Cutting force analysis on drilling parameters of sugarcane fibre reinforced polymer composite

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Abstract. Machining process in polymer composites is evolving and challenging to the material designers due to the delamination of fibre/matrix and its surface exposure to the environment. The present work gives attention to the drilling parameters associated with micro sugarcane fibre reinforced with polymer composites. Natural fibre reinforced with polymer composite makes less in cost, density and energy required for manufacture. Because of these numerous advantages, sugarcane fibres are selected as reinforcement. The composite material was processed by different volume fractions with short sugarcane fibre reinforced such as 1%, 3% and 5% along with unsaturated polyester & coupling agents, the whole process was carried out through manual hand layup. Drilling process was performed using HSS tool with different speed and feed, each material was optimized with the L9 orthogonal array. The thrust force for each drill for all materials was computed and correlated with neat polyester matrix composite. It is found that increase in fibre volume provides optimum cutting force of about 33.54 N and excellent surface finish.

Keywords: Sugarcane fibre, Polymer composites, natural fibres, Drilling, Thrust force, Short fibre.

1. Introduction

Materials field getting steered towards environmental friendly sustainable due to laws governing for global importance, this opens the great opportunity for material experts to excel in the area with immense hope. Polymer composite materials found larger interest in this era because of choosing their reinforcement and matrix with biodegradability, compared to conventional materials it provides higher strength to weight ratio, better durability, requires less energy, minimal cost etc., It also finds wide applications in area of aerospace, automobile, automotive, sporting goods, marine, infrastructure and package industries [1-5]. Natural fibres quickly emerged in this field because of its numerous advantage notably biodegradability, abundant availability and lesser density. Natural fibres vary from banana, bagasse, coir, hemp, jute, kenaf, luffa, sisal, pineapple these are processed from stems and leaves of plants and trees [6-9]. Machining is an unavoidable and important process in manufacturing industries to make a final required component from raw material through various operations. Machining a composite material is still a challenging task due to various limitations however without machining most of the material processing was not possible.

Muliniari et al. [10] examined the properties of polypropylene composites influenced by the modified surface of sugarcane fibres. The observation reveals that pre-treatment on sugarcane fibres removes other components such as impurities, amorphous constituents etc., and improves the tensile modulus. Gokul et al. [11] successfully incorporated the coconut shell filler in pre-treated sugarcane fibre polyester composites. The addition filler improves the stiffness of the material and provides excellent
mechanical properties. NaOH surface treatment to sugarcane fibres gives strong interfacial bonding. Oladele [12] evaluated the mechanical properties of polyester composites reinforced with short sugarcane fibre at different weight percent. Sugarcane particulate fibers with 5-10 w% holds the better properties, it evident that low fibre content is enough for enhancing properties. El-Fattah et al. [13] investigated the characteristics of recycled high density polyethylene with the effect of sugarcane bagasse fibre. The outcome states that compatibilized composites provides reasonable increase in tensile strength compared to uncompatibilized composites. Increase in bagasse volume in HDPE composites increases the water absorption property. Chedgani et al. [14] studied the effect on tribological behaviour influenced by fibre type while cutting natural fibre reinforced plastics. It shows bamboo fibre plastics exhibit smoother surface finish with high contact machining after machining compared to sisal and miscanthus. They also stated that fibre stiffness and interface quality highly influences the cutting surfaces of natural fibre reinforced plastic. Chye Lih Tan and Azwan Iskandar Azmi [15] made an analytical study on hybrid/ carbon glass composite for delamination damage by thrust force. It was observed that the size of delamination zone is strongly influenced by change thrust force. An analytical model was developed with energy balance equation predicted the thrust force during drilling which was highly agreed with the experimental thrust force. Chedgani F and El Mansori M [16] investigated the multi scale behaviour of natural fibre composite while drilling by changing the tool coating in the tool- composite interface. The result reveals that the tool coating at the different level of scaling strongly affects the tribo mechanical properties of a drilling operation. Machinability of bidirectional flax fibre reinforced polyethylene composites was deteriorated by diamond coating compared to TiB2. Navaneethakrishnan S and Athijayamani A [17] examined thrust force and torque of sisal fibre reinforced polymer composites filled with coconut shell filler composites while drilling. They found that thrust force reduces if the hole was predrilled and increases with increase in fibre volume fraction. Torque and thrust force increases with the change in feed rate and drill tool point angle.

Wang H et al. [18] investigated the evolution of delamination morphology during drilling composite laminates. The experimental critical delamination position at different depths matches with the theoretical delamination. Sunny T et al. [19] conducted an experimental study on the effect of process parameter while drilling GFRP composites using Taguchi method. The observations state that the increase in spindle speed and a decrease in feed rate reduces the delamination factor and keeps in the certain limit. Delamination factor is majorly influenced by feed rate compared to the speed of the spindle. Ismail S O et al. [20] examined the machinability of hemp and carbon fibre reinforced polymer composites. The result revealed that delamination and surface roughness tends to increase with an increase in feed rate and thrust force. The major objective of the work is to reduce the energy conserved for production of materials and utilization of agro waste materials in a well effective manner.

The current work aims to study the cutting force of sugarcane fibre reinforced polymer composites with varying fibre volume fraction as 1%, 3% & 5% and related to neat polyester composite under different drilling parameters.

2. Materials and Methods

Short sugarcane fibres are prepared manually by hammering it after collected from local juice shop and sundried from 72 hours which is shown in Figure 1. (b). Polyester resin and coupling agents were purchased from local suppliers in Chennai. Sugarcane shortfibers were reinforced with the polyester matrix in different volume fractions namely 1%, 3% & 5%, totally four types of material were fabricated including neat polyester using manual hand layup process. Mould of size 300 x 300 mm was made using a polyester sheet and rubber pad of 3mm thickness which was shown in Fig 1(a). Initially, micro fibres were mixed with polyester matrix and coupling agents by a manual stirring process and then it was poured in the mould cavity, the upper surface was covered with polyester thick sheet without airgap and allowed it 24 hours for perfect curing at room temperature. Specimen size of 75 x 75 x 3 mm was prepared from all four materials for the drilling operation. Drilling operation was carried out in 3 Axis VMC, Model- BMV 35 T12, Make – BFW and CNC controller – Siemens- Sinumerik 828CBasic, with
spindle power of 3.7 kW. Thrust force was calculated with the help of Multicomponent Dynamometer, Make – KISTLER, Top Plate 100 x 170 mm. Specimen after drilling operation was shown in Figure 2.

Figure 1. (a) Mould Setup & (b) Sugarcane Fibres

Figure 2. Composite specimen after drilling namely NP- Neat polyester & SG- Sugarcane Fibre.
Figure 3. Shows a clear view of experimental setup which consists of multicomponent dynamometer mounted above the work table, the workpiece was clamped using a holding device, HSS drilling tool coupled with high-speed spindle.

3. Results and Discussion

To study and compare the thrust force while drilling efficiently Neat polyester composite specimen was loaded initially for the operation. The operation was initiated with drilling parameters which are planned earlier as cutting speed of 1000, 1500 & 2000 rpm, a feed rate of 50,75, 100 mm/sec and the depth of cut of 8mm.

Figure 4. (a) & (b) Surface morphology of Sugarcane fibers

Sugarcane fibers which are used for reinforcement are analyzed through scanning electron microscope to study the surface structure shown in Figure 4 (a) & (b). The surfaces are characterized at two different magnifications of 1300 x & 400 x in high vacuum. It shows that surfaces are clear and segmented chamber like structure because those are short fibers.
The hole was set to drill with the offset of 15mm each in 3 x 3. The observed thrust force was recorded with the help of dynamometer and plotted as a graph which is listed in Figure 5. It was observed that thrust force shows increasing trend with an increase in feed rate and decreases with increase in cutting speed. The least cutting force was observed in 2000 rpm/ 50 mm/sec as 38.82 N and maximum cutting force was found at 1000 rpm/ 100 mm/sec as 103.4 N. Material subjected to fracture in the bottom surface of hole edges at the feed rate of 100 mm/sec. Though it is a neat polyester specimen the cutting force obtained was important for comparison among composites with reinforcement and to study the differences between all specimen & to get the optimum of all. This result gives the basic picture about the cutting force analysis for normal material with the parameters of increasing speed and feed.

![Figure 5. Thrust force for (a) Neat Polyester and (b) 1% SG.](image)

The next specimen with a volume fraction of 1% sugarcane fibre reinforcement subjected to the drilling of same parameters. The results also revealed the increasing speed and decrease in feed rate provides the optimum cutting force as 38.46 which slightly lower than the neat polyester and maximum force about 106.7 N. Here the addition of reinforcement with 1% sugarcane fibre fairly withstand for drilling without much deviation compared to neat polyester. Addition of reinforcement slightly increases the force at low speed and high feed rate. It was followed by increasing reinforcement as 3% underwent the cutting operation with prescribed parameters. It was found that result trends are well matching with the neat polyester and 1% reinforcement, cutting force increases with respect to increases in feed rate and decreases with lower feed rate. The fracture at hole bottom edges with the feed rate of 100 mm/sec at 1000 rpm as well as the neat polyester specimen in 1% reinforced specimen. The material breakages at the bottom of holes in the edges were critical in 3% reinforcement at 100 mm/sec with varying speeds. It shows that minor accumulation of fibre at the surface induces the breakage of material at hole edges during drilling at high feed rate.
Final specimen with increased reinforcement about 5% was used for drilling like other materials. The trend coincides with all the materials but the interesting observation was the cutting force reduced further and recorded as least value among all materials as 33.54 N. It clears that increasing volume fraction of sugarcane fibres in short and random orientation provide good results. If we talk about surface finish among all materials subjected under drilling, a material with 5% reinforcement provides good and it withstands better during operation.

4. Conclusion

The influence of increasing volume fraction of sugarcane fibres for cutting force analysis with varying parameters was successfully investigated in depth. The important outcome of the present study are:

• Cutting force increases with increase in feed rate and decreases with increase in speed for all four materials. Larger cutting forces are observed with higher feed rate at lower spindle speed.

• Increasing fibre volume fraction of short sugarcane fibres in random orientation provide the lesser cutting force. Least cutting of 33.54 N was observed in 5% sugarcane fibre reinforced polyester material at 2000rpm and 50mm/sec.

• Surface finish at the edges of holes after drilling is found improved with increasing fibre volume and lesser feed rate. A smoother surface at drilled edges is observed in the 5% SG reinforced material.

It opens the doors to bright future of sugarcane fibres to evolve in the field of decorative components, infrastructure, household products. The use of sugarcane fibre also reduces the limitations in agro-wastes and eco-friendly.
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