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# A comparison study on delamination in hand layup and compression moulded jute - human hair polymer composites

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**Abstract**

Natural fibre composites are presently used in various applications like automobile body panels to numerous house holding applications including furniture since it has various advantages such as better strength to weight ratio, reduced corrosion and ability to recycle. This composite panels need to undergo the drilling operation in order enable them to assemble with other components. Many a times the quality of drilled holes is not good because of the anisotropic nature of natural fibre composites. So, it is very important to select the best combination of machining parameters like drilling speed, feed rate and also the proper selection of dill bit material and its nomenclature. The mechanical strength of composite material also plays an important role in deciding the quality of hole. In this work, an effort has been made to study the effect of various parameters while drilling jute-human hair hybrid composites. In order to study the effect of strength, composite laminates were fabricated by hand lay-up and compressed moulding methods with 25% fibre volume. Three types of High-Speed Steel drill bits with 5mm diameter were used to investigate the delamination factor with three levels of spindle speed and feed rate. Diameter of drilled holes was measured by image processing technique to achieve better results.

**Keywords**: Compression moulding, Hand lay-up, Hybrid Composite, Delamination, Nomenclature

## Introduction

Natural fibre reinforced composites widely used in various applications now a days because of easy availability, reduced cost of manufacturing, renewable in nature and better mechanical properties. Jute fibre composites are used in automobiles for door panels and brake pads. It is also being used in various residential and commercial architectures [1]. Human hair is a low-cost natural fibre which is available abundantly. Human hair possesses better tensile strength, equal to that of copper wire with same diameter [2]. It is non-degradable in nature. By using human hair as reinforcement in composite, better management of this solid waste is ensured. Human hair can be used as reinforcement in concrete structures as well as pavement of roads to increase the load bearing capacity [3]. Hybrid composites made by using combination of multiple natural fibres will possess better strength than the single fibre composite.

Composite laminates can be manufactured by various methods namely open mould process, close mould process and pultrusion process. Hand lay-up and compression moulding process are the important type of open mould and closed mould processes respectively. These processes are widely used to prepare composite laminates. Drilling is the most frequently used operation in the composite laminates, since it enables the process of assembly. But drilling in composites leads many problems like delamination, surface roughness, fibre pull out and surface cracks, because it is anisotropic in nature. This imparts the proper understanding and selection of cutting parameters for the drilling process in order to achieve better quality products and cost-effective process.

Vinod Kumar Vankanti et al.[4] studied the influence of drilling parameters on GFRP composites using Taguchi's experimental design. They have also conducted analysis of variance test to determine the

significance of machining parameters. Results concluded that feed rate is the most important parameter which influence the thrust force than speed, chisel edge and point angle. Dilli Babu et al.[5] investigated the correlation of drilling speed and feed with delamination for hemp, jute, banana and glass fibre reinforced plastic composites, laminated by hand lay-up technique. Results indicated that higher speed and low feed leads to reduced delamination in drilling. They also found that delamination factor is small in hemp fibre reinforced plastics compared to other types of laminates. T. Panneerselvamet al.[6] conducted experiments on glass fibre reinforced plastics using high speed steel drill bit with 8 mm diameter, and found the influence of drilling parameters on delamination and suggested a spindle speed of 3000 rpm and feed rate of 50 mm/min for minimum delamination. V.Santhanam et al.[7] did experiments on drilling delamination in chopped and woven Banana-Glass fibre reinforced composites. They identified that the fibre volume fraction is having less influence on the quality of hole. P.Gopinath et al.[8]analysed the thrust force and torque in drilling of Glass fibre reinforced polymer composites. Also, they developed a fuzzy model to predict the thrust force and torque in drilling of FRP. M.Ramesh et al.[9] found low feed rate and moderate or higher speed can be used for drilling the glass-sisal-jute fibre reinforced composites.

K.S.K Sasikumar[10] studied the influence of various machining parameters on the induced delamination in drilling of agave reinforced composite. Using ANOVA, the most influencing parameters are found to be cutting speed and feed rate. Diameter of drill bit found to have least impact on delamination of drilled hole. J.Babu et al.[11] conducted drilling experiment with 5 levels of speed and feed rate in GFRP composites. Feed rate is found to be the most important influencing factor for delamination. P.N.E.Naveen et al.[12] analyzed the effect of varying the cutting parameters in drilled holes for different fibre volume fractions. Experiment was conducted in glass, hemp and sandwich fibre reinforced composites and the results revealed that delamination can be minimized at higher speed and lower feed rate. Tsao et al.[13] studied the correlation of drilling parameters with surface roughness and thrust force using candle stick drill. Experimental results found that evaluation of the roughness and thrust force can be calculated by RBFN more effectively. Design of Experiments and RSM method was used by Valarmathi et al.[14] to find the influence on process parameters on thrust force for PB composite panels. Results indicated that thrust force will be minimized when using drill bits with narrow point angle. The mechanical properties of jute and human hair hybrid composites with 25% fibre volume were investigated by S. Panneer Selvan et al.[15]. They have conducted mechanical properties test by varying the mixing ratio of jute and human hair within the 25% of fibre volume. Influence of process parameters in the delamination of drilled holes was analyzed by Taguchi's method and optimum cutting conditions were suggested. Pranav Kumar sarawati et al, [16] studied the mechanical properties of glass-sisal hybrid composites while adding fly-ask and graphene as fillers. They also checked the effect of drilling speed in circularity and delamination. Some researchers [17-19] identified that the type of drill bit had more impact on surface quality and delamination of drilled hole than the machining parameters. This indicates the importance of selecting the correct cutting tool and its nomenclatures.

## Experimental Work

### Composite Laminates Preparation

Fabrication of composites was done by hand lay-up and compression moulding methods. Both jute as well as human hair was used as reinforcement (20mm length). Epoxy resin (Araldite LY 556) and hardener (HY 951) were used as matrix material in 10:1 ratio. In jute and human hair hybrid composites[15] better tensile strength and flexural strength is experienced in 50:50 mixing ratio for a fibre volume of 25%. So, composite laminates were made in the combination of 25% fibre (12.5% jute and 12.5% human hair) and 75% epoxy in

volume fraction for the present work. Jute and human hair were cut into 20 mm length and mixed together properly in 50:50 ratio. Silicon rubber strips were used to make a mould for hand lay-up technique. After pouring the epoxy as first later of mould, mixture of jute-human hair fibre was spread over and the epoxy resin poured again as the top layer of mould. This mould was cured with a load of 50 Kg for duration of 24 hours. Later the laminate was removed from mould and cured in room temperature for another 24 hours.
Compression moulding process involves two steps namely preheating and pressurizing. The required quantities of resin and fibre are properly held in the mould available at the bottom half of the compression moulding machine. (Figure 1) Both sections of mould are brought together and kept at a pressure of 16 MPa for 6 hours at room temperature. After the pressure was released, the composite laminate was further cured for 24 hours at room temperature.

## Drilling of Composite Laminates

Drilling was carried out in the composite laminates using EV1020A vertical milling machine. (Figure 2)In this work, three different tools namely Straight Shank Twist Drill (SSTD), End Mill cutter with 4 Flutes (EM4F) and End Mill cutter with 2 Flutes (EM2F) made of High-Speed Steel with 5 mm diameter were used to study and analyse the delamination factor.
Taguchi's design of experiments method helps in organizing the parameters and levels of these parameters in order to reduce the variation in the process. This also helpful in reducing the number of experiments and results in reduced time and cost. Three factors (drilling speed, feed rate and types of tool) and three levels in each factor were considered for this work. The factors and its levels are given in Table 1.

Figure 1. Compression Moulding Machine

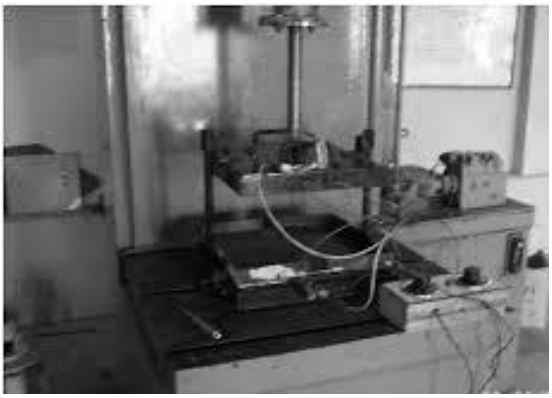
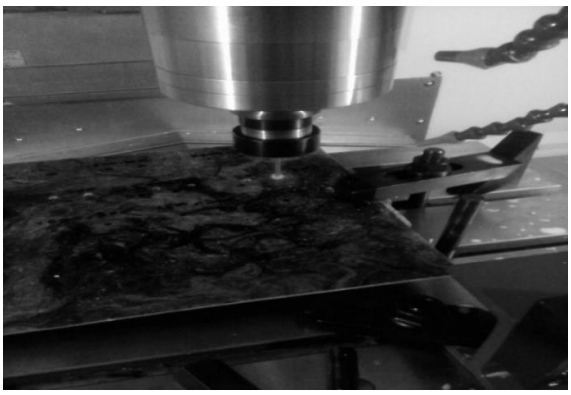


Figure 2. Drilling of Composite in Vertical Milling Machine



According to Taguchi's orthogonal array concept, $L_9$ array was selected for this work. The arrangement of three factors and its levels using $L_9$ orthogonal array is given in Table 2. Holes were drilled in 2 trials in both composite laminates for these 9 combinations.

Table 1. Various Drilling Parameters and its Levels

| **Parameter/ Level** | **Drilling speed** | **Feed rate** | **Type of tool** |
|---|---|---|---|
| Unit | rpm | mm/rev | - |
| 1 | 1000 | 0.1 | Straight Shank Twist Drill |
| 2 | 1500 | 0.2 | End Mill cutter with 4 Flutes |
| 3 | 2000 | 0.3 | End Mill cutter with2 Flutes |

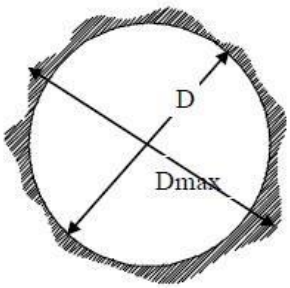
Table 2. Combination of Parameters and Levels

| **Experiment** | **Drilling speed** | **Feed rate** | **Type of tool** |
|---|---|---|---|
| 1 | 1 | 1 | 1 |
| 2 | 1 | 2 | 2 |
| 3 | 1 | 3 | 3 |
| 4 | 2 | 1 | 2 |
| 5 | 2 | 2 | 3 |
| 6 | 2 | 3 | 1 |
| 7 | 3 | 1 | 3 |
| 8 | 3 | 2 | 1 |
| 9 | 3 | 3 | 2 |

## Measurement and Calculation

Delamination (Figure 3) can be described as the separation of constituent materials on the entry and exit side of holes which will create serious problems in the fibre reinforced composites.[6] The deformations on the entry and exit side of drilled holes can be categorized as peel-up and push-down delamination. Calculation of delamination factor[15] was done by the formula given in equation 1.

Figure 3. Delamination




$F_d = D_{max} / D$ (1)

Where $F_d$= Delamination factor

$D_{max}$ = Actual diameter

D = Expected diameter

Figure 4. Original Image of a Drilled Hole

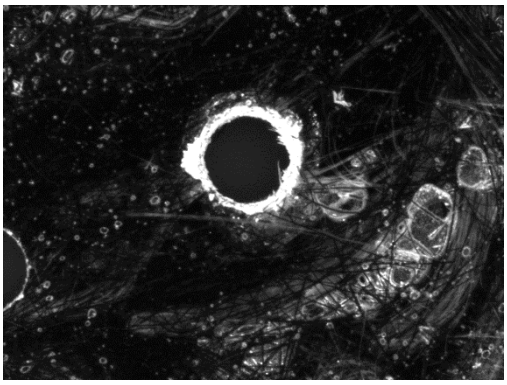


Figure 5. Threshold Image of a Drilled Hole

The drilled hole's images were taken using Soliton IEEE camera and HD Vision software was used for further analysis. Using this software, the image was being threshold and the maximum diameter of the deformation ($D_{max}$) was calculated by counting the number of pixels that covers the maximum deformation. Dimension of a single pixel was calibrated initially and this dimension was multiplied with number pixels counted. Figure 4 shows the original image taken by vision camera for a drilled hole and the threshold image of the same is shown in Figure 5. Calculated values of peel-up and push-down delamination, for hand lay-up and compression moulding are given in Table 3.

Table 3. Delamination Factors

| Experiment | Hand Lay-up | | Compression Moulding | |
|---|---|---|---|---|
| | Peel-up | Push-down | Peel-up | Push-down |
| 1 | 1.2175 | 1.396 | 1.055 | 1.0495 |
| 2 | 1.2374 | 1.4589 | 1.079 | 1.055 |
| 3 | 1.269 | 1.5447 | 1.238 | 1.2228 |
| 4 | 1.1744 | 1.3822 | 1.0286 | 1.041 |
| 5 | 1.24 | 1.406 | 1.056 | 1.0537 |
| 6 | 1.2427 | 1.5112 | 1.047 | 1.163 |
| 7 | 1.064 | 1.3443 | 1.0252 | 1.0246 |
| 8 | 1.2335 | 1.41 | 1.03841 | 1.052 |
| 9 | 1.23753 | 1.4594 | 1.0456 | 1.0844 |

## Results and Discussion

### Analysis of Delamination in Hand Lay-up Laminate

The effect of various drilling parameters on the peel-up and push-down delamination was studied using the graphs drawn between the delamination factor with drilling speed and feed rate. Variation of delamination factor at the entry and exit side (peel-up and push-down) of hole in hand lay-up laminates with respect to the drilling speed given in Figure 6 & Figure 7. Graphs were plotted for various feed rates.

Variation in delamination factor with respect to feed rate for both entry and exit side of hole for the hand lay-up laminates using three different types of tools is given in Figure 8 & 9. It is observed that delamination factor is reduces with respect to increase in drilling speed, for various values of feed rates. When the feed rate increases delamination factor is also increased for various type of tools. All the graphs are indicating that delamination reduced for higher speed and lower feed rate.

Figure 6. Peel-up Delamination with Drilling Speed

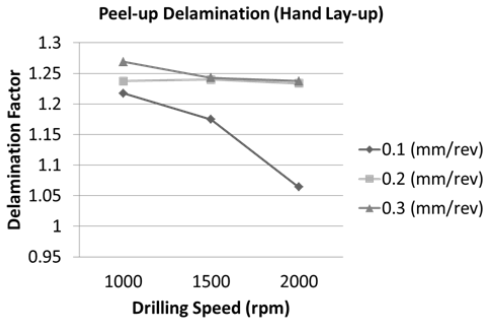



Figure 7. Push-dowm Delamination with Drilling Speed

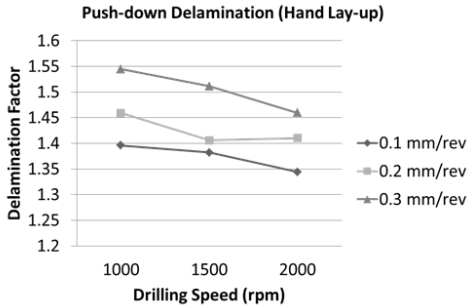



Figure 8. Peel-up Delamination with Feed Rate

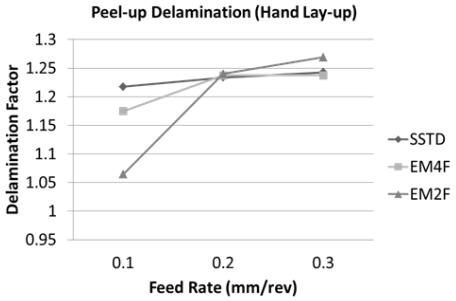
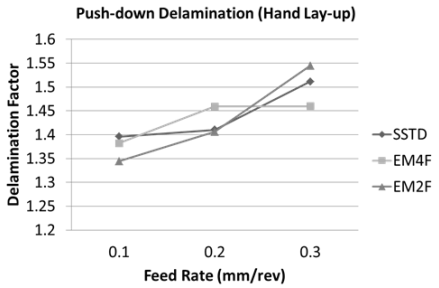



Figure 9. Push-down Delamination with Feed Rate




## Analysis of Delamination in Compression Moulded Laminate

Compression moulded composite laminates were also drilled with the combinations of drilling parameters discussed in Table 2. Figure 10 & Figure 11 shows the variation in the deamination factor with respect to drilling speed for compression moulded laminates.

Figure 10. Peel-up Delamination with Drilling Speed

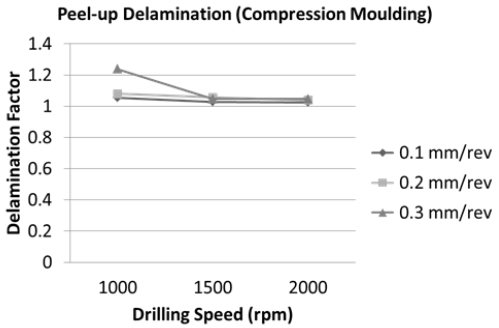



Figure 11. Push-dowm Delamination with Drilling speed

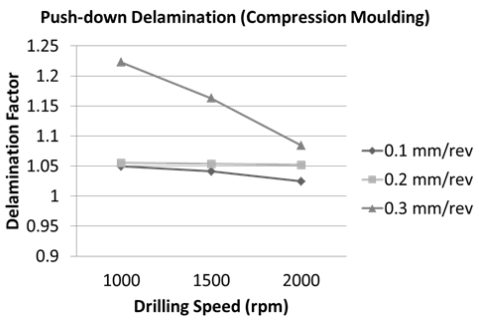



Figure 12 & Figure 13 indicates how delamination factor varies with respect to feed rate for both entry and exit side of the compression moulded composite laminates.

When analysing the Figure 10 and Figure 11, delamination factor is considerably reduced with increase in the drilling speed. This is applicable for various values of feed rates. Figure 12 and 13 indicate that the delamination factor is increases with increase in the feed rate for various types of tools. For the composite laminate fabricated in compression moulding process, lesser delamination factor is experienced for higher speed and lower feed rate. This is because of improved mechanical bonding and strength in the composites made by compression moulding. In both composite laminates, end mill cutter with 2 flutes gives reduced delamination in most of the cases. It is evident that the push-down delamination is greater than the peel-up delamination in most of the cases.

Figure 12. Peel-up Delamination with Feed Rate

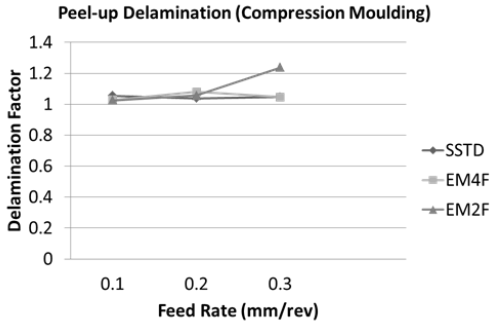
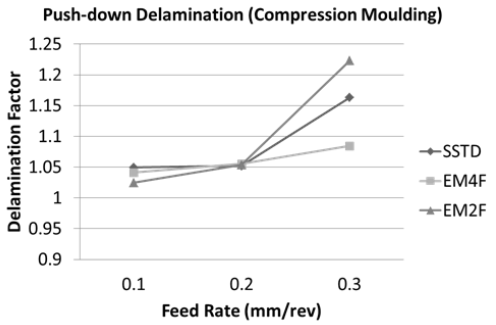



Figure 13. Push-down Delamination with Feed Rate




## Conclusion

Jute-Human hair hybrid composite laminates were fabricated in hand lay-up and compression moulding techniques. Drilling operation was done in both composites with three different parameters. The following points were revealed from the experimental work results.

- Delamination is being reduced when increase in the drilling speed.
- While increasing the feed rate, delamination is also increasing.
- Compared to conventional 2 flute drill bit and End milling cutter with 4 flutes, reduced delamination is experienced in End mil cutter with 2 flutes.
- Delamination of the exit side of hole is slightly more that the entry side for both types of laminates.
- Delamination on both entry and exit sides are considerably reduced in compression moulded composite compared to hand lay-up composite plate.

Image processing method is found to be very effective in the measurement of drilled holes and results in accurate calculation of delamination.

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