Prediction model for torque on drilling of metal matrix composites

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Abstract. In manufacturing and assembly units, drilling is one of the most important process to make the final form of the product by means of fasteners. The thrust force and drilling torque induced during drilling process affect the quality of holes drilled in the form of roughness, circularity error etc. This paper focuses on the investigation of parameters in drilling that have influence over the torque needed to cut the Metal Matrix Composites (MMC), by variation of the diameter of the twist drill bit, keeping the tip angle and other features in geometry as a constant. Roughness after machining is a key factor when it comes to high precision applications such as manufacturing of gauges in metrological operations. The input parameters include combinations of three different speeds and three different feeds and the output we concentrate on this paper is the torque as indicated by the title itself. The prediction models of the data sets are obtained using Response Surface Methodology and Fuzzy Logic, and the results obtained are compared to the experimental values themselves to see how much the models are accurate in predicting the results.

1. Introduction

By empowering machinists to identify the effects of cutting parameters on machining forces, predictive models are valuable tools especially when it comes to power consumption and sustainability issues. Specifically for drilling, torque and thrust predictions often represent a major challenge due to the complex drill geometry combined with the variation of work material characteristics being function of drilling parameters such as drilling feed, speed and drill bit geometry.

Empirical based models have been also employed to predict drilling forces. Empirical equations are traditionally developed by measuring the cutting forces and by employing a large experimental test matrix with wide value ranges for tested parameters (mainly feeds and speeds). This is followed by empirically fitting the generated forces as function of these parameters. The resulting empirical equations describe how the cutting forces respond to changes in cutting parameters. Such models relate the force per unit width of cut (or specific cutting force or cutting “pressure”) to feed (uncut chip thickness) and cutting speed raised to some power. Some equations also account for the effect of parameters such as rake angle and other geometric features. [1]
During drilling, the drill tool is subjected to rotation at various speeds set by the operator. Hence, torque is developed and its magnitude depends on various machining parameters. It was observed that all the factors, namely speed, feed, tool angle and work sample, predominantly affect the torque with a contribution of 3.35% for speed, 9.29% for feed 3.77% for tool angle and 55.35% for work sample. [2] Torque results of the experimental study of the influence of the precipitation temperature during the drilling of the Al 2219-SiCp composite material using a PCD drill indicated the following conclusions: The torque follows the rise-and-fall trend of the feed rate for 37 μm SiC composites, whereas the increasing trend is observed for 67 μm SiC compo-sites. The torque was observed to be the lowest at the lower feed rate and for the higher mass fraction re-gardless of the sizes of reinforcement. The trend of the torque remains the same for all the precipitation temperatures. The size of the reinforcement particle has an appreciable influence on the torque under different experimental conditions, whereas the pre-cipitation temperature does not have a significant influence on the torque. [3]

From the study of Thrust force and Torque with respect to Speed and feed, it was observed that the 6mm drill diameter gives lesser Thrust Force and Torque compared to 4mm drill diameter. However it is very much imperative to consider the significance of manufacturing method of the laminates which might play an effective role in Thrust force and Torque behavior, because at certain conditions the laminate may exhibit random behavior which may be due to the presence of voids. These defects may result in drastic reduction of strength of the laminate. [4]

This paper presents an experimental investigation on torque in drilling of Aluminium hybrid metal matrix composite (Al-15%SiC-4%Gr). The drilling parameters used here was spindle speed, feed rate, drill diameter for 3 levels. The optimized parameter of aluminium hybrid composite was found by Taguchi’s L27 orthogonal array experimentation. The significant parameter was found by ANOVA method. Minitab software has been used for Taguchi’s technique. The fabrication technique adopted was stir casting technique. 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. A response surface analysis is carried out. The effect of drilling parameters on Torque is studied and presented. The results indicated that feed rate is the main parameter which influences the Torque in drilling of hybrid metal matrix Composites. [5] Fuzzy modeling starts with fuzzification process during which membership functions were created for input and output factors. A triangular type member-ship function was made by taking three values namely low, medium and high as shown in Fig. 3. The next step was the defuzzification process in which membership functions were reduced in to a most representative value. During this stage, set of rules containing IF-THEN statements were framed based on the runs. Fuzzy gives a prediction plot from which output responses could be predicted for input values. The developed model was validated by comparing the D-optimal values with confirmatory trials and with fuzzy predictions. The error between each analysis was calculated. These errors were found to be minimal for both thrust force and torque. Hence, the optimization was found be highly satisfactory. [6]

2. Experimental Setup and Procedure

The specimens are prepared by stir casting method where Aluminium is the matrix in which reinforcements such as graphite, silica and boron carbide are added to the matrix. 3 different specimens, each containing a fixed quantity of Aluminium 6061 and 5% boron carbide B4C, is each combined with 5% of graphite, and Silica SiC, to make two different specimens. Each of these specimens are prepared carefully by first melting the aluminium in the furnace, and then pre heating the additives and then stirring the contents as shown in Figure1 below.
The contents are then poured into a mould where it takes its shape and solidified. The solidified part is then cooled to room temperature and it is ready to be machined. Then after machining, the raw material is ready for being tested. Drilling is carried out using carbide drill bit with TiAlN coating of varying point angles of 108, 118 and 128 degrees as shown in Figure 2.

3. Results and Discussion

For each specimen, each drill bit is used for varying feeds 0.05 mm/rev, 0.1 mm/rev and 0.15 mm/rev and speeds 1000 rpm, 2000 rpm and 3000 rpm, thus yielding 9 different values per specimen per drill bit. The values of torque are measured using a dynamometer [7] and the results are tabulated in Table 1. This table shows the values of torque obtained by experimental procedures, Response surface Methodology, and fuzzy logic. We take the values obtained by experimental procedure as the benchmark or reference to which we compare the predicted results. It is clear from the table that the results obtained by Fuzzy logic, predicts the result much better than the other types. RSM has the least accuracy of prediction because it has the degree of accuracy of only 2, whereas the other methods have no such limit in degree of accuracy. It is clearly observed that the torque is minimum 0.78 Nm when the speed is maximum, feed is minimum and for the highest point angle, matching with the literature. Torque for every other value is higher than this point.

Table 1. Experimental and prediction Values of Torque for Specimen1

| Expt.No | Point angle ° | Feed mm/rev | Speed rpm | EXPT | RSM  | FUZZY |
|---------|---------------|-------------|-----------|------|------|-------|
| 1       | 108           | 0.05        | 1000      | 1.08 | 0.502| 0.978 |
| 2       | 108           | 0.05        | 2000      | 1.57 | 1.220| 1.567 |
| 3       | 108           | 0.05        | 3000      | 1.96 | 1.706| 2.156 |
| 4       | 108           | 0.1         | 1000      | 1.28 | 1.191| 1.567 |
| 5       | 108           | 0.1         | 2000      | 1.91 | 2.207| 2.156 |
| 6       | 108           | 0.1         | 3000      | 2.55 | 2.992| 2.745 |
|   |   |   |   |   |
|---|---|---|---|---|
| 7 | 108 | 0.15 | 1000 | 1.62 | 1.574 | 1.567 |
| 8 | 108 | 0.15 | 2000 | 2.65 | 2.890 | 2.745 |
| 9 | 108 | 0.15 | 3000 | 3.63 | 3.973 | 3.923 |
|10 | 118 | 0.05 | 1000 | 1.08 | 1.630 | 0.978 |
|11 | 118 | 0.05 | 2000 | 1.38 | 2.173 | 1.567 |
|12 | 118 | 0.05 | 3000 | 2.14 | 2.485 | 2.156 |
|13 | 118 | 0.1  | 1000 | 1.52 | 2.181 | 1.567 |
|14 | 118 | 0.1  | 2000 | 3.65 | 3.024 | 3.923 |
|15 | 118 | 0.1  | 3000 | 4.33 | 3.635 | 4.512 |
|16 | 118 | 0.15 | 1000 | 2.40 | 2.428 | 2.156 |
|17 | 118 | 0.15 | 2000 | 4.16 | 3.569 | 3.923 |
|18 | 118 | 0.15 | 3000 | 5.10 | 4.479 | 4.92 |
|19 | 138 | 0.05 | 1000 | 0.39 | 0.159 | 0.57 |
|20 | 138 | 0.05 | 2000 | 0.59 | 0.529 | 0.57 |
|21 | 138 | 0.05 | 3000 | 0.78 | 0.667 | 0.978 |
|22 | 138 | 0.1  | 1000 | 0.64 | 0.574 | 0.57 |
|23 | 138 | 0.1  | 2000 | 1.18 | 1.243 | 0.978 |
|24 | 138 | 0.1  | 3000 | 1.72 | 1.679 | 1.567 |
|25 | 138 | 0.15 | 1000 | 0.78 | 0.684 | 0.978 |
|26 | 138 | 0.15 | 2000 | 1.47 | 1.651 | 1.567 |
|27 | 138 | 0.15 | 3000 | 2.01 | 2.387 | 2.156 |

**Figure 3.** Membership function of Torque for Specimen1.

The Figure 3 indicates, how many ranges the value of torque is divided into in the X axis, and the probability in the Y axis. The more the number of ranges, the better the results emerge. So it is shown in this specimen how the results are for 9 ranges. Figure 4 showing the variation of torque at different speed and point angles when the feed rate is constant.
Similarly Figure 5 and Figure 6 showing the variation of torque by fixing speed and point angles respectively and varying the other two parameters. From these figures, we can see that the torque is minimal for minimal feed and speed and high point angles. We can thus say that for best results in drilling i.e. lowest roughness, the torque has to be the minimum. But it would suffice just to say that torque has to be the minimum to yield good results in drilling. But it is clearly seen that its results are not as accurate as that of fuzzy logic. But it serves as a means to prove the points stated in theory that the minimum torque yields better results in drilling.

**Figure 4.** Response surfaces of Torque at the feed rate of 0.1mm/rev

**Figure 5.** Response surfaces of Torque at the speed of 2000rpm.
From the Table 2, we can see that the minimum torque occurs at the point angle of 128°, feed rate of 0.05 mm/rev but at a speed of 2000 rpm, still it tends to make the point specified in the literature. Every other point has higher torque as indicated clearly by the table.

Table 2. Experimental and prediction Values of Torque for Specimen2

| Expt.No | Point angle ° | Feed mm/rev | Speed rpm | EXPT | RSM | FUZZY |
|---------|---------------|-------------|-----------|------|-----|-------|
| 1       | 108           | 0.05        | 1000      | 1.079| 1.601| 1.274 |
| 2       | 108           | 0.05        | 2000      | 1.373| 1.557| 1.274 |
| 3       | 108           | 0.05        | 3000      | 1.913| 1.613| 1.716 |
| 4       | 108           | 0.1         | 1000      | 1.472| 1.919| 1.274 |
| 5       | 108           | 0.1         | 2000      | 2.060| 2.120| 2.158 |
| 6       | 108           | 0.1         | 3000      | 3.090| 2.421| 3.041 |
| 7       | 108           | 0.15        | 1000      | 1.472| 2.125| 1.274 |
| 8       | 108           | 0.15        | 2000      | 2.649| 2.571| 2.600 |
| 9       | 108           | 0.15        | 3000      | 3.924| 3.117| 3.789 |
| 10      | 118           | 0.05        | 1000      | 2.260| 1.076| 2.158 |
| 11      | 118           | 0.05        | 2000      | 1.370| 0.965| 1.274 |
| 12      | 118           | 0.05        | 3000      | 0.490| 0.954| 0.527 |
| 13      | 118           | 0.1         | 1000      | 1.960| 1.294| 2.158 |
| 14      | 118           | 0.1         | 2000      | 1.640| 1.428| 1.716 |
| 15      | 118           | 0.1         | 3000      | 1.100| 1.662| 1.274 |

Figure 6. Response surfaces of Torque at the Point angle of 118°
The experimental results of specimen 2 also been modeled by dividing the range into 9 and it is quite evident that the results by fuzzy logic converge more with the experimental results than that of RSM. So it would be good to infer that fuzzy logic would serve as a good means to optimize as well as predict results.

The membership function by fuzzy logic for the specimen 2 is given in the Figure 7.

![Figure 7. Membership function of Torque for Specimen 2.](image)
The mathematical model for the torque was created by response surface methodology and the predicted values from that model was given in Table 2. The variation of torque with speed and point angle are shown in Figure 8.

![Figure 8. Variation of Torque with Speed and Point angle.](image)

Similarly, the influence of feed rate and point angle is shown in Figure 9 and the effect of speed and feed shown in Figure 10.

![Figure 9. Variation of Torque with Feed and Point angle.](image)
From the above figures, we can say that the drilling torque is reduced at lower feed rate and lower drilling speed, but at higher point angles. We can thus say that for best results in drilling i.e. lowest roughness, the torque has to be the minimum. Moreover, it is clearly seen that its results are not as accurate as that of fuzzy logic. But it serves as a means to prove the points stated in theory that the minimum torque yields better results in drilling.

4. Conclusion

Thus two different composite specimen were prepared and drilling experiments were conducted. Based on the results of the experiments, prediction models were developed and compared. Finally, the following conclusions were made

1. For best results after machining (i.e. drilling in this case), it is desirable to have both torque and thrust force as minimal. This result directly reflects on the roughness of the drilled hole. So for a hole to be of good finish, it is better to keep the torque minimum.
2. It is observed that for all specimens, the result for which the point angle was maximum, keeping high speed and low feed, yielded the best result with minimum torque. So for any of the above specimens it is advisable to use a 128 degree point angle drill bit to obtain the best results.
3. For prediction models done by RSM and Fuzzy Logic, it is quite clear that fuzzy logic corresponds more closely to the experimental results, thus yielding a better model of prediction compared to RSM.

Figure 10. Variation of Torque with Speed and feed
5. References

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