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# Experimental Investigation and Analysis of Torque in Drilling Hybrid Metal Matrix Composites using Fuzzy Logic Approach

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***ABSTRACT*** *:This paper presents an experimental investigation on torque in drilling of aluminium hybrid metal matrix composite the machining parameters used here was speed, feed, drill diameter of the drill bits for 3 levels. The optimized response parameter of aluminium hybrid composite found by Taguchi $L_{27}$ orthogonal array experimentation. This hybrid metal matrix composite is fabricated using 50 micron sized Silicon Carbide and graphite particles are reinforced into aluminium matrix material via stir casting process. The torque is considered as experimental result and it is predicted using fuzzy logic. The results specify that the predicted torque values*

***Keywords:*** *Drilling, Fuzzy logic, hybrid metal matrix composite, torque*

## I. INTRODUCTION

Metal matrix composites have become the necessary materials in various engineering applications like aerospace, marine and automobile engineering applications, because of their light-weight, high strength, stiffness and resistance to high temperature [1]. Suresha et al., [2] have studied the percentage reinforcement of Gr in Al-Gr composite and SiC in Al-SiC composite is limited to certain level beyond which it is not beneficial to add either Gr or SiC as reinforcement. The use of multiple reinforcements yields hybrid composites to possess better tribological properties over the composites with single reinforcement. Mahajan et al., [3] an effort was made to fabricate a hybrid metal matrix composite, silicon carbide and titanium diboride reinforced In Al 6061 matrix using stir casting method. Microstructure and mechanical properties such as micro hardness and wear were studied for various compositions of reinforcements, 10% SiC and 2.5%, 5% and 10% $TiB_2$. The results indicate that the hardness value increases with the addition of the SiC and $TiB_2$ reinforcements to matrix Al6061, while the wear while the wear resistance increases up to certain amount and reduces drastically when crossed the transition load. MuniaRaj [4] Studied and presented the effect of drilling parameters on Torque in drilling of aluminium hybrid metal matrix composite (Al-15%SiC-4%Gr). The drilling parameters are used were spindle speed, feed rate, and drill diameter for 3 levels. The optimized parameter of aluminium hybrid composite was found by taguchi's $L_{27}$ orthogonal array experimentation. The experiments are conducted on computer numeric control vertical machining centre using multifaceted carbide drills of 4 mm, 8 mm and 12 mm diameter under dry drilling conditions. Stir casting technique was used to fabricate this composite and the results indicated that feed rate is the main parameter which influences The Torque in drilling of hybrid metal matrix Composites.

The fuzzy logic modeling technique is used for prediction. The theory of fuzzy logics, initiated by Zadeh, has proven to be useful for dealing the uncertain and vague information [5].This theory has proved to be an effective means for dealing with objectives that are linguistically specified. Linguistic terms, such as 'low,' 'medium' and 'high' may be defined by fuzzy sets [6]. Since its introduction, fuzzy set theory has attracted the attention of researchers in mathematical and engineering fields [7]. Jemielnaik [8] introduced the fuzzy decision support system for the estimation of the depth of cut and flank wear during the turning process. Arghavani et al., [9] used fuzzy logic approach for the selection of gaskets in sealing performance. Yue jiao et al., [10] used fuzzy adaptive networks in machining process modeling. They have used fuzzy logics for surface roughness prediction in turning operations. Palanikumar et al., [11] used fuzzy logic for optimizing the multiple performance characteristics.

In the present study, the fuzzy logic modeling technique is used as an efficient approach to predict the torque values in drilling of Al6061-15% SiC-Gr metal matrix composite and the drilling experiments are conducted as per Taguchi $L_{27}$ with TiN coated solid carbide twist drill

## II. EXPERIMENTAL

### 2.1Materials

Al-SiC-Gr Hybrid MMC work piece having aluminium alloy A6061 as the matrix and containing 15% wt. of silicon carbide particles of 50μm and 5% wt. of Graphite particles of 50 μm.

### 2.2Fabrication of Hybrid Metal Matrix Composites

The hybrid metal matrix composite was fabricated by stir casting process. The base metal Aluminium alloy 6061 is melted using electric arc furnace. Temperature of the melting process is 710 $^{o}$ C - 725$^{o}$C. Once the aluminium alloy is melted completely, then silicon carbide (15% by wt of particles) and graphite (5% by wt of particles) are now preheated to a temperature of 790$^{o}$ C. The melted aluminium alloy is stirred for about 5-6 minutes at 450 rpm. Silicon carbide, graphite particles are continuously added to the melt. After this stirring purpose the molten mixture is poured into the pre heated metallic steel moulds of required shape to make the Plate of 110mm x110mm x 5 mm size

### 2.3Experimental Procedure

The drilling tests were performed on ARIX - CNC machining center manufactured by ARIX CNC machine Co. Ltd, Taiwan with tool dynamometer integral with it are presented in Fig.1


Fig.1 Experiment setup with dynamometer arrangement

The cutting tool selected for machining Al-SiC –Gr hybrid metal matrix composites was Tin coated solid carbide twist drill having diameter 6 mm, 8 mm and 12 mm which are supplied by Onsrud Corporation, U.S.A and are presented in Fig.2

**Fig.2** TiN coated solid carbide twist drill bits used for experiments

Torque force was measured by using Unitech lathe tool dynamometer with digital indicator. The mean torque force developed in drilling the composite material was measured using Kistler piezoelectric

dynamometer. The drilling torque force signals were transmitted to Kistler charge amplifier and stored in Pentium IV computer for further analysis. The acquired data is represented graphically in conjunction with the various signals processing functions makes it easier to analyse the torque in Figure 3. The levels of machining parameter used in the experiment are given in Table 1.

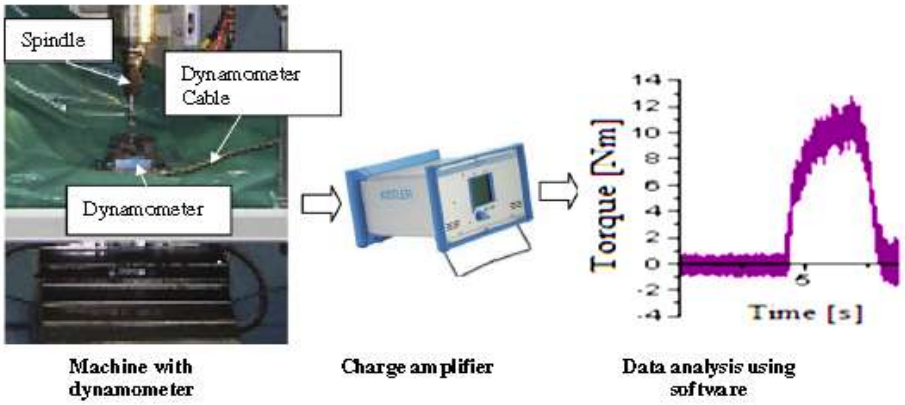


**Fig.3** Measurement system used for capturing the Torque in drilling.

**Table 1**. Machining parameter and their levels

| Level | Speed (V = rpm) | Feed rate (f = mm/rev) | Drill diameter (d = mm) |
|---|---|---|---|
| 1 | 1000 | 0.05 | 4 |
| 2 | 2000 | 0.10 | 8 |
| 3 | 3000 | 0.15 | 12 |

### 2.4 Taguchi Technique

Taguchi parameter design can optimize the performance characteristics through the setting of design parameters and reduce the sensitivity of the system performance to the source of variation [12]. Taguchi technique is a powerful tool for the design of high quality systems [13].It provides a simple, efficient and systematic approach to optimize design for performance, quality and cost. The methodology is valuable when design parameters are qualitative and discrete. Taguchi parameter design can optimize the performance characteristics through the setting of design parameters and reduce the sensitivity of the system performance to the source of variation [14]. This technique is multi step process, which follow a certain sequence for the experiments to yield an improved understanding of product or process performance. The data collected from all the experiments in the set are analyzed to determine the effect of various design parameters. This approach is to use a fractional factorial approach and this may be accomplished with the aid of orthogonal arrays

## III. FUZZY RULE BASEDMODEL FOR TORQUE IN DRILLING OF HYBRID METAL MATRIX COMPOSITES

For modeling torque in drilling of hybrid metal matrix composite materials fuzzy logic method is used in this work. Fuzzy logic describes the membership functions used in the fuzzy rules; and a reasoning mechanism, which performs the inference procedure upon rules and given facts to derive a reasonable output or conclusion [15-17]. The structure of a fuzzy logic system consists of three conceptual components: a fuzzy rule base, which contains a selection of fuzzy rules; a data base. The fuzzy reasoning for three-input-two-output fuzzy logic unit is designated as follows:

The fuzzy rule base contains of a group of IF- THEN statements with three inputs statements with three $x_1$, $x_2$ and $x_3$ an output y, i.e.

$$\begin{aligned}&\text{Rule 1: if } x_1 \text{ is } A_1 \text{ and } x_2 \text{ is } B_1 \text{ and } x_3 \text{ is } C_1 \text{then } y_1 \text{is } D_1 \text{ and } y_2 \text{ is } E_1 \text{ else}\\&\text{Rule 1: if } x_1 \text{ is } A_2 \text{ and } x_2 \text{ is } B_2 \text{ and } x_3 \text{ is } C_2 \text{then } y_1 \text{is } D_2 \text{ and } y_2 \text{ is } E_2 \text{ else}\\&\text{---}\\&\text{Rule n: if } x_1 \text{ is } A_n \text{ and } x_2 \text{ is } B_n \text{ and } x_3 \text{ is } C_n \text{ then } y_1 \text{is } D_n \text{ and } y_2 \text{ is } E_n \text{ else} \quad (1)\end{aligned}$$

**$A_i$, $B_i$, $C_i$, $D_i$** and **$E_i$** are fuzzy subsets defined by the corresponding membership functions, i.e. $\mu_{Ai}$, $\mu_{Bi}$, $\mu_{Ci}$, $\mu_{Di}$ and $\mu_{Ei}$. The membership functions used for the drilling machining parameters drill diameter, speed and feed rate is presented in Figures 4, 5 and 6

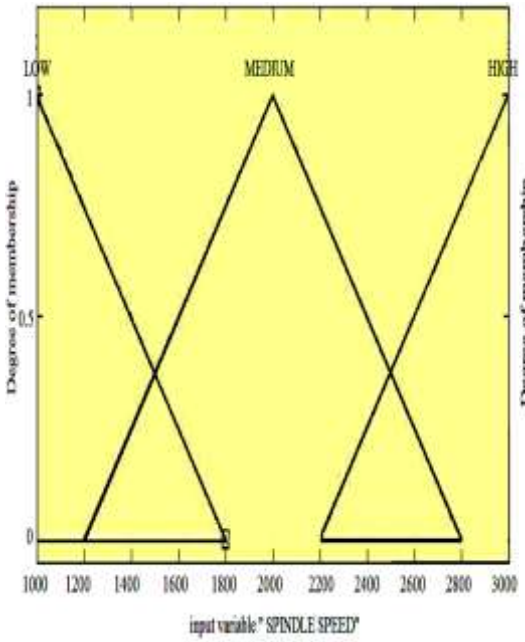


Fig.4 Membership functions for input parameter speed

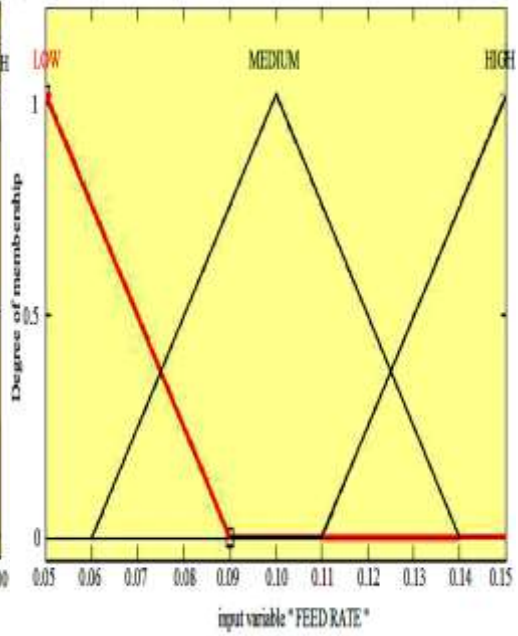


Fig.5 Membership function for input parameter feed

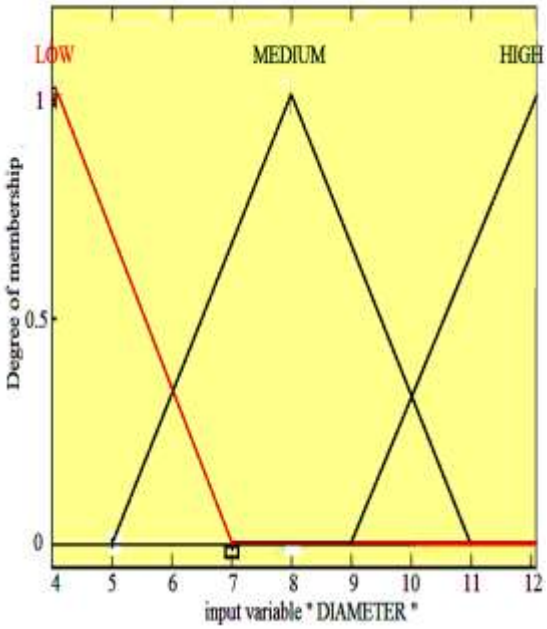


**Fig.6** Membership function for input parameter Diameter

Similarly, the membership functions used for the output responses torque is presented in Figs.7. The number of membership functions used for the output response is nine such as LOWEST, LOWER, LOW, LOW MEDIUM, MEDIUM, HIGH MEDIUM, HIGH, HIGHER AND HIGHEST. Further accurate results can be attained by means of more number of membership functions and hence 9-membership functions were designated for the current work.

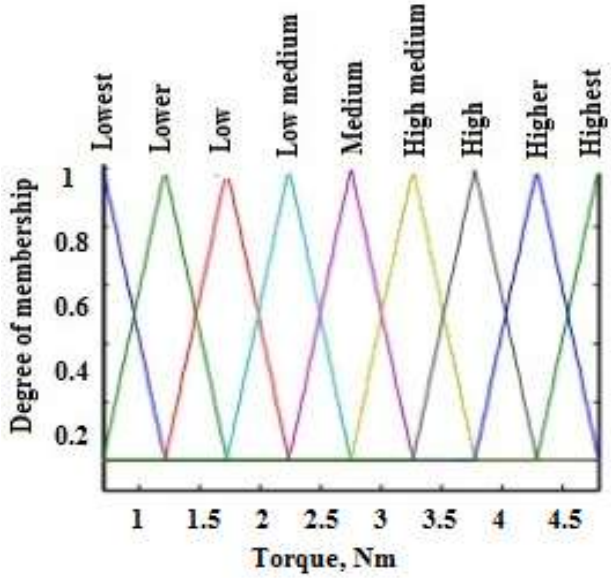


**Fig.7** Membership function for Torque

## IV. RESULT AND DISCUSSION

Hybrid metal matrix composite materials are composed of three different phases' viz., Aluminium metal matrix phase reinforced with hard ceramic phase Silicon carbide and another one is soft lubricating phase graphite. The joining of structures is an important concern. The effective joining is attained by using correct drilled holes size in the work piece material. The torque developed in drilling operation is an important concern. To model and analyze the torque in drilling of composite materials, fuzzy logic rule based model is introduced in this work. Fuzzy logic is an important tool and it can be very useful for modeling the mechanical processes. Fig.8 shows the comparison of experimental and fuzzy prediction result for torque in drilling of hybrid metal matrix composites

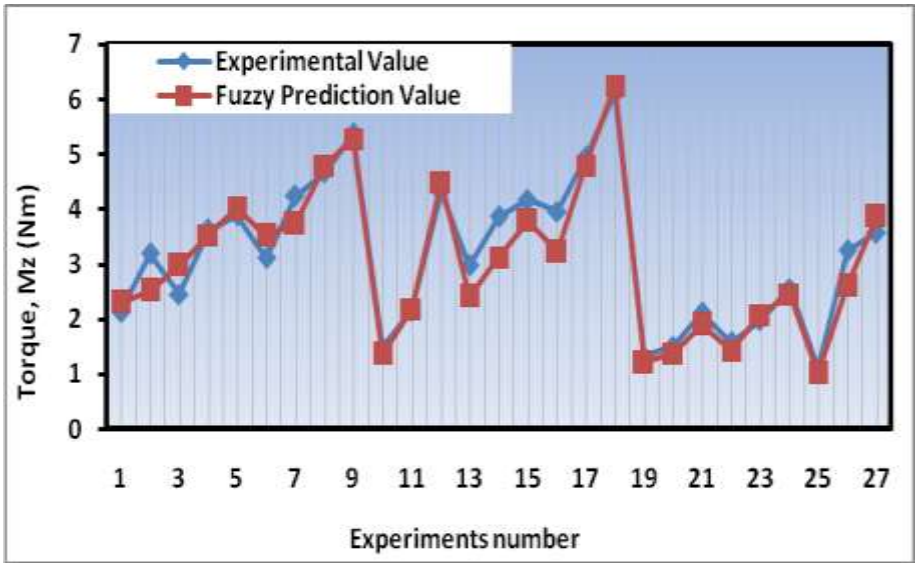


Fig.**8 Comparison of results between Fuzzy and experimental result for Torque**

The graph is drawn for various experimental conditions with respect to the torque. The torque advanced in drilling operation is proportional to the amount of damage that occurs in around the hole of the composite materials. Proportional results were attained for drilling of composite materials. When tool torque observed in machining is more, it leads to the damage to be occurring in the composite. The amount of torque in drilling of

composite materials is to be reduced. For reducing of torque, modeling and optimization of process parameters are required. In this work, fuzzy rule based modeling is used for the prediction of torque in drilling of composite materials. From the Figs 8, it can be emphasized that the results attained through the fuzzy logic model are lmost similar to that of the experimental results.

The analysis of cutting parameters on torque is an important concern. The increase of feed rate and diameter increases the torque. The increase of drill diameter and feed rate increases the contact between the workpiece material and it leads to high torque in drilling of composite materials..By keeping the low feed rate and drill diameter one can reduces the torque in drilling of composite materials.

The adequacy of the developed fuzzy logic model has been verified through R-sq value. The quantity R-Sq called as coefficient of determination is used to judge the adequacy of regression models developed. 0 **≤ R** –Sq. R-Sq value is the variability in the data accounted by the model in percentage as

$$R - Sq = 1 - \frac{SSError}{SStotal} \qquad (2)$$

Where SS*Error* is sum of square error and SS *total is* sum of square total. The coefficient of determination is calculated using the above expression and does more than 98% for the present investigation for toque, which shows that there is high correlation that exists between the experimental and predicted values.

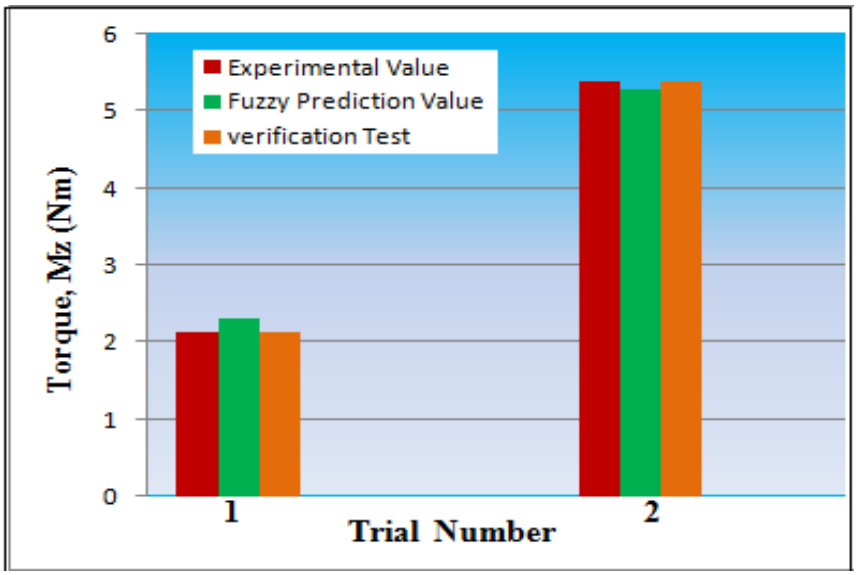


**Fig.9** Verification Test Results for Torque

Fig. 9 shows the Verification test results for torque, the experiment and verification test are very small and hence fuzzy rule based modeling technique can be effectively used for the prediction of torque drilling of metal matrix composites.

## V. CONCULSIONS

The torque developed during drilling of composites has been investigated. Fuzzy rule based model has been developed for predicting torque in drilling of composites. Based on the experimental and fuzzy modeling results, the following conclusions are drawn:

1. Rule based fuzzy logic model for torque is developed from the experimental data.
2. The predicted fuzzy output values and measured values are fairly close to each other, which indicate that the Fuzzy logic model can be effectively used to predict the torque in drilling of metal matrix composites.
3. The verification test results reveal that the fuzzy rule based model is suitable for predicting the torque in Drilling of hybrid metal matrix composites.

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