Experimental Investigation and Analysis of Machining Characteristics in Drilling Hybrid Glass-Sisal-Jute Fiber Reinforced Polymer Composites

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Abstract

In the highly competitive manufacturing world, the ultimate goals of the manufacturer are to produce high quality products at minimum cost and in less time. The use of composite materials is growing at a fast rate, because these materials have many constituents and each has its own unique characteristics. While focusing on the composite materials, the main points to be considered are environment friendliness and light weight, with high specific properties. To fulfill these requirements, the natural fibers are incorporated into manmade fibers, and partially eco-friendly hybrid composites have been developed by using glass, sisal and jute fibers as reinforcing material in the polymer resin matrix. The drilling of composite materials is difficult when compared to metals, because the tool has to pass alternately through the matrix and reinforcement, which have different properties. In this experiment, drilling is carried out in an auto feed drilling machine, attached with a multi component piezo-electric dynamometer, by using a coated carbide drill. The aim of this work is to emphasize the machining characteristics of the hybrid composites by varying the cutting speed, feed rate and tool diameter. The drilling induced damage is analyzed with the help of the profile projector, and the cutting edges of the drilled holes are examined, by using the scanning electron microscopy (SEM) analysis. From the results it has been observed, that all the above said parameters affect the drilling process, and the induced damage has been reduced by varying the feed rate.

Keywords: Hybrid composites, Thrust force, Torque, Delamination

1 Introduction

Composites are manmade materials that are a combination of two distinct components, created to obtain properties that cannot be achieved by any one of the components acting alone. An attempt has been made to utilize the advantages offered by renewable sources for the development of the composite materials mixed with synthetic reinforcements, using a polymer resin matrix. The applications of natural fiber reinforced composites are growing rapidly, due to their inherent properties of light weight, easy availability, and environment friendliness (Ramesh et al. 2013). The mixing of natural fibers with synthetic fibers increases its strength, and it is found to be a good alternative reinforcing material (Ramesh et al. 2013). The banana, sisal and roselle fiber reinforced composites are fabricated by the mould method, and the drilling is carried out, using HSS twist drills (Chandramohan and Marimuthu, 2011). From the experiment they found that, the cutting speed, feed rate and drill diameter are the most significant factors affecting the thrust force. They further observed that the thrust force and torque increases with the increase in the feed rate, and decreases with the increase in cutting speed.

Composite materials have become valuable construction materials in the aerospace, defence and automotive industries, due to their higher specific strength, stiffness and fatigue characteristics. Composite components are joined by mechanical fasteners; and accurate, precise high quality holes need to be drilled to ensure proper and durable assemblies. The drilling of composite materials causes several damages, such as: delamination, fiber-pull out, edge chipping, uncut fibers, and others. It causes poor assembly tolerance, reduces the structural integrity of material, and deterioration of the potential for long term performance (Koboevic et al. 2012). Drilling is carried out by using the HSS-Co twist drill, the multi construction twist drill, and the brad & spur drill, and reported that the brad & spur drill produced less induced damage around the hole surface, and lesser thrust force than the other two drills. The HSS-Co twist drill is always a bigger delamination factor, which means higher damage in a composite laminate.
Natural fibers have many advantages, such as low density, high specific strength and modulus, non-abrasiveness, and low cost, when compared to synthetic fibers. Natural fiber reinforced composite materials are recognized as better materials for structural applications, and the machining of these composites causes a number of problems (Dilli Babu et al. 2013). In order to overcome these problems an experiment has been carried out by using a cemented carbide end mill cutter, and the results are compared with those of the glass fiber reinforced polymer composites. From the experiment, they found that the delamination factor and surface roughness of the natural fiber reinforced composites are better than those of glass fiber reinforced composites. The effect of cutting speed and feed rate on delamination in drilling glass, hemp and sandwich fibers reinforced composites with different fiber volume fractions, is observed by Naveen et al. (2012). It is found that the damage around the hole is predominant at higher feed rates, and a partial elliptical shape along the direction of fibers. Optimization of the machining parameters in drilling hemp fiber reinforced composites was carried out by Dilli Babu et al. (2013), and it was found that the feed rate and cutting speed made the largest contribution to the delamination. An investigation has been carried out to study the mechanical and machinability characteristics of coir–polyester composites by Jayabal et al. (2011). They found that the drill diameter of 6mm and the spindle speed of 600rpm gave the minimum value of thrust force, torque and tool wear. An effort has been made for the development of hybrid composites from natural fibers instead of orthopedic alloys, for internal fixation of fractured bones in the human body by Chandramohan and Marimuthu (2010). From the study it is revealed, that composites made from natural fibers are the best materials, when compared with orthopedic composites made from orthopedic materials.

Coir fiber reinforced composites have been developed; the thrust force, torque and tool wear during drilling optimized by Jayabal and Natarajan (2010). An experiment has been conducted to carry out the mechanical and machinability characteristics of glass-coir-polyester composites, using factorial design methodology (Jayabal et al. 2011). A regression model is developed for correlating the drilling parameters and their effects by design of experiment techniques, and it is found that the feed rate plays a major role than the other variables. A desirability function based method is applied for optimizing the drilling parameters, based on multiple performance characteristics, by Rajmohan and Palanikumar (2012). The results indicated that the medium spindle speed and lower feed rate are optimum, for the minimum burr height during drilling, and the surface roughness of the hybrid composites. In the present research, the glass-sisal-jute fibers reinforced hybrid composites have been developed, and the drilling characteristics of these composites are analyzed, by varying the cutting speed, feed rate and tool geometry. The results indicated that all the above said parameters affect the drilling characteristics, and subsequently drilling induced damage.

2 Methodology

2.1 Materials

The fibers used in the present experiment for fabricating composite specimens are sisal (Agave sisalana) fiber, jute (Corchorus olitorus) fiber and glass fiber. The sisal and jute fibers are collected from Dharmapuri District, Tamil Nadu, India. The glass fiber, polyester resin, and drill bits used for drilling are purchased from the local dealer in Chennai. The fibers used for the fabrication are presented in Figure 1.

![Figure 1 Fibers used for fabrication](image)

2.2 Specimen preparation

The glass, sisal and jute fiber reinforced hybrid composite laminates are fabricated, by using the hand moulding technique and then applying pressure, using the compression molding machine. Initially, the fibers are dried under the hot sun for more than 48 hours before processing, to remove the moisture. For the entire specimen, the natural fibers and synthetic fibers are stacked alternatively. The whole assembly was pressed at a temperature about 60°C for 8 hours, and then the composite was cooled under room temperature and normal pressure. Then the composite laminates are removed from the mould and the thickness of the prepared composite sample was 5mm. The experiment has been carried out at room temperature.

2.3 Experimental set-up

The drilling of hybrid composites is carried out on an auto feed drilling (Model:PA/30/GT, Make:CKP), by using a coated carbide drill with the tool geometry of the Brad and spur type, and having three different diameters of 6mm, 9mm and 12mm. The dynamic and quasi-static measurements of the thrust force and torque are recorded, by using a multi component piezoelectric dynamometer (Model: 9257B, Make:Kistler). The experimental set up is given in Figure 2. The experiments have been carried out at three different spindle speeds of 1000rpm, 2000rpm and 3000rpm, with different feed rates of 0.04mm/rev, 0.06mm/rev and 0.08mm/rev. The thrust force and torque signals recorded during the drilling operation by using the multi
component piezoelectric dynamometer, are presented in Table 1.

![Figure 2 Experimental set-up](image)

**Table 1 Experimental thrust force, torque and delamination of the composite samples**

<table>
<thead>
<tr>
<th>Spindle Speed (rpm)</th>
<th>Feed rate (mm/rev)</th>
<th>Tool dia (mm)</th>
<th>Thrust force (N)</th>
<th>Torque (Nm)</th>
<th>Delamination (mm)</th>
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<td>190.48</td>
<td>1.486</td>
<td>1.196</td>
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</table>

2.4 Drilling induced damage

While drilling polymer matrix composites, different types of damages like matrix burning and cracking, fiber pullout, and delamination, occurs around the drilled hole. In the present study, the damage was directly visible around the drilled holes, and identified with the help of the profile projector (Type: MEGA 8021A Junior, Make: Metzer). The drilling induced damage depends upon the process parameters, matrix type, nature and properties of fibers, layer sequence etc. The delamination factor is calculated, using the following equation and tabulated in Table 1.

\[
F_d = \frac{D_{\text{max}}}{D_{\text{act}}} \tag{1}
\]

Where

\[
D_{\text{max}} = \text{Maximum diameter}
\]

\[
D_{\text{act}} = \text{Actual diameter}
\]

3 Results and discussion

3.1 Thrust force analysis

During the drilling operation, the thrust force signals recorded at three different feed rates and speeds, by using a coated carbide brad and spur drill have been analyzed. The thrust force vs. spindle speed graphs of the hybrid composite samples recorded from the piezoelectric dynamometer are presented in Figures 3, 4 and 5. From Figure 4 it can be observed that the thrust force decreases when the spindle speed increases.

![Figure 3 Thrust force variation with respect to the spindle speed](image)

![Figure 4 Thrust force variation with respect to the drill diameter](image)
3.2 Torque analysis

In the present experimental study, the torque signals are recorded with the help of the piezoelectric dynamometer. The torque recorded from the dynamometer with respect to the spindle speeds, drill diameters and feed rates are presented in Figures 6, 7 and 8.

From the figures it can be seen that the variation of the torque is almost the same as the thrust force variation. From the figures it has been further observed that the torque at a higher feed rate is greater than that at lower feed rates.

3.3 Delamination analysis

The variation of delamination with respect to the spindle speed for all the feed rates is presented in Figure 9. From the figure it can be seen that, the delamination at a lower speed is the maximum, and it decreases when the spindle speed increases.
The delamination with respect to the drill diameter for all spindle speeds is given in Figure 10. The figure clearly shows the increasing trend of the delamination when the diameter of the tool increases for all the spindle speeds. The delamination factor with respect to the feed rates for different drill diameters is presented in Figure 11. The delamination with respect to the feed rates also shows the same trend, as the delamination with respect to the drill diameters. From the analysis it can be concluded, that the delamination increases when the feed rate and drill diameter increase, and it decreases with an increase in the spindle speed.

![Figure 11 Delamination factor with respect to the feed rate](image1)

It has been proved from the past results that the high value of drilling forces results in larger damage around the drilled hole. This fact has been substantiated by the present experimental investigation. The maximum values for the thrust force and torque were recorded at higher feed rates and subsequently they resulted in the maximum delamination.

### 3.4 Morphology analysis

The cutting edges of the drilled holes are examined, by using the scanning electron microscopy (Model: JEOL JSM-6480LV) analysis. The SEM images of the drilled surfaces at the feed rates of 0.04mm/rev, 0.06 mm/rev and 0.08mm/rev are presented in Figures 12, 13 and 14. The different layers of the specimen in the drilled surface are clearly visible in Figure 12. The void formed between the layers of the specimen and the fibers that came out due to drilling are clearly shown in Figure 13. The cutting edges of the natural fiber layers are clearly indicated in Figure 14. Further it can be observed that, there are more number of fibers dislocated at higher feed rates than at lower feed rates. Therefore, it is concluded, that lower feed rates are more suitable for drilling hybrid composites, as discussed in the earlier.
4 Conclusion

In the present experimental study, drilling characteristics of glass-sisal-jute fibers reinforced hybrid composites has been investigated at different combinations of spindle speeds, feed rates and drill diameters. From the experiment the following conclusions have been arrived at:

- The thrust force increases with an increase in the feed rate, and drill diameter, and decreases with an increase in the spindle speed. The maximum thrust force is recorded at higher feed rates.
- The torque also shows the same trend as thrust force and, recorded the maximum at lower spindle speeds and minimum at medium and higher spindle speeds.
- The drilling induced damage shows an increasing trend with higher cutting speeds and feed rates. The maximum delamination has been observed at higher feed rates, and the minimum at medium and lower feed rates.
- From the SEM images we can clearly see the cutting edges of the fibers, fiber pullout due to the cutting forces, and the drilling induced damage areas.
- From the experimental analysis it can be suggested that low feed rates, and high or moderate spindle speeds are more suitable for drilling of glass-sisal-jute fiber reinforced hybrid composites, as they subsequently reduced in drilling induced damages.

References


