An experimental investigation of surface roughness in the drilling of MWCNT doped carbon/epoxy polymeric composite material

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Abstract. The objective of this research is to investigate the effect of multi-walled carbon nanotube (MWCNT) loading on the surface roughness of drilled hole, in the drilling of MWCNT doped carbon/epoxy polymeric composite material. Root mean square roughness (Rq) was used to assess the effect of MWCNT. Rq was measured at the both side i.e. entrance and exit of hole. Experiment was performed using Box-Behnken Design to develop an empirical model to predict the surface roughness value at the entrance and exit. The developed model was accurate within the level of confidence. Due to loading of MWCNT in polymer matrix, surface roughness of hole at entrance and exit are improved.

Keywords: MWCNT, CFRP, Drilling, Surface roughness

1. Introduction

Carbon fiber reinforced composite (CFRP) materials are extensively used in aircraft, vessels, automobiles and construction industries, due to its excellent mechanical properties. They have high strength to weight ratio, good corrosion resistance and low thermal expansion. During drilling of fiber reinforced polymer (FRP) composite material, some serious damage occur such as; fiber pull-out, delamination and cracking of matrix. This is due to the anisotropy behavior of the material. Mohan et al. [1] investigated the effect of process parameters on thrust force, they found that drill bit size and speed are the main parameter which affect the machining of composite material. Murthy et al. [2] studied that material thickness is the main parameter for the surface roughness as compared to the other processing parameters.

According to Mohan et al. [3] use of low feed rate favors lower delamination on both entry and exit side of hole which leads to better surface finish. Davim et al. [4] studied about the effect of cutting parameters on the surface roughness. They found that feed rate is the most influencing parameter on surface roughness. Ramulu et al. [5] carried out an experiment on machining of
polymer composite. They found that higher cutting speed gives better surface finish. However, according to Takeyama and Lijiya [6] higher speed produces more damage on the machined surface. Which enables the higher cutting temperature, resulting softening of work material. Chandrasekaran et al. [7] announced that arithmetic average roughness varies linearly with feed rate and inversely with spindle speed. It’s depends mainly on feed rate, spindle speed and depth of cut. Reddy Sreenivasulu [8] who said that depth of cut is the important factor which influences the roughness followed by feed rate and cutting speed.

Most of the studies on carbon fiber reinforced polymer composite machining shows that minimizing the surface roughness is a serious task. So in order to get quality surface and dimensional properties, some theoretical model employed for prediction purpose. For the prediction, the response surface methodology (RSM) is economical, practical and relatively easy to use [9]. Response surface methodology (RSM) is a collection of mathematical and statistical technique which are useful for modelling and analysis of problem [10]. Palanikumar [11] investigated the effect of cutting parameters on surface roughness by developing a second order mathematical model for predicting the surface roughness. Sarma et al. [12] examined turning of GFRP composites and established a model for analysis of the cutting force by using the RSM. Krishnamoorthy et al. [13] carried out an experiment and presented an empirical model to study the delamination factor in the drilling of CFRP composite materials. They found the developed model to be compatible with experimental results. Palanikumar and Davim [14] used RSM for predicting tool wear during the machining of the GFRP composites.

The objective of present study is to determine the influence of MWCNT on the surface roughness of hole at entry and exit side. An RSM technique has been employed to correlate the drilling parameters and wt% of MWCNT to the output responses. Analysis of variance has been used to examine the more and less significant parameter on surface roughness at the entrance and exit.

1.1 Response surface methodology

Response surface methodology (RSM) is collection of mathematical and statistical technique used for modeling and analyzing the engineering problems [15]. In this experiment RSM is used to establish the mathematical relation using Box Benhken Method, between responses and drilling parameters. Surface roughness are used as output responses for mathematical modeling. Now representing the surface roughness ‘Rq (entrance)’ and Rq (exit)’ is a function of spindle speed ‘v’, tool feed rate ‘f’ and wt% of MWCNT ‘w’.

\[
\text{Rq (entrance)} = f(v, f, w) \tag{1}
\]

\[
\text{Rq (exit)} = f(v, f, w) \tag{2}
\]
The quadratic response surface model used to evaluate parametric effect is presented in equation (3).

\[ Y = \beta_0 + \sum \beta_i x_i + \sum \beta_{ii} x_i^2 + \sum \beta_{ij} x_i x_j \]  

(3)

Where \( \beta_0 \) is the coefficient for the constant term and the coefficient of linear, square and interaction terms are \( \beta_i, \beta_{ii}, \beta_{ij} \) respectively.

2. Materials and Method

2.1 Fabrication of materials

Carbon fiber reinforced polymer (CFRP) composite material was prepared by using 12 layers of plain woven carbon fiber of stacking order [45/-45], [45/-45], [30/-60], [30/-60], [30/-60], [0/90] // [0/90], [30/-60], [30/-60], [30/-60] [45/-45], [45/-45]. Then calculated amount of MWCNT was added in acetone such as; 0.5, 1.0 and 1.5 wt% of MWCNT and sonicated for an hour. Then the mixture of MWCNT was stirred by magnetic stir for 30 min at 80°C to evaporate the acetone. The curing agent hardener was added to the mixture in the ratio of 10:1, again mixing for 10 min with the help of mechanical stir rotating at 950 rpm for 10 minutes. Finally the mixture was applied on desire layup by hand lay-up technique and pressurized under the pressure of 700 mm of Hg for 24 hour as presented in figure 1. The average thickness of prepared laminates are 5.40 approximately.

Figure 1. Schematic representation of material preparation
2.2 Drilling experiment and measurement technique

Drilling of CFRP was conducted on radial drilling machine (BATLIBOI BVR 5) having 8 kW of spindle power. Solid carbide drill (figure 2) was used for drilling of CFRP composite materials, for each laminates new drill bit was used to avoid any tool wear effect on hole quality. Drilling experiment was performed according to Box Behnken Design and their levels of parameters presented in table 1. The details of experiment design presented in table 2.

![Figure 2. Solid carbide drill](image)

| Parameters               | Levels of Parameters |
|--------------------------|----------------------|
| MWCNT (wt %)             | 0.5                  |
|                          | 1.0                  |
|                          | 1.5                  |
| Spindle speed (rpm)      | 800                  |
|                          | 1400                 |
|                          | 2000                 |
| Feed rate (mm/rev)       | 0.10                 |
|                          | 0.30                 |
|                          | 0.50                 |

Surface roughness was measured using SJ-210 stylus type profilometer provided by (Mititoyo America Inc.) as shown in figure 3. To measure the surface roughness at entry side, profilometry was conducted from mid line to the top of hole. However, for exit side profilometry was conducted from mid line to bottom of hole. For each hole four measurement was taken at different cut section for entrance and exit, their average value was used for analysis. Cutoff length i.e. 0.08 mm was chosen for surface roughness measurement at entrance and exit of hole. Obtained results are presented in table 2.

![Figure 3. Surface roughness measurement (a) line of measurement and (b) set-up of surface roughness.](image)
Table 2. Details of experiment design and obtained results.

| Std. order | MWCNT (wt%) | Spindle speed (rpm) | Feed rate (mm/rev) | Rq (Entrance) | Rq (Exit) |
|------------|-------------|---------------------|---------------------|---------------|-----------|
| 1          | 0.5         | 800                 | 0.3                 | 1.13          | 0.57      |
| 2          | 1.5         | 800                 | 0.3                 | 0.80          | 0.35      |
| 3          | 0.5         | 2000                | 0.3                 | 0.95          | 0.48      |
| 4          | 1.5         | 2000                | 0.3                 | 0.47          | 0.34      |
| 5          | 0.5         | 1400                | 0.1                 | 1.18          | 0.36      |
| 6          | 1.5         | 1400                | 0.1                 | 0.70          | 0.24      |
| 7          | 0.5         | 1400                | 0.5                 | 0.84          | 0.39      |
| 8          | 1.5         | 1400                | 0.5                 | 0.32          | 0.21      |
| 9          | 1.0         | 800                 | 0.1                 | 0.73          | 0.47      |
| 10         | 1.0         | 2000                | 0.1                 | 0.78          | 0.35      |
| 11         | 1.0         | 800                 | 0.5                 | 0.55          | 0.28      |
| 12         | 1.0         | 2000                | 0.5                 | 0.58          | 0.51      |
| 13         | 1.0         | 1400                | 0.3                 | 0.47          | 0.31      |
| 14         | 1.0         | 1400                | 0.3                 | 0.43          | 0.33      |
| 15         | 1.0         | 1400                | 0.3                 | 0.49          | 0.34      |

3. Modelling of surface roughness

Modelling of Rq(entrance) and Rq(exit) has been carried out using Box-Behnken Design. Quadratic model which is obtained from regression analysis are denoted in Eqn. 4 and 5.

\[
Rq \text{ (entrance)} = 2.85374-2.14417A-0.00101829B-1.42292C+0.948333A^2+3.80787E-07B^2+1.48958C^2-1.2500E-04AB-0.100000AC-4.16667E-05BC \\
(4)
\]

\[
Rq \text{ (exit)} = 1.36800-0.236667A-0.00110324B-0.445833C+0.0116667A^2+2.92824E-07B^2-0.739583C^2+6.66667E-05AB-0.150000AC+0.000729167BC \\
(5)
\]

From figure 4 and 5, it can be noticed that the developed empirical model fit accurate with experimental results within the level of confidence.
Figure 4. Experimental vs predicted value of Rq at entrance
4. Results and discussions

During the drilling of CFRP composite material, surface roughness plays important role when part subjected under fatigue load. Surface roughness is important parameter which is must be minimizes during drilling. Figure 6 and 7 represents the effect of drilling parameters and wt% of MWCNT on surface roughness at entrance of hole. Figure 6, denotes the contour plots of Rq with feed rate and spindle speed for various amount of MWCNT. It can be noticed that, as wt% of MWCNT increases surface roughness decreases due to less protruded fiber on cut surface. However as feed rate increase surface roughness increases due to strain hardening effect. Figure 7, represents the surface plot of Rq. It can be seen that at 0.5 wt% of MWCNT and 2000 rpm of spindle speed surface roughness is maximum due to built-up edge formation. Which is occurred due to high cutting temperature, however in 1.5 wt% of MWCNT surface roughness decreases due to improvement in conductivity of polymer matrix.

Figure 5. Experimental vs predicted value of Rq at exit
Figure 8 and 9 represents the effect of drilling parameters and wt% of MWCNT on surface roughness at exit in the drilling of MWCNT doped carbon fiber reinforced composite material. From figure 8, it can be noticed that, as feed rate and spindle speed increases surface roughness increases, however surface roughness decreases with an increase in MWCNT percentage in polymer matrix due to proper severing of fiber, less cracking of matrix and less formation of built-up edge on hole wall. Figure 9 denotes the surface plots of surface roughness at exit, it can be noticed that surface roughness is minimum at 1400 rpm and 1.5 wt% of MWCNT. However
maximum surface roughness value has been observed at 0.30 mm/rev of feed rate and 0.5 wt% of MWCNT. Surface roughness at exit is lower than at entrance due to less damage at exit side.

**Figure 8.** Contour plots of Rq at exit

**Figure 9.** Surface plots of Rq at exit
5. Conclusions

In this work, surface roughness at entrance and exit of hole has been investigated for MWCNT doped carbon/epoxy polymeric composite material. Following conclusions are drawn on the basis of experiment:

- Surface roughness at entrance is more than at exit, due to less damage at exit.
- Minimum surface roughness has been observed at 1.5 wt% of MWCNT doped carbon/epoxy polymeric composite material. However maximum surface roughness recorded in 0.5 wt% of MWCNT doped carbon/epoxy polymeric composite material.
- Drilling parameters has also influences on surface roughness. Rq increases with increases in spindle speed and feed rate.
- The developed empirical model for Rq(entrance) and Rq (exit) are predicted the value accurately within level 95% level of confidence.

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