INTERNATIONAL JOURNAL OF AUTOMOTIVE AND MECHANICAL ENGINEERING (IJAME)
ISSN: 2229-8649 e-ISSN: 2180-1606
VOL. 17, ISSUE 1, 7618 – 7628
DOI: https://doi.org/10.15282/ijame.17.1.2020.11.0566

ORIGINAL ARTICLE

Experimental Study and Investigation of Thrust Force and Delamination Damage of Drilled Ramie Woven Reinforced Composites

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ABSTRACT – One of the machining failures in composite materials is delamination damage. In this paper, machining parameters and delamination damage caused by the drilling process on ramie woven reinforced composite material with an unsaturated polyester matrix were investigated. The ramie woven used is ramie yarn type 12S/3. The machining process used 1.5 kW pillar drills, with variations in the diameter of the brad and spur drill of 4 mm, 6 mm, 8 mm and 10 mm. This work focused on the influence of machining parameters like feeds rate and spindle speed. Holes quality was analysed in terms of thrust force and delamination failure. From the results of this study, the thrust force value obtained at the time of drilling is very closely related to the delamination damage that happens. Delamination damage occurs on both sides of the holes drill.

ARTICLE HISTORY
Revised: 20th Nov 2019
Accepted: 10th Dec 2019

KEYWORDS
Delamination;
Thrust force;
Ramie woven

INTRODUCTION

Machining of laminated composite materials is still a complicated process for various reasons, such as high specific stiffness, fragility, anisotropic, non-homogeneous, and low thermal conductivity. This condition have an impact on the quality of machining, which gains on tears, defects, low surface quality, and high wear of the chiseled surface. To acquire excellent quality machining, need accurate and precise predictions to determining parameters such as cutting force, cutting speed, and feed rate. Incorrect in determining parameters, tool geometry, and the material increases the rejection rate. The rejection rate for machining laminated composites, especially in the drilling process, reaches up to 60%. Most of the damage is in form of delamination, concentration of stresses, and poor quality of the borehole affects the increase in production costs, [1].

Many previous studies have been conducted to analyse and study the effect of machining on composite materials. According to Quadros et al. [2], statistical analysis shows that the feed rate gives a significant influence on the thrust force and torque behaviour than cutting speed. The widest delamination occurs at a higher feed rate due to the increased thrust force [3]. In research on drilling of thermoplastic composite materials, Srinivasan et al. [4] indicate increased feed rate and drill bits diameter increased thrust force while spindle speed gradually reduced the thrust force. Kavad et al. [5], have concluded that in conventional machining, delamination damage is greatly influenced by feed rate, material tools, and cutting speed. In investigations on CFRP drilling, the change in diameter does not contribute significantly to the increase in thrust force when compared to the feed rate and spindle speed, [6]. In a study of investigating tools geometry, Feito et al. [7] reported that between the stepped drill and twist drill indicated fewer thrust force values and delamination factor, especially at low feed rates. Abrao et al. [8] have previously examined the effect of drill bit geometry on thrust force and holes damage. Abrao et al. recommends “brad & spur” drill bits because it produces the lowest thrust force, although in the study it was said that thrust force and delamination were not directly proportional.

Melentiev et al. [9] has investigated the effect of machining parameters and concluded that increasing both feed rate and cutting speed has consequences in improved thrust force and delamination failure. The feed rate was mentioned to have the most substantial impact on delamination. Therefore it is recommended to use machining parameters with lower values. Velaga and Cadambi [10] studied experimentally and simulated variations of machining parameters such as spindle speed and feed rate to obtain optimal process parameters. The results show that both the experiment and the simulation correspond to each other. In another study, Eneyew and Ramulu [11] examined the effect of machining parameters on the drilled hole surface quality in a composite laminate. The result obtained that the thrust force is more influenced by the feed rate than the cutting speed. Bonnet et al. [12] reported, the correlation between fiber orientation and holes quality in the inner wall of the hole cannot be denied.

Research on machining behaviour in composite materials is more emphasised in composites reinforced by synthetic fibers, mainly glass fibers (GFRP). Meanwhile, research on machining behaviour in natural fiber reinforced polymer composites (NFRP) is rarely studied. On the other hand, the development of the use of this material is increasing. Goda et al. [13] have reported that glass fiber reinforced plastic materials have advantages in thermal and mechanical properties, but have deficiencies in the disposal and decomposition processes. This problem is becoming serious with world environmental issues related to the recycling process. There are several reasons why people turn to natural fibers, among others, due has the advantages of a lightweight, durable, biodegradable, renewable, and abundant presence. In the last

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few decades, the use of natural fibers like ramie [14], hemp [15], jute [16], sisal [17], kenaf [18], banana [19], gnetum [20], coir [21] fibers and others has been developed as a composite reinforcement in lieu of synthetic fibers.

The use of natural fibers as a material of automotive interior panels has been developed since the 1940s until now, [20]. Chandrabakty et al. [20] have carried out research using composite materials reinforced with gnetum bast fibers as vehicle door panel materials. These fibers have a continuous fiber structure and strength natural woven and can reduce weight from 10% to 30% (which is the main thing in automotive design). Bakri et al. [21], reported that coir reinforced polymer composites are potential using as an alternative material for making windmill blades. Natural fibers have different properties and characteristics from synthetic fibers, thus requiring different machining parameters. Therefore this study aims to investigate the machining behaviour on ramie woven reinforced composites to obtain optimal process parameters.

MATERIALS AND METHOD

Materials

Ramie woven reinforced unsaturated polyester laminates were used as workpiece materials. Hand lay-up technique is carried out to produce laminates with a volume fraction of 19%, were to produce a thickness of laminates 5.0 ± 0.2 mm, we apply six alternating layers. Ramie woven (density 1.52 gr/cm^3) is formed by ramie yarn type 12S/3 which is spinning by a loom machine (Figure 1), and the unsaturated polyester resin is YUKALAC @157 BQTN-EX (density 1.215 gr/cm^3) product of PT. Justus Kimiaraya.

Figure 1. Ramie plain weave fabric model with 12S/3 yarn type.

Drilling Operation

Drilling process executes by pillar drill TCA-35 ERLO on a 1,5 kW power and maximum 1420 rotational speed machine center. Brad and spur drill is the tools materials and geometries chosen in this experimental work with varied diameter of 4 mm, 6 mm, 8 mm, and 10 mm, as shown in Figure 2. This tool drill type widely used in drilling wood material. The advantage of this tool is that they have a brad point end that functions to match the drilling position and "spurs" that function to produce the surface of a clean and smooth hole, as shown in Figure 3(a). The parameters and their ranges used for the experimentation are given in Table 1.

The thrust force that occurs due to the drilling process is measured using a dynamometer sensor equipped with a 20 kg maximum pressure load cell and placed under the specimen that connected to acquisition data, after which to the computer. Then the MakerPlot software was engaged in reading the thrust force data, the experimental set-up, as shown in Figure 4. To analyse delamination failure around the inlet and exit sides of the borehole, firstly, the hole recorded take by the scanner with resolution 2400 DPI, then evaluated using Image-pro plus v4.5 application.

Figure 2. “Brad & spur” drill diameter 4, 6, 8 and 10 mm.

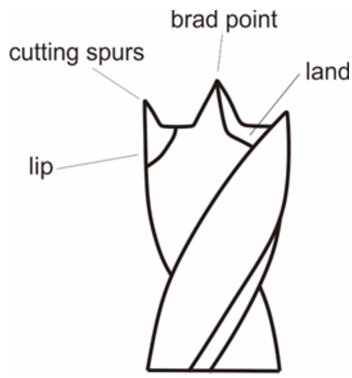


Figure 3. Brad and spur drill's detail.

Table 1. Design of experiments.

Parameter	Range			
Tools diameter (mm)	4	6	8	10
Feed rate (mm/rev)	0.1	0.18	0.24	
Spindle speed (rpm)	93	443	1420	

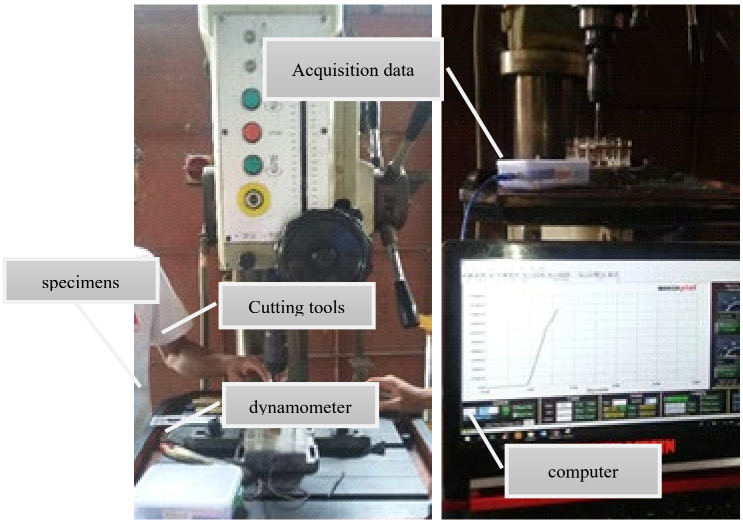


Figure 4. Experimental set-up.

Delamination Factor (F_d)

Delamination around the drilling hole impacts reduced the strength of the structure, poor assembly quality, and reducing the life span of the laminated composite. Delamination due to the drilling process occurs on both sides of the drill hole [22]. The rate of delamination can be determined using an index or a factor namely the delamination factor (F_d). The delamination factor (F_d) can be solved using the following equation, [23] :

$$F_d = \frac{D_{max}}{D} \tag{1}$$

where D_{max} is the maximum diameter formed by delamination around the hole, while D is the diameter of the borehole. The definition of delamination measurement is illustrated in Figure 5. Delamination damage appears on both sides of the borehole, i.e., the inlets and exits. As was mentioned by Khasabah et al. [24] that the occurrence of delamination is caused by a peel-up mechanism on the entry side and a push-out on the exit side of the drill tool.

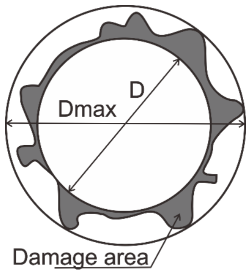


Figure 5. Delamination measurement method [25].

RESULT AND DISCUSSION

Thrust force

Figure 6 to Figure 9 show the complete drilling cycle on composite material reinforced by ramie woven with variations in tool diameter 4, 6, 8, and 10 mm. The drilling process consists of four stages, as illustrated in Figure 6(a). Phase I begins when the drill tip has been touched the surface of the workpiece until the "spur" cutting edges penetrate the top layer of the specimen. Phase II is the process when the drill bit penetrates the matrices until it touches the ramie's woven plies. At this stage, the thrust force tends to be flat. Phase III is when the brad-point tip pierces the ramie woven layer, and at the same time, the spur cutting edges cut the ramie woven layer to ensure the desired holes diameter. The thrust force moves to its peak at this stage. Phase IV occurs when the drill bit has penetrated the last layer of the workpiece until the reaming process it happens, the thrust force will decrease drastically to zero. In some operations, small peaks appear caused by thrust force when the "spurs" edges were cutting and penetrate the last matrices ply to ensure holes drilling.

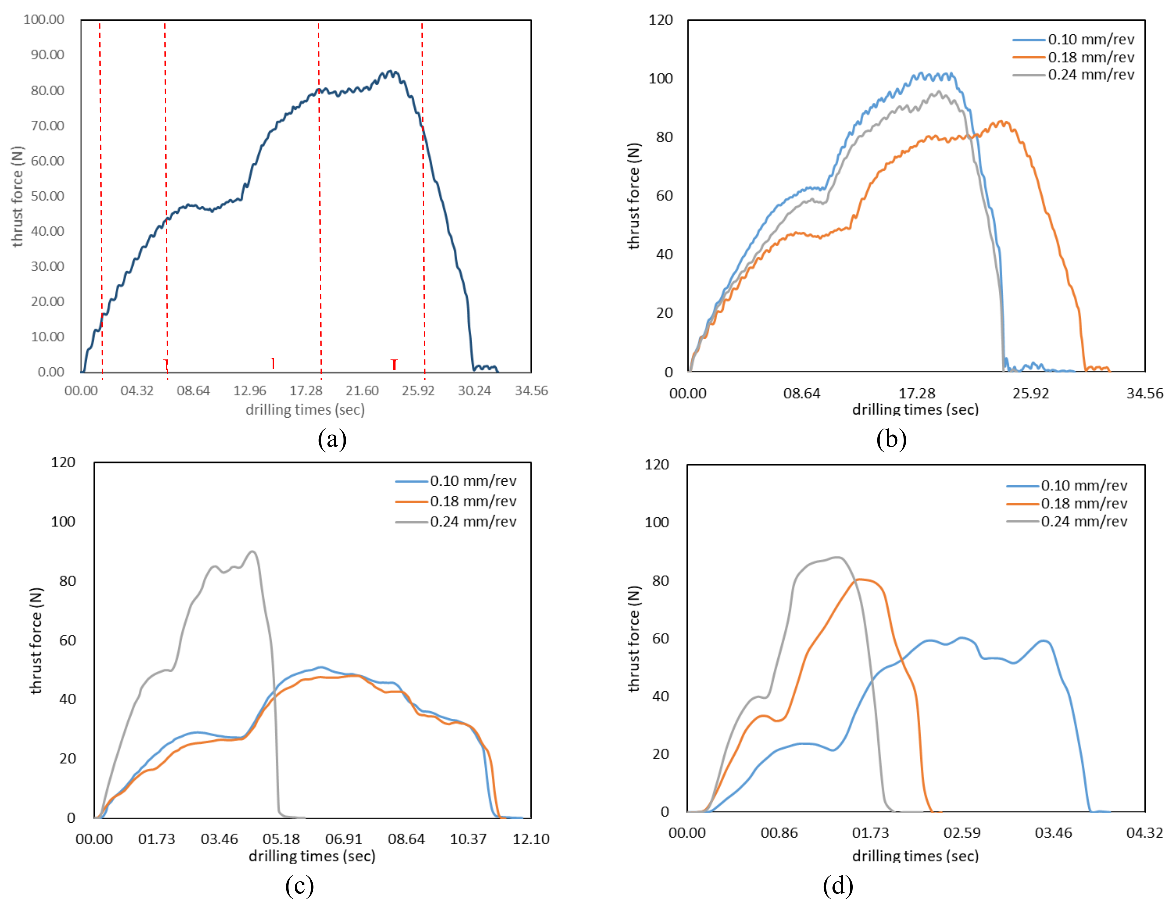


Figure 6. Thrust force over drilling cycle of tools diameter 4 mm for (a) a single drilling operation, at spindle speed of (b) 93 rpm, (c) 443 rpm and (d) 1420 rpm.

The thrust force value is significantly related to the length of the drilling time. Where the feed rate and spindle speed more influence drilling time. The more feed rate and spindle speed increases, the faster the drilling time is used, while the increase in tool diameter does not have much effect on the time of drilling. The longer the drilling time is used, the lower the thrust force. This phenomenon occurs because there is a "time" for the spurs to cut the fibers in each ply. It is thereby reducing the pressure, which can increase the load and cutting force.

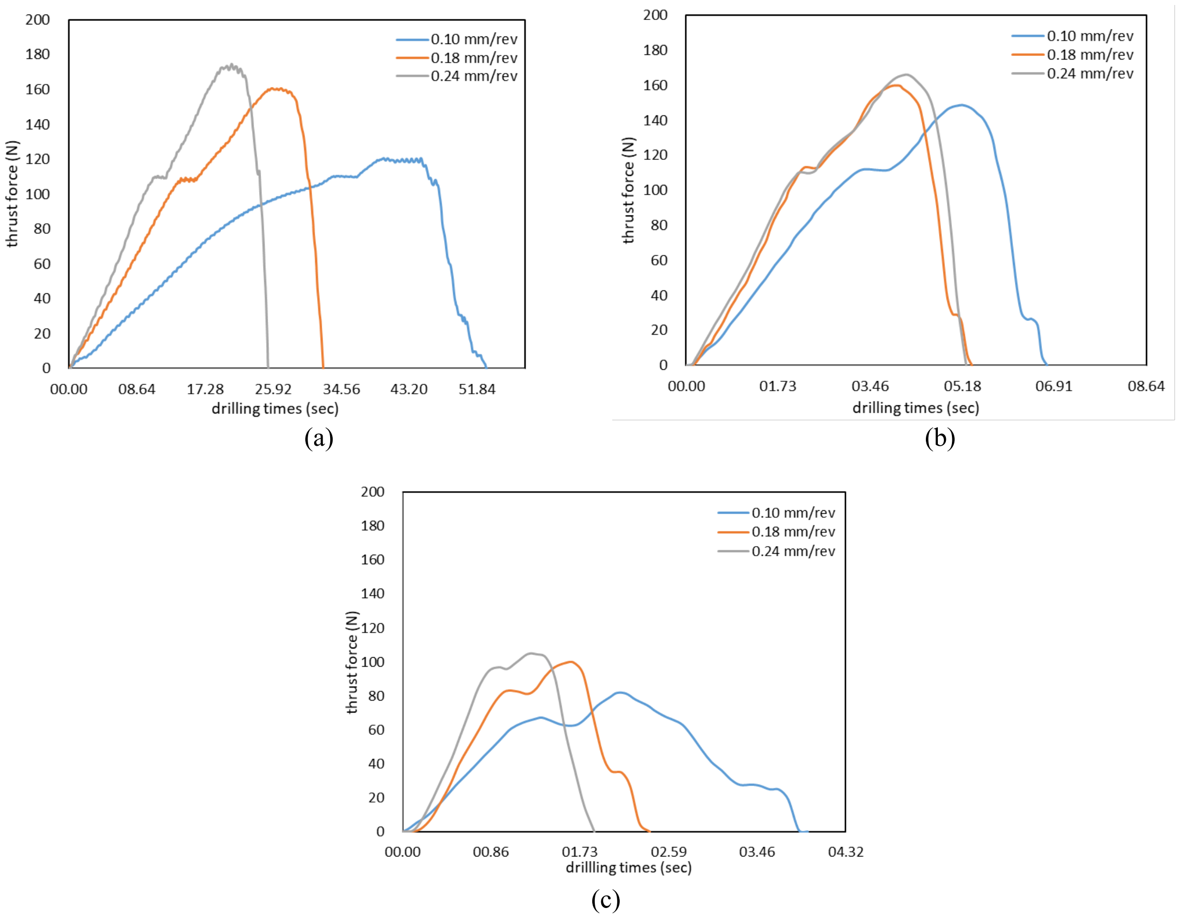
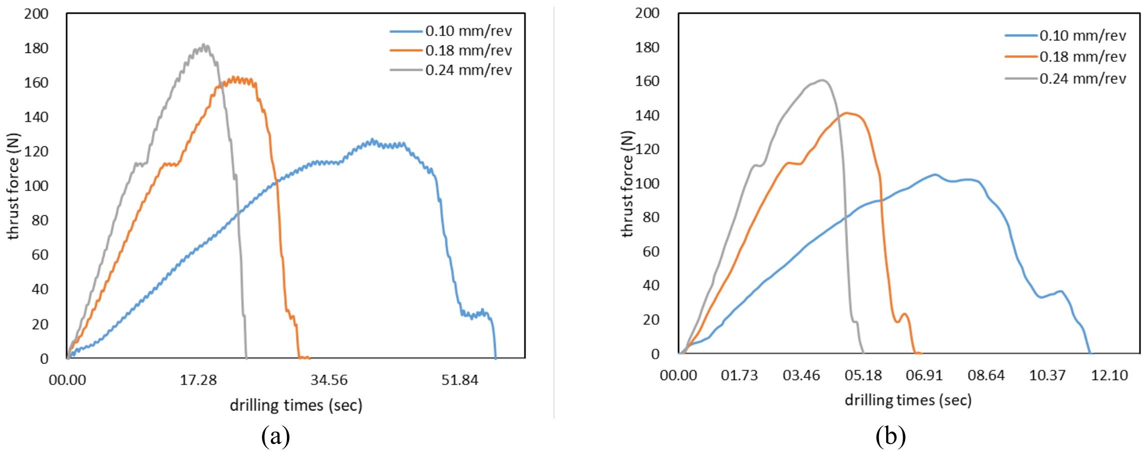
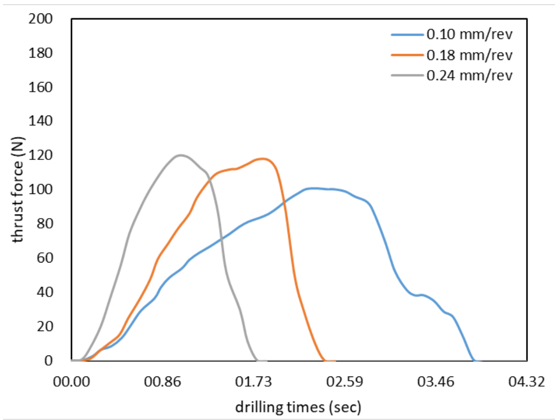


Figure 7. Thrust force over drilling cycle of tools diameter 6 mm at spindle speed of (a) 93 rpm, (b) 443 rpm and (c) 1420 rpm.

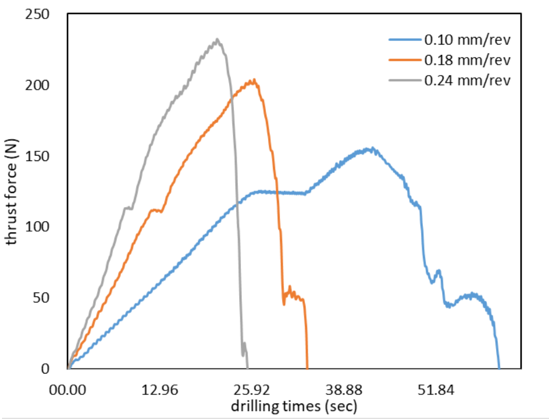
Figure 10 shows the relationship between the thrust force and feed rate, where the increasing thrust force is obtained as the feed rate increases. This tendency is appearing in all variations in tool diameter used. However, with the different results when viewed from the effect of spindle speed, there is a decrease in thrust force during the increase in spindle speed. The impact of high spindle speed plays a role in facilitating the drill bit to cut the matrices and the layer of ramie's woven perfectly. High spindle speed makes cutting force lower by reducing the occurrence of splintering, and the cutting process becomes smooth.



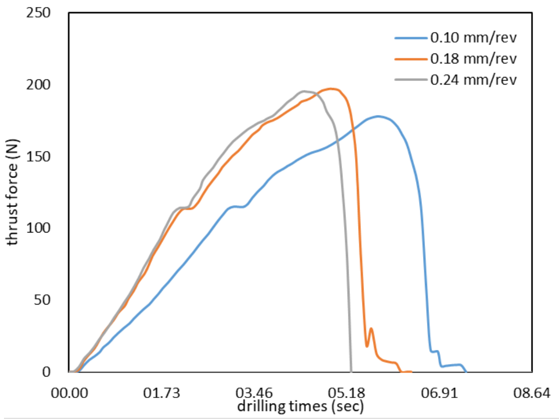


(c)

Figure 8. Thrust force over drilling cycle of tools diameter 8 mm at spindle speed of (a) 93 rpm, (b) 443 rpm and (c) 1420 rpm.



(a)



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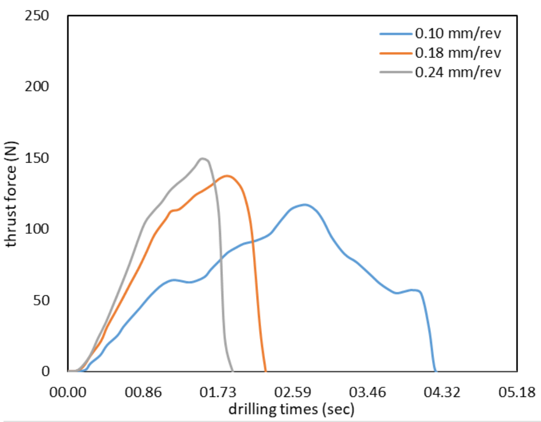
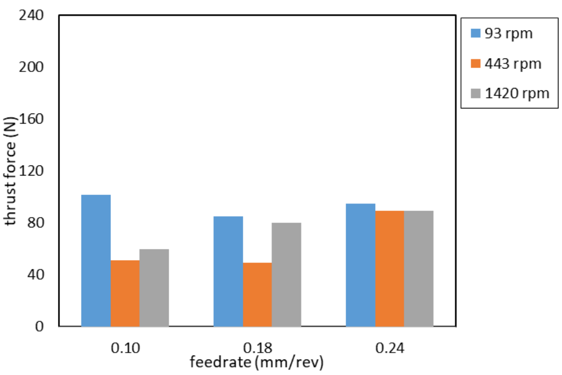
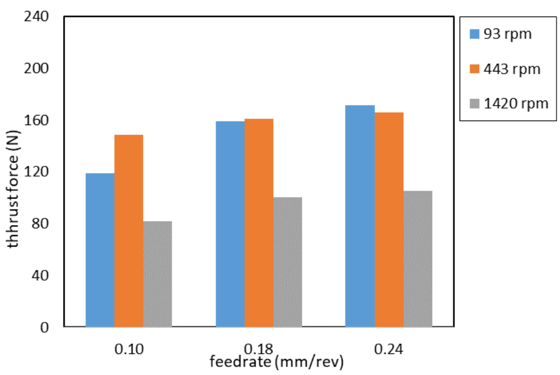


(c)

Figure 9. Thrust force over drilling cycle of tools diameter 10 mm at spindle speed of (a) 93 rpm, (b) 443 rpm and (c) 1420 rpm.



(a)



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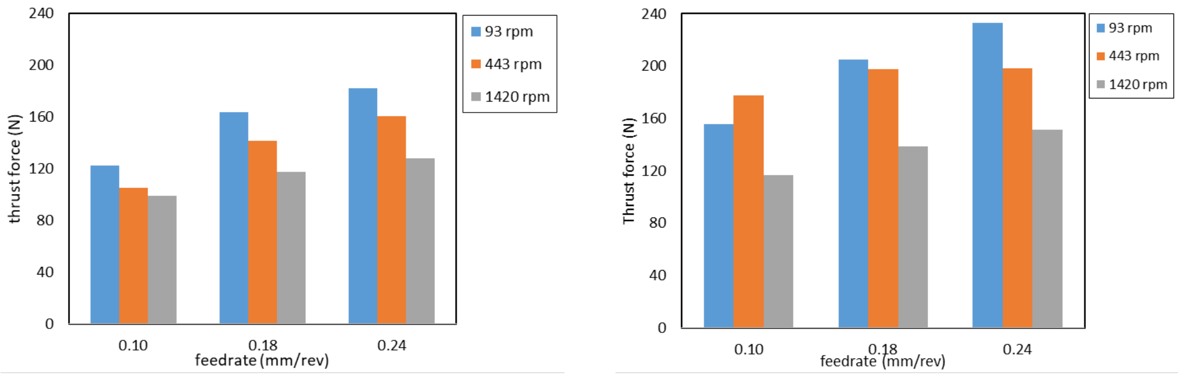
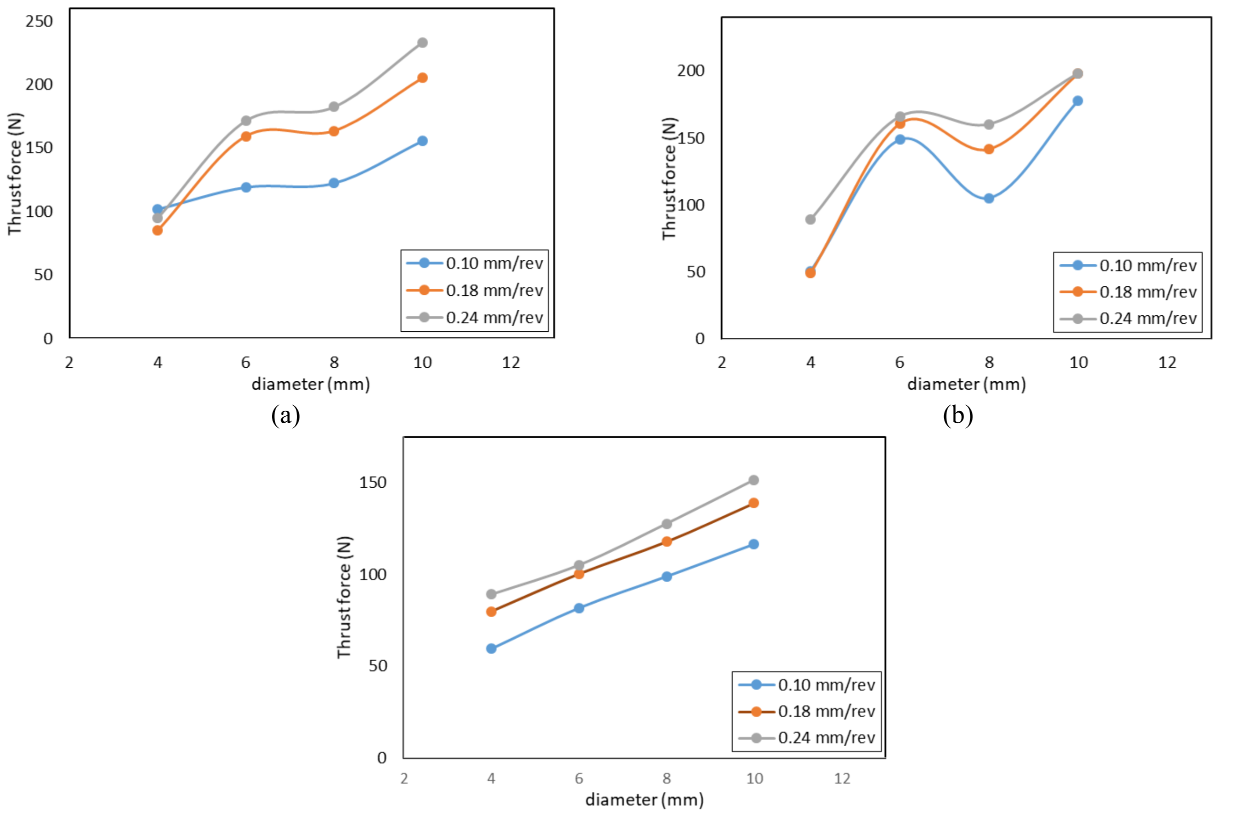


(c) (d)

Figure 10. Correlation between thrust force and feed rate at the tool's diameter of (a) 4 mm, (b) 6 mm, (c) 8 mm and (d) 10 mm.

Whereas, when examined from the diameter of the drill bit, obtained the lowest thrust force at a smaller diameter, wherein the 4 mm diameter, produces thrust force below 100 N. Then it will increase with increasing tool diameter, as shown in Figure 11. The low thrust force obtained at smaller diameters is likely due to the tool surface area in contact with smaller specimens, causing lower heat dissipation during the drilling process. In line with Shetty et al. [26], said the thrust force could produce higher hardness, wear resistance, thermal conductivity, and high levels of heat dissipation from the drill bit. Because of these factors, the heat generated by the contact between the drills tip and the materials becomes reduced and produces smaller friction. In a previous study, Srinivasan et al.[4], argue that the smallest thrust force is obtained at high spindle speeds, small drill bit diameters, and low feed rates. Furthermore, it is said that the size of the hole is the cause of the development of the thrust force, the larger the hole, the more thrust forces occur.



(a) (b)

(c)

Figure 11. Correlation between thrust force and tools diameter on the spindle speed of (a) 93 rpm, (b) 443 rpm and (c) 1420 rpm.

Delamination Factor

In this study, we also observed the factors of damage arising from changes in feed rate and spindle speed. Photographs of the drilling results are described and analysed in Figure 12. Two drilling sides observed were the entry and exit side of the borehole. From Figure 13 and Figure 14, we note the evolution of delamination factors on both sides. At 4 mm diameter, the delamination factor on the entry side does not show a significant change due to the feed rate and the spindle speed. On the contrary, on the exit side, there is a tendency enhancement of the delamination factor along with an increasing feed rate. From the tool diameter of 6 mm, the entry side shows a definite increase due to the increase in feed rate and spindle speed. A similar trend also occurs on the exit side even though the difference is not as sharp as the entry side. Delamination factors that arise in 8 mm diameter tools have the same trend on both sides. Feed rate and spindle speed play an essential role in increasing delamination damage in the ramie's woven composite drilled. Likewise, at 10 mm tool diameter, noted that the delamination factor seen to grow with increasing feed rate and spindle speed. The increasing trend is observed on both sides.

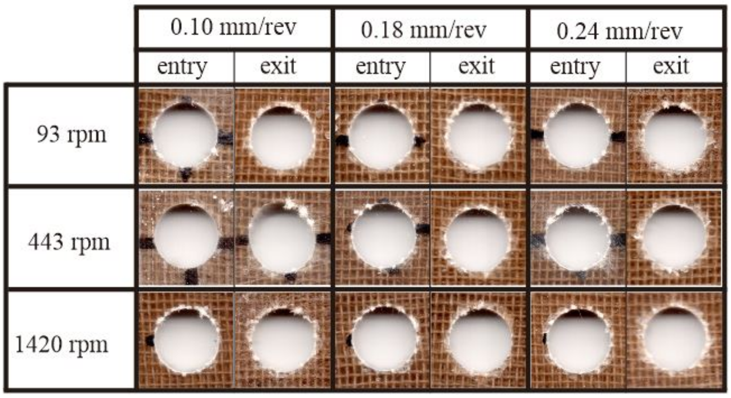


Figure 12. Photographs illustration the delamination in drilled ramie woven composites.

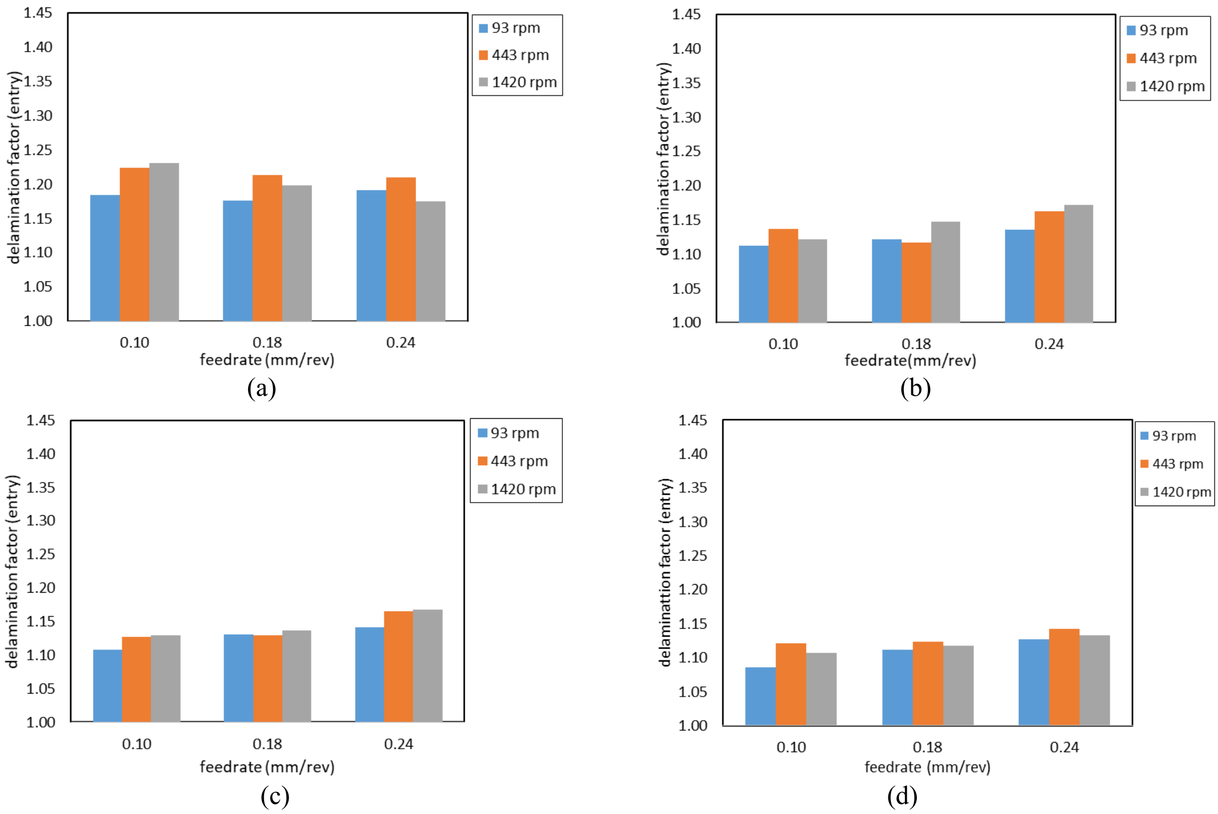
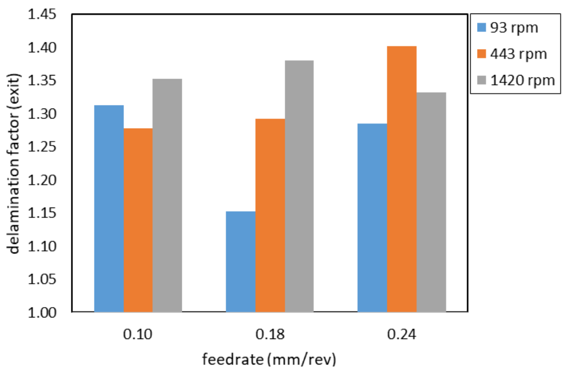
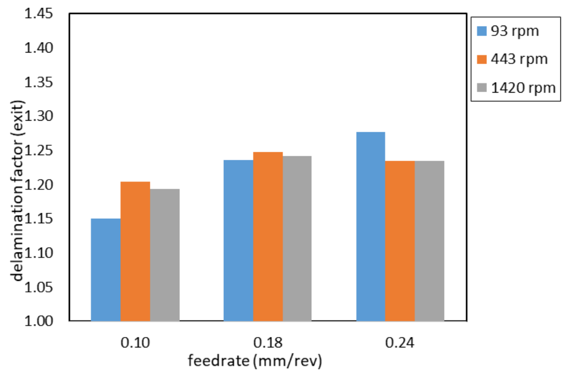


Figure 13. Effect of spindle speed concerning feed rate on delamination factor at the entry side, with the tool's diameter of (a) 4 mm, (b) 6 mm, (c) 8 mm and (d) 10 mm.

When reviewed from changes in diameter, Figure 15 to Figure 17 shows that the increasing tool's diameter tends to decrease the delamination factor in the machining process for ramie's woven composites. The same trend can be seen in delamination in the entry side and exit side specimens. This outcome is contradictory to previous research, which has argued that the increase of drill bit diameter increases the delamination factor in the drilling of the sandwich's composites, [27]. This dissimilarity can be caused by differences in specimen material and tool geometry used. As mentioned by Melentiev et al. [9], brad and spur drills can reduce delamination factor when compared to twist drill.



(a)



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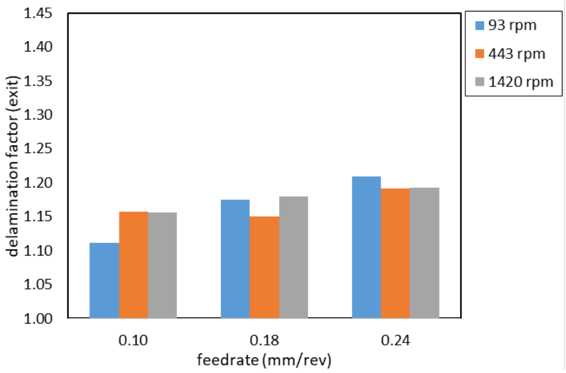

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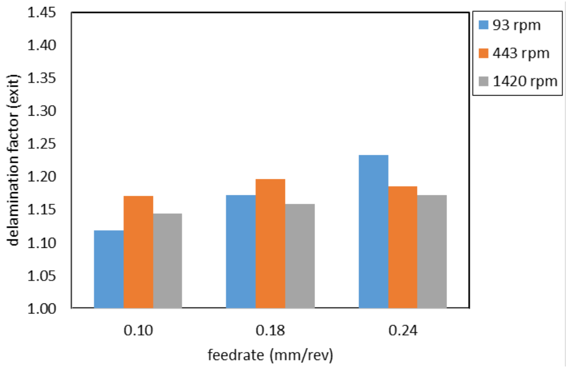
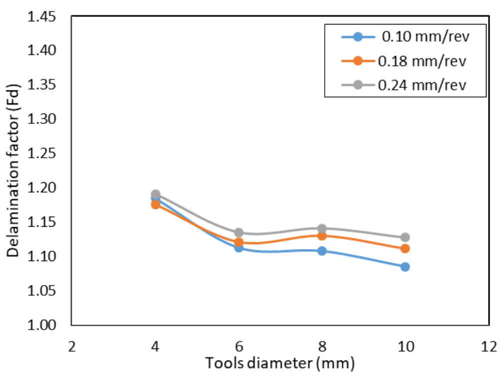
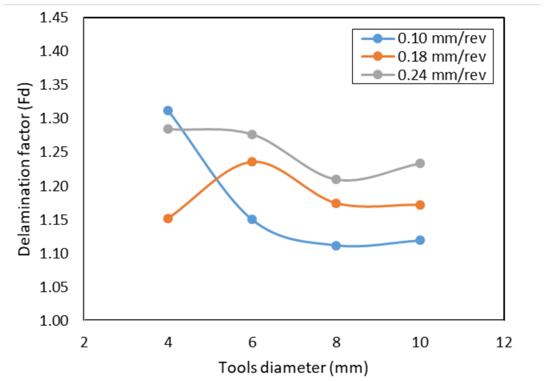


(d)

Figure 14. Effect of spindle speed concerning feed rate on delamination factor at the exit side, with the tool's diameter: a) 4 mm; b) 6 mm; c) 8 mm and d) 10 mm

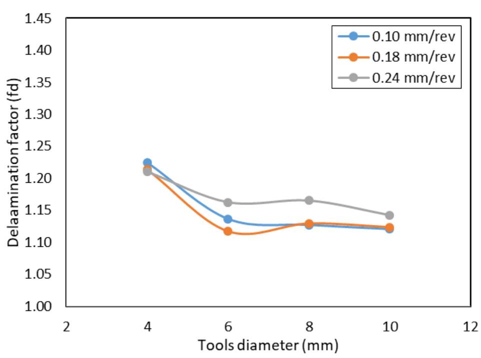


(a) entry side

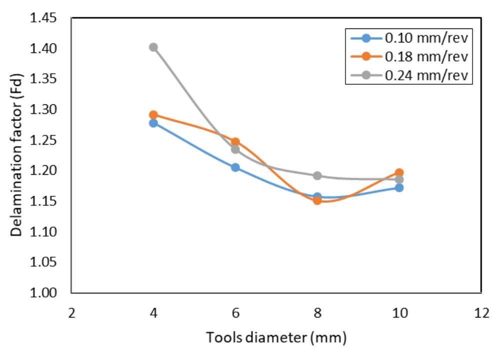


(b) exit side

Figure 15. Correlation between delamination factor and tool's diameter at spindle speed of 93 rpm.

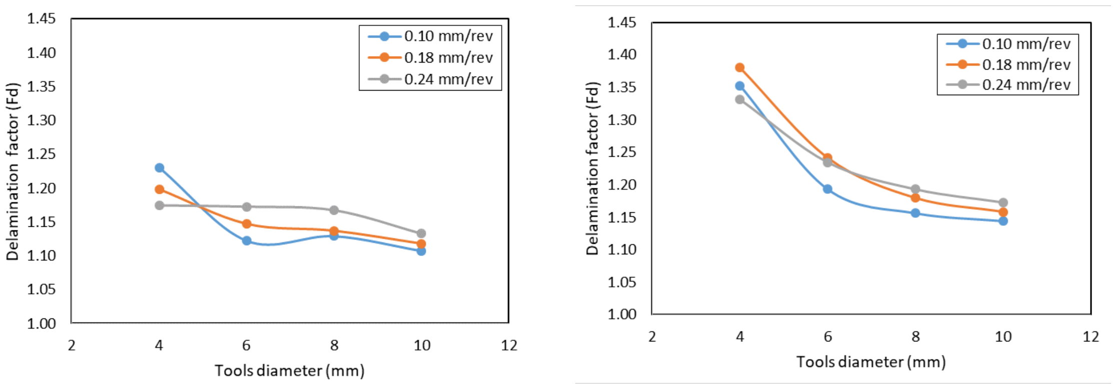


(a) entry side



(b) exit side

Figure 16. Correlation between delamination factor and tool's diameter at spindle speed of 443 rpm.



(a) entry side (b) exit side

Figure 17. Correlation between delamination factor and tool's diameter at spindle speed of 1420 rpm.

CONCLUSION

The effect of machining parameters on four different diameters of drill bits has been analysed in this study. Composite reinforced by ramie woven with an unsaturated polyester matrix was chosen as the workpiece in this study, and the brad and spur drill type was used as cutting tool. There are several interrelated factors, such as drilling times, thrust force, and delamination damage that affect the surface quality of borehole. Based on the experimental results, some conclusion can be drawn in the following paragraph.

Drilling times affect increasing thrust force while the drilling time is affected by the feed rate and spindle speed. The higher the feed rate, the faster the drilling time occurs. When viewed from the tool's diameter, it can be seen that the tool's diameter increases significantly, followed by the increase in thrust force. When analysed in terms of delamination damage, there was an increase in delamination factor along with an increase in feed rate and increased spindle speed; which can be found on both sides. While the changes in the tool's diameter, it is precisely seen that there is a decrease in the delamination factor as the tool's diameter increases. The same thing happens on both sides of the hole. Moreover, when compared between the entry side and exit drill holes, more significant delamination damage was found on the exit side.

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