1992) stated that the thrust force and torque formed during drilling have important information connected to quality of the hole and wear of the drill bit. Lin et al (1996) carried out a study on drilling composite material at high speed and accomplished that an

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increase of the cutting velocity leads to an increasing drill wear that in turn provokes an increase in the thrust force. By the research of Saghizadeh and Dharan (1986) who identified that the thrust force is a function of the speed of drilling and the feed rates., when feed rates are increased thrust forces also increase resulting in larger amounts of delamination.

The experimental work conducted by Inoue (1997) involved drilling of a Glass Fiber Reinforced Plastic (GFRP) with a cemented carbide drill (1mm diameter). The author concluded that due to the pre-drilled hole to 0.4 mm or above, thrust force is drastically reduced. Palanikumar et al (2006) used fuzzy logic for optimizing the multiple performance characteristics. Latha and Senthil Kumar (2009) have successfully applied fuzzy logic for the prediction of delamination in drilling glass fibre reinforced plastics. Yue jiao et al (2004) and Sengottuvel et al (2013) used fuzzy adaptive networks in machining process modeling. They have used fuzzy logics for surface roughness prediction in turning operations.

In the present work a user friendly fuzzy logic based system has been designed for the prediction of thrust force in drilling GFRP composites. The experiments were conducted on CNC milling machine. Carbide drill bit of various diameters is used for the investigation. L₉ orthogonal array is used for experimentation. Thrust force and tool wear were obtained as output parameter. The results indicated that the fuzzy logic model can be effectively used for drilling of composites.

2. Experimental Work

The drilling test were performed on Hass S5YT USA model CNC milling machine with maximum torque 102 Nm@1400 rpm, maximum power rating 20 HP and maximum feed rates 25.4 m/min. Figure 1 represents the experimental setup.

2.1 Cutting Tools and Specimen Preparation

A total of nine uncoated carbide drill bits, three drill bits of diameter 6 mm, 8 mm and 10 mm were used in this experiment. The performance of each drill bit was examined and monitored for nine conditions of feed rate and speed of spindle rotation. The dimensional properties of the drilling tool are tool overhang 47 mm, point angle 140°, helix angle 30° and Shank type is cylindrical. In

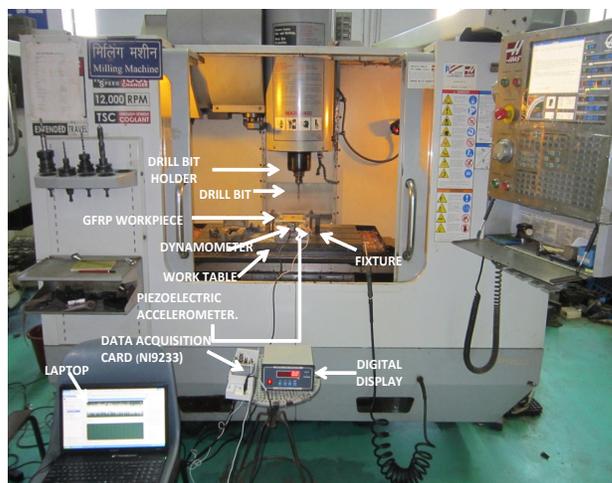


Figure 1. CNC Milling Machine and Thrust Force Measurement Setup.

these experiments, the GFRP specimen with dimensions 150 x 150 x 8 mm prepared through Compression moulding technique and used as work piece. High strength 360 CSM OCV Make Glass Mat was used as reinforcement in epoxy resin with araldite as hardener and processed to a temperature of 155⁰C to 160⁰C for approx 35minutes to fabricate GFRP.

2.2 Cutting Conditions

The experiment was tested for three levels of feed rates, spindle speeds and Drill diameter. All these three levels are summarized in Table 1. The Taguchi methodology for three factors at each of these three levels was used for the implementation of the plan of experiments. The cutting condition was selected from ASM machining composites data book.

Table 1. Three Levels of Testing the Experiment

Symbol	Factors	Level 1	Level 2	Level 3
F	Feed (mm/min)	5	10	15
S	Spindle speed (rpm)	750	1000	1250
D	Tool diameter	6	8	10

The orthogonal array selected was L₉ (3³). A total of 9 experiments were carried out considering speed, feed and coolant pressure for drilling each experiment has been repeated for three times and the thrust force was recorded for each experiment.

2.3 Thrust Force and Tool Wear Measurement

The thrust force developed in drilling the composite material was measured using Drill tool dynamometer. The drilling thrust force values are stored in laptop for further analyses. Tool wear is determined by measuring the wear as it develops, specifying the effective cutting time elapsed before a stipulated degree of wear is reached. Tool wear were measured using profile projector.

3. Fuzzy Rule Based Model for Thrust Force in Drilling GFRP Composites

A fuzzy logic unit consists of a fuzzifier, membership functions, a fuzzy rule base, an inference engine, and a defuzzifier. The input and output values are fuzzified using membership functions. The fuzzy reasoning works on fuzzy rules to generate a fuzzy value to be used by inference engine. Finally, fuzzy value is converted into a crisp output by defuzzifier. In this work, defuzzification is done according to the Centre of Area (COA) method. Two fuzzy models namely mamdani and sugeno are available. Sugeno outputs are used for linear or constant; for others the mamdani is preferred. Between the two, Mamdani fuzzy inference is used in modeling the process parameters due to the non-linear relation with outputs. Modeling of thrust force was done by using MATLAB R2011b software¹.

3.1 Fuzzy Expression

For the prediction of output parameters such as thrust force the drilling operation depends on three input parameters, namely Federate , Speed and Tool, diameter.

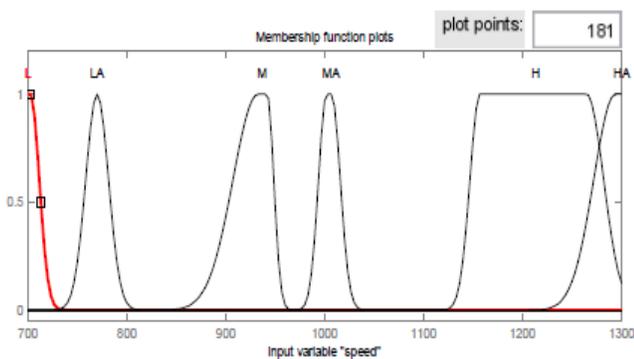


Figure 2. Membership Function for Input Parameter Spindle Speed.

The first step in establishing the algorithm for fuzzy model is to choose the fuzzy sets of the process variables².

3.2 Degree of Membership Functions of Input and Output Variables

The first step in generating a fuzzy logic is to identify the ranges of input and output variables. Then, the range of each process variable is divided into groups of fuzzy subsets. Each fuzzy subset is given a proper name and assigned a membership function³.

The membership function is assigned without depending on the results of the experiments. In the MATLAB R2011b, the maximum number of membership function levels available is 9. Six levels membership functions are considered in this work⁴. Individual notations are assigned to each membership value based on our need. The notations used in fuzzy subsets were as follows for spindle speed, feed rate and tool diameter are: L-LOW, LA-LOW AVERAGE, M-MEDIUM, MA-MEDIUM AVERAGE, H-HIGH AND HA-HIGH AVERAGE as shown Figure 2, 3 and 4⁵. More precise results can be obtained by using more number of membership functions. The maximum thrust force values for each experiment is used for fuzzy logic rule based modeling of drilling parameters in drilling GFRP composites⁶.

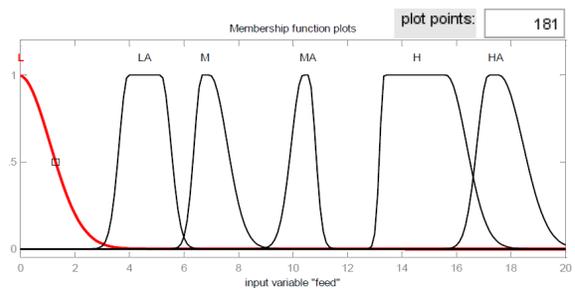


Figure 3. Membership Function for Input Parameter Feed Rate.

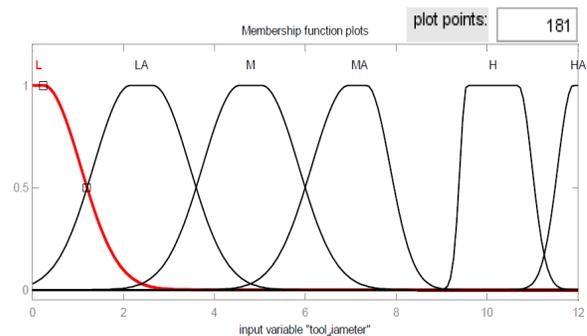


Figure 4. Membership Function for Input Parameter Drill Diameter.

4 Results and Discussion

The tensile strength of composites is up to six times greater than that of conventional materials with higher strength to weight ratios⁷. They have high torsional strength and impact properties. Their ability to withstand fatigue is 60% higher than that of conventional materials. In addition they are up to 45% lighter than aluminum structures with low embedded energy levels. The thrust force developed in drilling is an important concern⁸.

Table 2 shows the influence of thrust force and tool wear for 10mm diameter drill bit for all the nine experiment⁹.

Table 2. Thrust force and Tool wear values for each Experiment for 10mm diameter drill bit

Exp. No	Feed (mm/min)	Speed (rpm)	Thrust Force (KgF)	Tool wear (mm)	Time(secs)
1	5	750	10	0.91	61.4
2	5	1000	13	0.956	60.35
3	5	1250	14	0.9565	60.32
4	10	750	12	0.921	30.92
5	10	1000	14	0.974	30.84
6	10	1250	19	0.9	20.52
7	15	750	17	0.986	30.8
8	15	1000	20	0.99	20.28
9	15	1250	21	1.010	19.26

From the above Table 2 it is observed that average thrust force for all the experiment is around 15.5Kg F. The range of thrust force varies from 10 KgF to 21KgF. The average maximum thrust force 21KgF was recorded at 9th experiment, since the speed and feed given is high. In the same way average minimum thrust force 10KgF was recorded at 1st experiment. Since the speed and feed given is very less when compared to other experiments¹⁰.

During the experiment numbers 1 to 3, feed is kept constant 5 mm/min and speed varied to 750 rpm, 1000 rpm, and 1250 rpm as a result thrust force and drill wear increases gradually from 1st experiment to 3rd experiment due to significant increase in the speed¹¹. Similar inference can be referred in the Table 2 for 4th to 6th experiment as well as 7th to 9th experiment. During the experiment numbers 4 to 9, feed is more and hence the machining time is less as, when compared to experiment numbers 1 to 3 as shown in Table 2. Since the machining time is less the cutting edges of the drill bit is subjected to

severe shock leading to high thrust force and tool wear. This shows the significance of feed towards thrust force in drilling¹².

Table 3. Thrust force and Tool wear values for various diameter drill bit

Feed (mm/min)	Speed (rpm)	Drill Diameter (mm)	Thrust Force (KgF)	Tool wear (mm)	Time (secs)
5	750	10	10	0.91	61.4
5	1000	8	9	0.755	60.35
5	1250	6	7	0.525	60.32
10	750	10	12	0.921	30.92
10	1000	8	11	0.815	30.84
10	1250	6	9	0.63	20.52
15	750	10	14	0.986	30.8
15	1000	8	12	0.921	20.28
15	1250	6	11	0.631	19.26

From the Table 3 it is observed the thrust force value for 6mm drill bit in cutting condition 3 is 14 KgF where as for cutting condition 6 and 9 is 19 KgF and 21KgF. This shows the significance of feed in thrust force when the speed is constant. Similar observation is observed for 8mm and 10mm diameter drill bit. Similarly we can observe an increase in drill wear due to increase in cutting condition and increase in drill diameter¹³. This is due to increase in the chisel edge length for larger diameter drill bit compared to smaller diameter drill. Hence we can observe a decrease in thrust force and tool wear in cutting condition I for speed 750rpm and feed 5mm/min.

Figure 5 and 6 represent the comparison of experimental and fuzzy results for thrust in drilling composite materials¹⁴.The results indicated that the thrust force varies with the experimental condition. The graph is drawn for the nine set of experimental condition with respect to thrust force. The tool wear developed in drilling in drilling operation is proportional to the amount of thrust force¹⁵.

When the tool thrust observed in machining is more it leads to the tool wear. For reducing of thrust force, modeling and optimization of process parameter are required. In this work fuzzy rule based modeling is used for the prediction of thrust force¹⁶. From the Figure 5 and 6 it can be observed that the results obtained through the fuzzy logic model are almost similar to the experimental results¹⁷.

To validate the experimental results ,the thrust force was measured for arbitrary cutting condition and validated

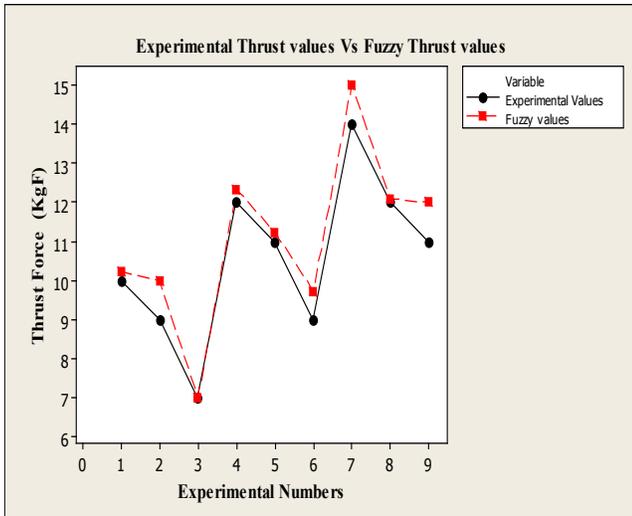


Figure 5. Comparison of Results for Experimental Thrust Force Values and Fuzzy Thrust Force Values (10mm Diameter Drill Bit).

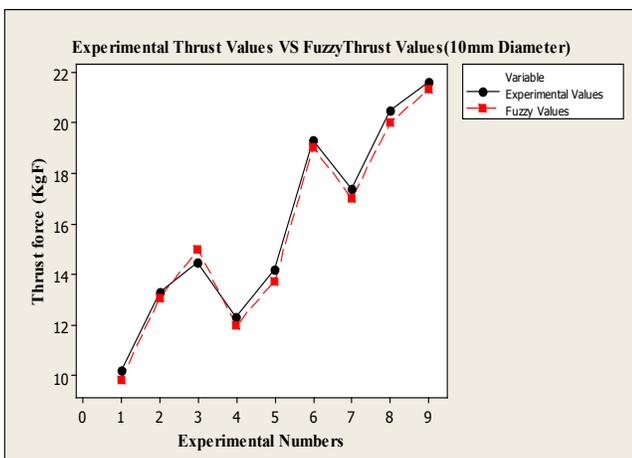


Figure 6. Comparison of Results for Experimental Thrust Force Values and Fuzzy Thrust Force Values.

with the modeling fuzzy based results. It was found that the percentage of error is less than 2%¹⁸. Hence fuzzy rule based modeling technique can be effectively used for the prediction of thrust force in drilling GFRP composites¹⁹.

5. Conclusions

The objective of the present was to identify the negative side effects that occur whilst drilling GFRP's. From the literature review, it was identified that due to increase in thrust force the tools get abraded very quickly as compared to metals. Hence in the present work the thrust force and tool wear developed during drilling GFRP

composites has been investigated according to L9 orthogonal array experiments. Fuzzy rule based model has been developed for predicting thrust force in drilling GFRP composites. Based on the experimental and fuzzy logic modeling results the following conclusions are drawn.

- Based on the investigation optimized cutting parameter which minimizes thrust force and tool wear during drilling GFRP composites is speed 750rpm and feed 5mm/min.
- Lesser diameter drill bits minimize thrust force and tool wear during drilling GFRPs.
- Fuzzy rule based model is best method for predicting the thrust force in drilling GFRP composites.

The present work can be extended to investigate the effect of using different tool materials on the quality of drilled hole in different types of GFRPs.

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