


Experimental Investigation on the Drilling Characteristics of Kenaf/PLA-Based Laminates [†]

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[†] Presented at the International Conference on Processing and Performance of Materials, Chennai, India, 2–3 March 2023.

Abstract: Natural fiber composites are gaining popularity in manufacturing due to their cost-effectiveness, sustainability, reusability, and eco-friendly nature. Kenaf fiber is increasingly used as a reinforcing component in organic fiber-strengthened polymers for engineering purposes. Drilling is a crucial machining process used to create holes in composite constructions for the easier assembly of complex parts. Limited research has focused on drilling organic fiber-strengthened materials, as indicated by literature surveys. Consequently, this study investigates the drilling of weaved kenaf fiber-augmented polymeric composites. The study assesses the impact of drill bit varieties and cutting settings on delamination size and thrust force in poly (lactic acid) (PLA) composites supplemented with kenaf fibers. The investigation revealed that drill bit selection significantly influences surface finish and delamination index. Feed is the cutting variable that, when drilling kenaf fiber-reinforced materials, has the most impact on the thrust force for every drill bit. When using an HSS twisting drill with the Coro Drill-856 (CD-856), the thrust force produced is less than when using the Coro Drill (CD-854) design.

Keywords: kenaf fiber; PLA; sustainability; thrust force; drill bits; sliding speed; feed rate



Citation: Masannan, V.; Anbalagan, C.; Lakshmaiya, N.; Kumar, P. Experimental Investigation on the Drilling Characteristics of Kenaf/PLA-Based Laminates. *Eng. Proc.* **2024**, *61*, 9. <https://doi.org/10.3390/engproc2024061009>

Academic Editors: K. Babu, Anirudh Venkatraman Krishnan, K. Jayakumar and M. Dhananchezian

Published: 26 January 2024



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1. Introduction

Due to their excellent mechanical characteristics, synthetic fiber-strengthened polymeric materials, including fiberglass-strengthened plastic (GFRP) and carbon-fiber-strengthened polymers (CFRPs), have gained popularity in various engineering applications. However, these materials can result in serious ecological issues as they are not sustainable, biodegradable, or environmentally friendly. In contrast, fibers made from natural sources are increasingly popular in composites due to their low cost, light weight, eco-friendliness, non-abrasive nature, and versatility in substituting for synthetic fibers across different industries [1]. These natural fiber composites (NFCs) are utilized in diverse technical fields like construction, sports products, vehicle parts, and non-structural aerospace components due to their strength and lightweight properties. The production of complex composite structures involves the mechanical attachment of multiple parts, and even if composites are created in near-net shapes, hole creation is essential for joining processes [2,3]. While various methods exist for creating holes, conventional drilling is frequently employed in laminated composites. The drilling technique for fiber-reinforced polymeric composites differs significantly from that of metallic composites due to the multi-step production process involved [4].

Delamination is identified as a significant flaw resulting from the drilling process, posing a risk to the stability and solidity of the manufactured component over time. Common delamination issues include peel-up or push-out delamination occurring at the entry

or exit of drilled constructions. As observed in experimental results, push-out delamination is deeper than peel-up delamination [5]. Researchers [6,7] have established several delamination variables to measure and compare delamination in composites. Thrust force during drilling appears to be the primary cause of delamination, which can be mitigated by carefully selecting cutting variables, such as feeding and cutting rate. The study's findings emphasize the importance of drill bit selection in determining the drilling ability of composite laminates. [8,9] Furthermore, the drilling exterior of fiber-reinforced polymers (FRPs) is often coarser than metal due to variations in fibers and polymers. The surface state of a drilled hole is influenced by cutting factors, such as the material being drilled, feed, spinning velocity, and drill bit. While ample information is available about polymers supplemented with synthetic fibers during drilling, our understanding of the drilling behavior of natural fiber composites (NFCs) is still in its early stages [10].

Jayapal and Natarajan [11] investigated how the tool's dimensions, feed rate, and spindle rotation speed affected the drilling of coir polyester composites. By employing an 8 mm drill bit, a spindle velocity of 600 r/min, and a feeding velocity of 0.3 mm/rev, they identified the minimum values of thrusting force, acceleration, and tool wear in drill evaluations. In contrast to drilling with CFRPs and GFRPs, the smallest cutting pressure was achieved using the lowest velocity and highest feed rate. Velmurugan et al. [12] examined how various drill bits with different cutting settings influenced the drilled performance of polymers supplemented with woven kenaf cloth and polyethylene. Even with a single drill variable, different drill geometries resulted in a noticeable variation in thrusting forces and delamination factors. Parabolic drilling showed superior cutting performance among the drill bits employed, exhibiting lower drill forces and higher bore cleanliness [13].

The drilling properties of kenaf/PLA-based laminates, a new bio-based composite with potential uses in sustainable industries, are investigated in this work. Knowing whether such materials can be machined has become increasingly important as the market for environmentally acceptable substitutes expands. In order to thoroughly examine drilling operations, the study will evaluate the impacts of several parameters on cutting forces, surface quality, and thermal regulation, including spindle speed, feed rate, and tool geometry. In order to understand the complex behaviors of kenaf/PLA laminates throughout the drilling process, the study uses sophisticated technology, such as sensors and scanning electron microscopy. It is anticipated that the results will advance the basic knowledge of bio-based composites' machinability and offer useful information to sectors thinking about using these materials for everything from construction to automobile parts. The larger objective of developing environmentally friendly building solutions for a future with greater environmental consciousness aligns with this study. The scientific literature demonstrates how the external characteristics of composite materials vary, leading to a range of impacts and outcomes. For NFCs, reducing drilling-induced degradation is crucial, just as for GFRPs and CFRPs. Thus, it is imperative to conduct a research investigation to determine how the drilling behavior of NFCs is impacted by cutting factors, including feeding rate, spindle velocity, and drill bit shape. The current work aims to investigate these impacts on the drilling behavior of composites supplemented with weaved kenaf.

2. Experimental Work

2.1. Sample Preparation

The investigation employed kenaf laminates, composites made of symmetrical flat weave ($90^\circ/0^\circ$) 230 gsm kenaf fiber. PLA, or poly (lactic acid), had an average thickness of 120 μm and was the supporting structure. Utilizing a hot press and manual lay-up process, a total of six layers of 3 mm thick fiber containing a 40% fiber weight percentage in PLA were used to create the specimens. The curing procedure occurred in a hot press at 70 $^\circ\text{C}$ for 24 h and in an oven at 150 $^\circ\text{C}$ for 24 h. Then, 450 mm by 250 mm samples were trimmed using an air-cooled diamond table cutter [14].

2.2. Drilling Experimentation

AEV-74, a maximum vertical CNC milling cutter with the highest spindle speed and power of 4000 r/min and 4.2 kW, was used to drill holes in kenaf blends. Each test was run without adding a supporting plate or coolant under dry-cutting conditions. To secure and situate the laminated material on top of the dynamometer, a suitable and movable attachment that had a 40 mm central bore was utilized. As shown in Figure 1, the samples were placed on the fixtures and then atop a dynamometer on the CNC device's board. A four-component electromechanical Kistler (Winterthur, Switzerland), the Type 1256 device, and a supplemental four-channel Kistler Type 5070 A charging amplifier were utilized to quantify the thrust generated throughout the drilling of kenaf blends. Information was sent through connections via a digital-to-analog converter in a Kistler 5697A DAQ system to a desktop computer. The drilling bits for CoroDrill-854 (CD-854) and CoroDrill-856 (CD-856) are 5 mm and 7 mm in size, respectively. While the other variables stay constant, research has been carried out on the impact of several important process variables, including feed rate, drilling size, and rotation speed. The drilling process was loaded into the equipment's routine operation based on the experimental model [15].



Figure 1. Depicts the photographic image of the drilling of kenaf/PLA composite materials.

3. Result and Discussion

3.1. Result Based on Feed Rate and Spindle Velocity

Since the thrust force's size impacts the quality of the hole that was dug, evaluating that force constitutes one of the most important factors. Figure 2 displays the drilling pressure indications acquired from the drilling of kenaf-PLA layers using an HSS twisting drill, CD-854, and CD-856 at a spindle rate of 2400 r/min and a feed rate of 0.20 mm/rev. It is evident that there are three distinct phases in the drilling operation. Utilizing a drill bit diameter of 5 mm, Figure 2 illustrates the impact of the feed rate on the thrust force. Phase 1 commences when the drill tip and laminate start interacting, and it is characterized by a sudden increase in time when the blade lips penetrate the material. Stage 2 displays the continuous drilling of the thrust force region when the drill tip leaves the lamination's bottom interlayer and the mixed lamination is actually machined [16]. When the full cutting lip emerges from the plastic laminates, stage 3 starts. A tendency toward a decrease in the force of thrust is observed throughout this phase. The forward force-time indication for the HSS twisted bit for drilling is shown in this section. Additionally, Figure 2 shows how all three drill bits' feeds and rotation speeds affect thrust pressure. For each kind of drill bit that was studied in the studies, the thrust forces increase as the feeding rate increases, as shown in the figure. This resulted from the undeformed wafer's expanding cross-sectional dimension and resistance to thrust force during chip creation [17].

The outcome validates the conclusions of several studies. Additionally, it has been shown that the thrust force diminishes when spindle velocity increases at high feeding levels. This is because heat dissipation rises in tandem with the spindle's velocity. Because NFCs have poor thermal conductivity, the heat produced during drilling is concentrated near the outermost layer of the borehole. Since polymers are susceptible to temperature spikes, warmth buildup causes the interconnected structure of polymers to plastically distort [18]. As a result, the thrust force decreases. Nevertheless, when drilling at low feed levels, the spindle rate has a negligible impact on thrust force. It is clear from Figure 3 that variations in the drill bits cause a discernible shift in the thrust force values. The HSS twisting drill design at lower feeds produces the lowest amount of thrust force, while the CD-854 design produces the greatest amount. Because of the HSS twisting drill's tip design, there may be reduced drill interactions with the sample in this case. It was also shown that at greater feed rates, the CD-856 drill shape produces the lowest amount of thrust force [19]. This is related to CD-856's geometric design, which was created to decrease thrust force. Additionally, the findings demonstrate the proximity of thrust force measurements for the CD-856 and HSS twisting drill geometries. It is necessary to stress that the drilling bit's substance is essential. HSS drilling instruments perform admirably on pliable materials [20]. Conversely, brittle and sharp substances are drilled using drill bits of solid tungsten coated with diamonds [21]. Thus, we anticipate determining the impact of the drill bit's materials when drilling is carried out on soft, non-uniform materials, such as the fiber-reinforced laminated composites utilized in the present investigation. Utilizing a 5 mm drill bit diameter, Figure 3 shows the impact of feed rates on thrusting power.

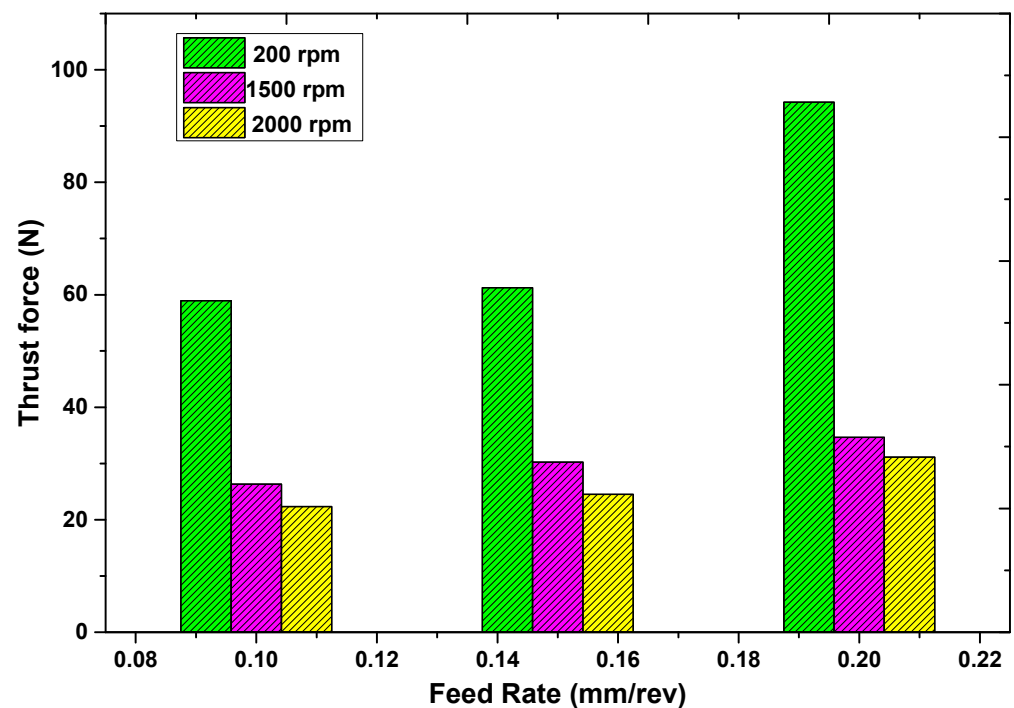


Figure 2. Feed rate performance on thrust force determined at 5 mm diameter.

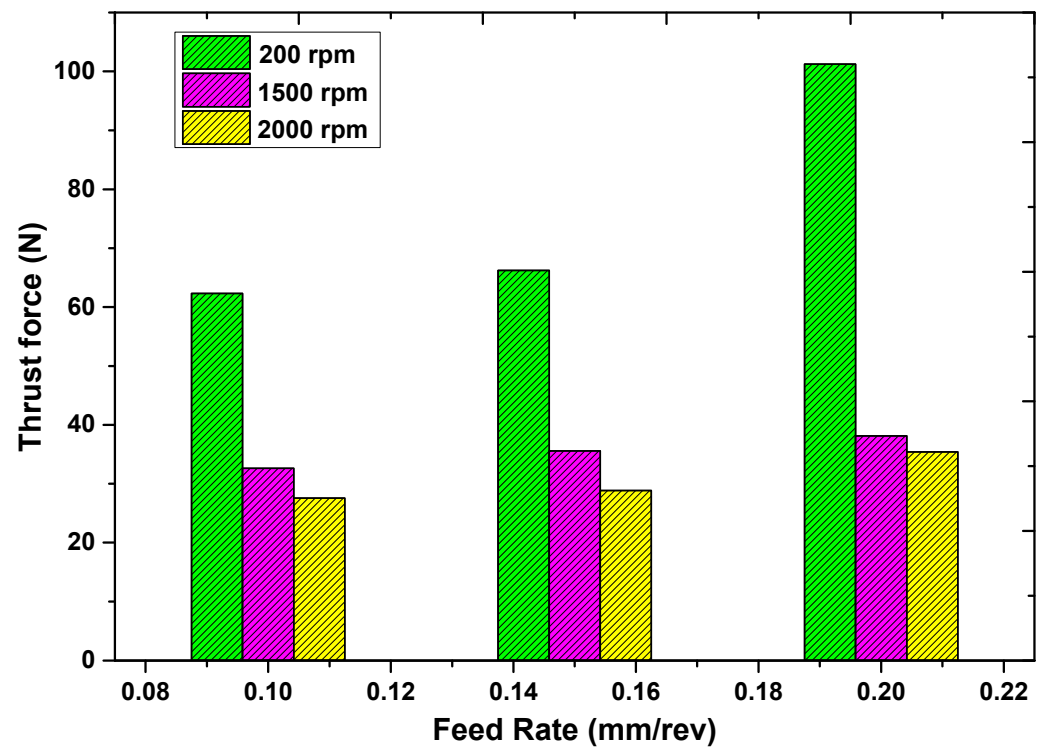


Figure 3. Feed rate performance on thrust force determined at 7 mm diameter.

3.2. Results Based on Delaminations

When drilling composite laminated material, their susceptibility to twisting and the number of uncut plies holding the sample diminish as the drill approaches the sample's departure.

The laminated material at the bottom may separate from the interlaminar connection surrounding the hole when the force of the bend applied to the layers reaches an essential thickness larger than the interlaminar stiffness among the layers [22,23]. Delamination happens when the force applied near the hole exceeds the integrity of the interlaminar bond. Delamination happens before a drill bit penetrates the laminated material completely [24]. All the samples' entry and exit paths showed signs of delamination throughout the drilling process of the kenaf composites made from fiber-reinforced composites. Push-out breakdowns were worse than peel-up breakdowns, as was predicted and previously indicated. Thus, this research assessed and quantified push-out delamination. Drill bit effects on push-out delamination dimensions are displayed in Figure 4 (for both 5 and 7 mm diameters). The aforementioned figures' findings show that push-out delamination differs depending on the kind of drill bit used and is at its lowest with respect to HSS twisted drills. The drill bit materials and thrust level may be able to explain the behavior above using HSS twist drills. The HSS twisting drill's modest tip angle also contributes to better bore cleanliness [7,25,26]. Figure 5a,b show the SEM micrographs of the drilled hole surface taken with multiple drill bits at a feed rate of 0.1 mm/rev and a spindle speed of 2000 r/min. The trials' surface characteristics reveal common flaws like fiber pullout, voids, and interior delamination over time. Wide pullouts and significant surface roughness indicate more drilling-induced degradation in CD-856, as observed in Figure 5b. The SEM pictures support the finding of the greatest substrate values when using CD-856 to measure roughness.

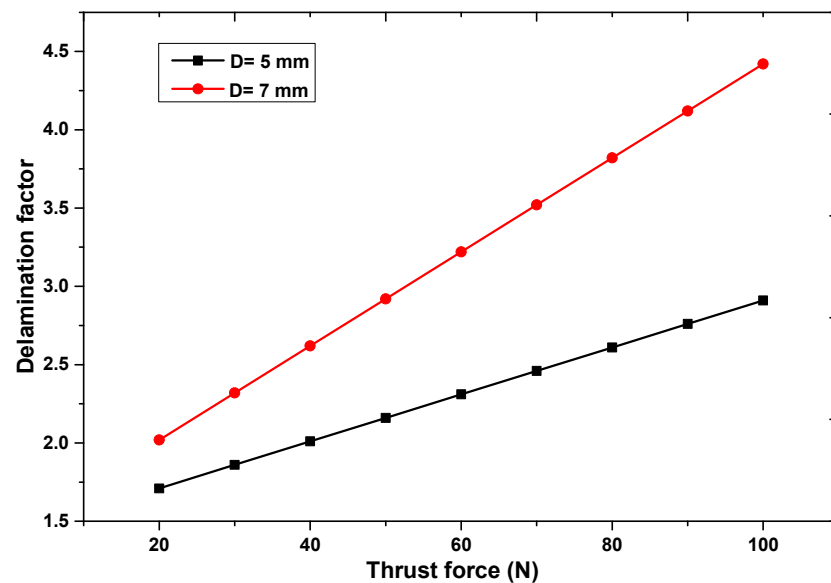


Figure 4. The relationship between the 5 and 7 mm drill's delamination variables and thrust force.

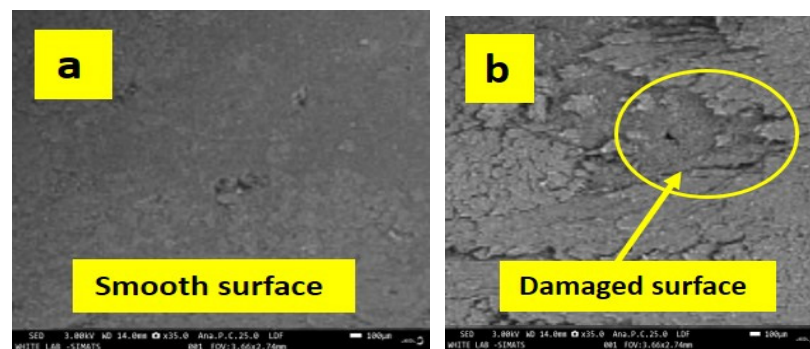


Figure 5. Microstructural analysis of the drilled surface of (a) CD-854 and (b) CD-856 bits.

4. Conclusions

The current research investigation examined the drilling behavior of polymers strengthened with woven kenaf cloth. The behavior of the created polymers during drilling was investigated by utilizing three distinct kinds of drilling tools and cutting settings. The subsequent findings are the result of the empirical inquiry. Feeding is the cutting variable that, when drilling kenaf fiber-strengthened materials, has the most impact on the thrust force for every drilling bit. When using an HSS twisting drill in CD-856, the thrust force produced is less than when using the CD-854 design. A reduction in the size of the delamination was obtained when using an HSS twist drill as opposed to CD-854 and CD-856. This may be linked to the fact that kenaf fibers are supple and gentle, making them suited for drilling with an HSS twisting drill, and the force of thrust decreases when using this type of drilling. Throughout the measured range, there is no discernible relationship between the spindle velocity and feed and delamination magnitudes.

5. Future Scope of the Research

Future research on the drilling properties of laminated materials based on kenaf and PLA has great promise for improving and using environmentally friendly manufacturing methods. Subsequent investigations may focus on refining the parameters of the drilling operation to maximize effectiveness and minimize harm to the environment. Investigating other processing methods, like ultrasonic or laser drilling, may provide new insights on how to shape these bio-based composites. Furthermore, examining the drilled laminates' mechanical and thermal characteristics might help to comprehend how well they function

in various practical settings. Promising research directions include creating cost-effective techniques for producing large-scale products using kenaf/PLA-laminated materials and researching the ability to scale manufacturing methods. Multidisciplinary research that includes materials science, technology, and ecological impact assessments may also give a full picture of these bio-based laminates' life cycle and long-term viability. The future of ecologically sound material discovery rests in realizing the full capabilities of kenaf/PLA composites and applying the study results to create workable solutions for environmentally conscious companies.

Author Contributions: Conceptualization, N.L. and C.A.; methodology, N.L.; software, P.K.; validation, C.A., N.L. and P.K.; formal analysis, V.M.; investigation, C.A.; resources, P.K.; data curation, V.M.; writing—original draft preparation, N.L.; writing—review and editing, V.M.; visualization, P.K.; supervision, N.L.; project administration, C.A.; funding acquisition, P.K. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Data are contained within the article.

Conflicts of Interest: The authors declare no conflicts of interest.

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