Measurement and analysis of thrust force in drilling sisal-glass fiber reinforced polymer composites

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Abstract. Drilling of composite materials is difficult when compared to the conventional materials because of its in-homogeneous nature. The force developed during drilling play a major role in the surface quality of the hole and minimizing the damages around the surface. This paper focuses the effect of drilling parameters on thrust force in drilling of sisal-glass fiber reinforced polymer composite laminates. The quadratic response models are developed by using response surface methodology (RSM) to predict the influence of cutting parameters on thrust force. The adequacy of the models is checked by using the analysis of variance (ANOVA). A scanning electron microscope (SEM) analysis is carried out to analyze the quality of the drilled surface. From the results, it is found that, the feed rate is the most influencing parameter followed by spindle speed and the drill diameter is the least influencing parameter on the thrust force.

Keywords: Drilling; Thrust force; Response surface methodology; ANOVA; Sisal-glass fiber composites.

1. Introduction

The composite materials are only an alternative for traditional materials due to its properties such as high strength-to-weight ratio, good wear resistance and damage tolerance, lower thermal expansion and lightweight, provided they can be machined to any shapes and sizes at an acceptable cost and quality [1-6]. Some of the factors which affect the drilling process are spindle speed, feed rate, drill geometry and properties work material. With the advent of composite materials and their wide use in structural applications, it has become necessary to drill holes into the laminates, to facilitate bolting or riveting to the main load bearing structure. According to statistics, more than 60% of the scrapped parts during aircraft assembly are caused by unqualified holes [7, 8]. Drilling of composite materials can destruct of fiber continuity and cause damages such as surface delamination, fiber/resin pull out, matrix thermal degradation etc [9-11]. Some of the challenges faced during drilling include dimensional variation, high temperature distribution, disintegration of material etc [12]. Machining of composite materials has started during 1970’s and concentrating on drilling of conventional fiber reinforced composites [13]. Then later stages the naturally available plant fibers as alternate reinforcement in the polymer matrix composites due to their inherent superior properties which make them highly competitive against conventional materials for any structural applications6. The selection of the reinforcement, fiber
orientation, tool geometry and material, and cutting conditions are very important, while machining composite materials [14-16].

In order to overcome the difficulties during machining an experiment has been carried out by using cemented carbide end mill and the results are compared with glass fiber reinforced polymer composites (GFRPs) [17]. From the experiment, it is found that the delamination and surface roughness of the natural fiber reinforced composites are better than the GFRPs. The effect of machining speed and feed rate on delamination in drilling of glass-hemp fiber reinforced composites with different fiber volume fractions was studied [18]. From the study, it is found that the damage around the hole is predominant at higher feed rates and the holes are in elliptical shape along the direction of fibers. Optimization of cutting parameters in drilling of hemp fiber reinforced composites are carried out by Dillibabu et al. [19] and found that the feed rate and cutting speed have largest contribution on the delamination. The hybrid composites from natural fibers instead of orthopedics alloys for internal fixation of fractured bones on human body have been developed by Chandramohan and Marimuthu [20]. From the study it is found that the composites made from natural fibers are best materials, when compared with composites made from orthopedic materials. Drilling of composites is carried out by using HSS-Co twist drill, multi twist drill and brad & spur drill and reported that the brad & spur drill produces less damage and thrust force when compared to the other two drills [21]. In the present experimental study, sisal-glass fibers reinforced composite laminates have been prepared and the influence of various cutting parameters, such as spindle speed, feed rate and tool diameter on thrust force is examined in the drilling of composites. The modeling of drilling parameters is carried out using RSM and the adequacy of the models has been checked by using ANOVA.

2. Experiment and measurement

2.1. Experimental setup

The machining operation is carried out on an auto feed drilling machine, with a variable speed (Model: A/30/GT, Make: CKP Industries), attached with the multi component piezoelectric dynamometer (Model: 9257B, Make: Kistler). The drilling set up is presented in Figure 1. The orthogonal components of the cutting forces are measured, using a multi component piezolectric dynamometer. The drilling operation was performed using a carbide drill with three different feed rates, spindle speeds and drill diameters.

![Figure 1 Drilling set up](image)

2.2. Experimental results

The drilling of the composites is carried out, using carbide drills. The experimental results of the thrust force during drilling is presented in Table 1.

| Trial No. | Speed, V (rpm) | Feed rate, f (mm/rev) | Tool dia, d (mm) | Thrust force, FZ (N) |
|-----------|----------------|-----------------------|------------------|---------------------|
| 1         | 1000           | 0.04                  | 6                | 136.32              |
2.3. Observations on the drilling of sisal-glass fiber composites

It is known that the variables in the drilling process, such as spindle speed, feed rate, and drill diameter, have great influence on the thrust force and the quality of the holes drilled. The typical thrust force developed during the drilling of sisal-glass fiber composites is presented in Figure 2. The figure shows that the thrust force is minimum at the entry of the drill and the maximum thrust force is observed at the middle of the hole. When the drill penetrates the composite laminate, the thrust force increases, and it decreases when the drill bit exits out on the other side of the laminate.

![Figure 2](image-url)

*Figure 2* Typical thrust force observed in the drilling of sisal-glass fiber composites
2.4. Response surface regression model for sisal-glass fiber composites

The machining parameters considered in this experiment are the spindle speed \( V \) in rpm, feed rate \( f \) in mm/rev, and drill diameter \( d \) in mm. The quadratic response models for thrust force are developed for the observed experimental results of sisal-glass fiber composites. The regression model developed for the thrust force \( F_Z \) for the composites is presented in Eq. 1.

\[
F_Z = (54.52963) + (0.097219 \times V) + (862.50000 \times f) + (14.50185 \times d) - (0.97000 \times V \times f) - (1.25000E-004 \times V \times d) - (22.50000 \times f \times d) - (1.80944E-005 \times V^2) + (25972.22222 \times f^2) - (0.16975 \times d^2)
\]

(1)

The summary statistics of the results of measured and the RSM predicted values for thrust force are presented in Table 2.

| Standard order | Experimental thrust force (N) | RSM predicted thrust force (N) |
|---------------|-----------------------------|------------------------------|
| 1             | 136.30                      | 144.4                        |
| 2             | 162.90                      | 210.3                        |
| 3             | 212.40                      | 190.1                        |
| 4             | 196.80                      | 204.3                        |
| 5             | 196.20                      | 244.9                        |
| 6             | 230.20                      | 230.4                        |
| 7             | 233.00                      | 253.5                        |
| 8             | 326.00                      | 260.2                        |
| 9             | 295.60                      | 350.1                        |
| 10            | 127.40                      | 132.5                        |
| 11            | 158.80                      | 164.3                        |
| 12            | 230.00                      | 242.3                        |
| 13            | 169.10                      | 177                          |
| 14            | 200.20                      | 204.9                        |
| 15            | 232.20                      | 244.6                        |
| 16            | 230.40                      | 242.6                        |
| 17            | 237.10                      | 262                          |
| 18            | 256.70                      | 254.3                        |
| 19            | 122.50                      | 132.4                        |
| 20            | 136.10                      | 140.3                        |
| 21            | 147.50                      | 155.6                        |
| 22            | 132.50                      | 136.8                        |
| 23            | 137.30                      | 146.5                        |
| 24            | 176.50                      | 192.2                        |
| 25            | 114.90                      | 121.4                        |
| 26            | 187.90                      | 192.5                        |
| 27            | 213.50                      | 230.4                        |

2.5. Analysis of thrust force using ANOVA

The ANOVA results obtained for the thrust force during drilling of sisal-glass fiber composites are presented in Table 3. From the table it can be observed that the \( R^2 \) values are 90.24\%, which shows that high correlation exists between the developed model and the experimental results. Further, it can be asserted that the developed models agree well with the experimental results, and hence, the developed RSM models can be used for predicting the thrust force in the drilling of these composites. From the ANOVA tables it is further observed, that all the input parameters are significant terms, which influence the thrust force in the drilling of sisal-glass fiber composites. Among all three parameters, the feed rate is the most influential one, as its F-value is higher when compared to the other parameters. The next contributing factor is the spindle speed followed by the drill diameter.
### Table 3. ANOVA for thrust force in the drilling of sisal-glass fiber composites

| Source | Sum of squares | DoF | Mean square | F value | Prob>F |
|--------|----------------|-----|-------------|---------|--------|
| Model  | 68563.62       | 9   | 7618.18     | 17.46   | < 0.0001 |
| V      | 21403.81       | 1   | 21403.81    | 49.07   | < 0.0001 |
| f      | 24264.58       | 1   | 24288.08    | 55.68   | < 0.0001 |
| d      | 15705.83       | 1   | 15705.83    | 36.01   | < 0.0001 |
| V\*f   | 4516.32        | 1   | 4516.32     | 10.35   | 0.0051 |
| V\*d   | 1.69           | 1   | 1.69        | 3.869E-003 | 0.9511 |
| f\*d   | 21.87          | 1   | 21.87       | 0.050   | 0.8255 |
| V\^2   | 1964.45        | 1   | 1964.45     | 4.50    | 0.0488 |
| f\^2   | 647.57         | 1   | 647.57      | 1.48    | 0.2397 |
| d\^2   | 14.00          | 1   | 14.00       | 0.032   | 0.8599 |
| Error  | 7415.36        | 17  | 436.20      |         |        |
| Total  | 75978.98       | 26  |             |         |        |

R-Squared=90.24%

### 3. Results and discussion

#### 3.1. Effect of the machining parameters on thrust force

The influence of the cutting speed on thrust force in the drilling of sisal-glass fiber composites is presented in Figure 3. From the figure it can be observed that the thrust force decreases when the speed increases, that is the thrust force at 3000 rpm is lower than the 2000 and 1000 rpm. The influence of the feed rate on thrust force is depicted in Figure 3 (b). The feed rate plays a vital role on the thrust force, and the experimental results showed that the thrust force is increased by increasing the feed rate. The reason is that while increasing the feed rate the load on the drill bit increases, which in turn, increases the thrust force. Figure 3(c) shows the variation of the thrust force with respect to the drill diameter. The drill diameter also shows almost the same trend as feed rate, in which the thrust force increases with the increase in the drill diameter. The thrust force is the minimum at a lower diameter, and maximum at a higher diameter of the drill, because the higher diameter drill increases the contact area between the tool and the work piece, and also the subsequent increase in load. The optimum cutting conditions for machining of composites is higher cutting speed, lower feed and dept of cut [22].

![Figure 3](image_url)

**Figure 3** Influence of (a) spindle speed, (b) feed rate and (c) drill diameter on the thrust force in the drilling of sisal-glass fiber composites

#### 3.2. Scanning electron microscopy (SEM) analysis

Figure 4 shows the SEM micrographs of the surface of the drilled holes, observed in drilling of sisal-glass fiber composites using carbide drills, under various cutting conditions. The surfaces of the microstructure show the smooth edges, and some damages like fiber pull out, fiber dislocation, uncut fibers and uneven distribution of fibers etc. These are the common problems in the drilling of any material, including composites. Figure 4(a) is the SEM image of the sisal-glass fiber composite laminate subjected to drilling at the low feed rate of 0.04 mm/rev and at the low spindle speed of 1000 rpm. From the micrograph the cutting edges of the fibers are clearly visible. The SEM image of the composite laminate subjected to drilling at the medium feed rate of...
0.06mm/rev and at the medium spindle speed of 2000rpm is presented in Figure 4(b). The fibers at the inner surface of the drilled hole are clearly seen from the image.

![Figure 4 SEM images of the inner surfaces of the drilled holes in the drilling of hybrid composites](image)

3.3. Comparison of experimental results with RSM model

The comparative results for thrust force between the experimental results and the models developed using RSM, are presented in Figure 5. The figure clearly shows that there is prediction potentials exist between the experimental results and the developed model; hence, this model can be effectively used for the prediction of thrust force in drilling of hybrid composites.

![Figure 5 Comparison plot for thrust force in the drilling of sisal-glass fiber composites](image)

4. Conclusion

The drilling experiments are planned and conducted to predict the influence of cutting parameters on thrust force in drilling of sisal-glass fiber composite laminates by using carbide drills. Based on the experimental results the following conclusions have been arrived.

- The maximum thrust force absorbed by the sisal-glass fiber composite laminates is 326 N.
- The thrust force increases with an increase in the feed rate and drill diameter, and decreases when the spindle speed increases for all cutting combinations.
- The thrust force is highly influenced by the feed rate followed by the spindle speed. The drill diameter has the least influence on the thrust force.
- The coefficient of correlation for the models is nearly equal to 1, and hence, these models can have very good prediction potentials.
- From the SEM analysis, the interfacial relationship between the fiber and the matrix, fiber debonding during drilling and the internal cracks of the drilled surfaces are observed.
- The results indicated that the high spindle speed, low feed rate and drill diameter are preferred for drilling of sisal-glass fiber reinforced hybrid composites.
5. References

[1]. Songmene V and Balazinski M 1999 Machinability of graphitic metal matrix composites as a function of reinforcing particles. *CIRP Ann. Manuf. Technol.* **48** 77.

[2]. Ramesh M, Sudharsan P and Palanikumar K 2015 Processing and mechanical property evaluation of flax-glass fiber reinforced polymer composites. *Appl. Mech. Mater.* **766-767** 144

[3]. Bhoopathi R, et al. 2015 Experimental investigation on mechanical properties of hemp-banana-glass fiber reinforced composites. *Appl. Mech. Mater.* **766-767** 167

[4]. Ramesh M, Palanikumar K and Reddy K H 2013 Mechanical property evaluation of sisal-jute-glass fiber reinforced polyester composites. *Compos. Part B Eng.* **48** 1

[5]. Ramesh M, Palanikumar K and Reddy K H 2013 Comparative evaluation on properties of hybrid glass fiber-sisal/jute reinforced epoxy composites. *Proc. Eng.* **51** 745

[6]. Dandekar C R and Shin Y C 2012 Modeling of machining of composite materials: a review. *Int. J. Mach. Tool. Manuf.* **57** 102

[7]. Khashaba U 2004 Delamination in drilling GFR-thermoset composites. *Compos Struct.* **63** 313

[8]. Liu DF, Tang YJ, Cong WL. A review of mechanical drilling for composite laminate. *Composite Structures*. 2012; 94: 1265–79.

[9]. Davim J P, Reis P and Antonio C C 2004 Experimental study of drilling glass fiber reinforced plastics (GFRP) manufactured by hand lay-up. *Compos. Sci. Technol.* **64(2)** 289.

[10]. Zitoune R, et al. 2011 Behaviour of composite plates with drilled and moulded hole under tensile load. *Compos. Struct.* **93** 2384

[11]. Wern C W, Ramulu W and Shukla A 1996 Investigation of stresses in the orthogonal cutting of fiber-reinforced plastics. *Exp. Mech.* **36(30)** 33

[12]. Kolhar A S 2007 Masters Thesis, Wichita State University, USA.

[13]. Doran J H and Hanley F 1972 Machining of boron/epoxy composites. *Met. Eng. Qly.* **12(3)** 38.

[14]. Singh I and Bhattachar N 2006 Drilling of unidirectional glass fiber reinforced plastic (UDGFRP) composite laminates. *Int. J. Adv. Manuf. Technol.* **27** 870

[15]. Yusup N, Zain A M and Hasim S Z M 2012 Evolutionary techniques in optimizing machining parameters: Review and recent applications (2007-2011). *Exp. Sys. Appl.* **39** 9909

[16]. Dandekar C R and Shin Y C 2008 Multiphase finite element modeling of machining unidirectional composites: Prediction of debonding and fiber damage. *J. Manuf. Sci. Eng.* **130(5)** doi: 10.1115/1.2976146

[17]. Dillibabu G, Sivajibabu K and Gowd UM 2013 Effect of machining parameters on milled natural fiber reinforced plastic composites. *J. Adv. Mech. Eng.* **11**

[18]. Naveen P N E, Yasaswi M and Prasad R V 2012. Experimental investigation of drilling parameters on composite materials. *IOSR J. Mech. Civil Eng.* **2** 30.

[19]. Dillibabu G, Sivajibabu K and Gowd UM 2013 Optimization of machining parameters in drilling hemp fiber reinforced composites to maximize tensile strength using design experiments. *Ind. J. Eng. Mater. Sci.* **20** 385.

[20]. Chandramohan D and Marimuthu K 2010 Thrust force and torque in drilling the natural fiber reinforced polymer composite materials and evaluation of delamination factor for bone graft substitutes-A work of fiction approach. *Int. J. Eng. Sci. Technol.* **2**(10) 6437.

[21]. Jayabal S and Natarajan U 2010 Optimization of thrust force, torque, and tool wear in drilling of coir fiber-reinforced composites using Nelder–Mead and genetic algorithm methods. *Int. J. Adv. Manuf. Technol.* **51** 371

[22]. Ramesh M, Elvin R P, Palanikumar K and Reddy K H 2011 Surface roughness optimization of machining parameters in machining of composite materials. *Int. J. Appl. Res. Mech. Eng.* **1** 26