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Optimization of Drilling Parameters and Tool Design for Enhanced Performance in Wood Composite Materials

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DECLARATION

I declare that this thesis entitled "Optimization of Drilling Parameters and Tool Design for Enhanced Performance in Wood Composite Materials" is the results of my own research except as cited in the references.

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Optimization of Drilling Parameters and Tool Design for Enhanced Performance in Wood Composite Materials

ABSTRACT

This research aimed to evaluate and optimize drilling parameters and tool design for improved machining quality in wood composite materials. The effects of drill bit type (twist vs. spotting), spindle speed, and composite formulation (varying wood species and ratios) on hole diameter, defect formation, and dimensional accuracy were systematically analyzed using a controlled experimental approach. Results showed drill speeds above 600 rpm exponentially increased hole over sizing and variability. Twist bits provided greater dimensional stability across speeds versus spotting bits. A wood-based composite type mixed with 50% Kelempayan Wood (*Neolamarckia cadamba*) and 50% rubber showed the most minor defects in the holes across various parameters in this study. The twist drill bit consistently outperformed the spotting drill bit, yielding holes with fewer defects and enhanced dimensional precision, as indicated by the results. Among the five tested drill speeds (300rpm to 1500rpm), the lowest speed of 300rpm consistently produced holes with the lowest overall defect rates across various drill bits and composite materials. The findings provide comparative insights into the complex interplay between operating factors influencing machined hole quality in wood materials. They highlight the need for meticulous drill condition and parameter selection to minimize undesirable tear-out while meeting target hole dimensions. Further work is recommended to expand the parameter space and analytical techniques. This will enable more comprehensive determination of optimal methodologies for precision drilling in high-performance wood composites suitable for advanced engineering applications.

Keyword : Wood-based Composite, Twist drill bit, Spotting drill bit, CNC Machine.

Pengoptimuman Parameter Penggerudian dan Reka Bentuk Alat untuk Prestasi Dipertingkatkan dalam Bahan Komposit Kayu

ABSTRAK

Penyelidikan ini bertujuan untuk menilai dan mengoptimumkan parameter penggerudian dan reka bentuk alat untuk kualiti pemesinan yang lebih baik dalam bahan komposit kayu. Kesan jenis mata gerudi (twist vs. spotting), kelajuan gelendong, dan rumusan komposit (spesis dan nisbah kayu yang berbeza-beza) pada diameter lubang, pembentukan kecacatan, dan ketepatan dimensi telah dianalisis secara sistematik menggunakan pendekatan eksperimen terkawal. Keputusan menunjukkan kelajuan gerudi melebihi 600 rpm secara eksponen meningkatkan saiz dan kebolehubahan lubang. Bit twist memberikan kestabilan dimensi yang lebih besar merentasi kelajuan berbanding bit bintik. Jenis komposit berasaskan kayu yang dicampur dengan 50% Kayu Kelempayan (Neolamarckia cadamba) dan 50% getah menunjukkan kecacatan paling kecil pada lubang merentasi pelbagai parameter dalam kajian ini. Mata gerudi pintal menghasilkan lubang dengan kecacatan yang lebih sedikit dan ketepatan dimensi yang lebih tinggi berbanding dengan yang digerudi dengan mata gerudi bertompok, seperti yang dibuktikan oleh hasilnya. Daripada lima kelajuan gerudi yang diuji antara 300rpm hingga 1500rpm, kelajuan terendah 300rpm menghasilkan lubang dengan kadar kecacatan keseluruhan terendah merentas bit gerudi dan bahan komposit yang berbeza. Penemuan ini memberikan gambaran perbandingan tentang interaksi kompleks antara faktor operasi yang mempengaruhi kualiti lubang mesin dalam bahan kayu. Mereka menyerlahkan keperluan untuk keadaan gerudi yang teliti dan pemilihan parameter untuk meminimumkan koyak yang tidak diingini semasa memenuhi dimensi lubang sasaran. Kerja lanjut disyorkan untuk mengembangkan ruang parameter dan teknik analisis. Ini akan membolehkan penentuan metodologi optimum yang lebih komprehensif untuk penggerudian ketepatan dalam komposit kayu berprestasi tinggi yang sesuai untuk aplikasi kejuruteraan lanjutan.

Komposit berasaskan kayu, Mata gerudi twist, Mata gerudi spotting, Mesin CNC.

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CHAPTER 1

INTRODUCTION

1.1 Research background

Wood composites are crafted from diverse materials, typically incorporating the same types of wood found in lumber. The amalgamation of these woods enhances strength and durability. Wood, a historically valued construction material, is renowned for its innate strength and appealing natural aesthetics, Papadopoulos et al. (2019). There are numerous varieties of timber composites, such as particleboard, medium-density fiberboard (MDF), and oriented strand board (OSB). There are numerous varieties of timber composites, such as particleboard, medium-density fiberboard (MDF), and oriented strand board (OSB). MDF is created from fine wood fibers that are joined with a resin, while particleboard is created by compressing tiny wood particles together with a glue. OSB is composed of larger wood filaments oriented in specific directions and bonded with an impermeable resin. They are often used as a substitute for natural wood products in construction and furniture manufacturing due to their many advantages over traditional wood.

Wood composite has a wide range of applications in various industries, including construction, furniture, and interior design. Wood composites, like furniture and cabinet making, flooring, decorative panels, and outdoor living, are used in the construction industry. The purpose of using wood composite is to create a material that has the look, feel and durability of natural wood. Additionally, wood composite is easier to work with than solid wood, as it can be cut, drilled, and shaped with standard wood working tools. It is also more cost-effective and environmentally friendly than solid wood, as it makes use of waste wood products. Overall, wood composites are a versatile and cost-effective alternative to natural wood products, and their use continues to grow in a variety of industries.

In a variety of different sectors, drilling is an essential component of the machining process, Tolouei-Rad et al. (2021). Drilling is the machining procedure that is utilized for assembly activities in the wood working sector the most frequently out of all the different machining processes, Kumar, A., et al. (2018). Therefore, the analysis and development of this process are of considerable importance in boosting productivity and competitiveness, where many existing studies reported on the optimization and improvement of this process. This process has been the subject of numerous studies that have reported on its optimization and improvement, Tolouei-Rad et al. (2021). The production of a wide variety of goods and components relies heavily on this method, which is indispensable because to its adaptability, accuracy, and efficiency in terms of cost.

1.2 Problem statement

In previous research, drilling characteristics of bio composites, notably those incorporating natural fibers, were studied. The intricate structure of natural fibers, with their hierarchical geometry and potential for fibrillation, contributes to heightened risks of hole irregularities and complex penetration modes, ultimately leading to composite damage. Precision machining and drilling processes in the composite industry have garnered considerable attention, focusing on addressing issues such as surface roughness, hole misalignment, edge fracture, splintering, and material sensitivity. Thorough investigation into these challenges and the development of specialized tools remain imperative for enhancing the overall efficacy of machining parts in the composite sector.

1.3 Expected outputs

Optimization of drilling parameters and tool design is crucial for achieving enhanced performance in wood composite materials. Studies have shown that the retention of tensile strength in natural fiber composites is greatly affected by the size, number, and diameter of holes, as well as the fiber architecture. Unidirectional fiber composites tend to have the highest tensile strength due to more fibers in the loading direction. Proper tool geometry and drilling parameters can minimize onset damage and achieve damage-free drilling. Different types of drills can also affect the extent of damage during drilling of composite materials. The use of techniques such as Taguchi and multi-objective optimization can lead to cutting parameters that allow damage-free drilling of fiber-reinforced plastics. Delamination is identified as the major mechanism causing exit defects during drilling. In addition, finite element simulation analysis combined with experimental research can provide a more accurate analysis of drilling parameters and their effect on wood composite materials.

1.4 Objective

I. To evaluate the efficiency and quality of the drilling parameters and tool design for wood composite materials.
II. To optimize the drilling process, reduce tool wear, and minimize defects in the final product.

1.5 Scope of this study

Based on the search results, the scope of the optimisation study of drilling parameters and tool design is to discover the problems that will occur and improve the performance in the drilling process and wood composite materials. In other words, it involves retaining tensile strength, preventing delamination and exit defects, and finding cutting parameters that allow damage-free drilling. This study also investigates the effect of drilling parameters on the performance of wood composite materials. Further evaluated the effect of drilling parameters and tool design on tearing and penetration in wood composite materials. Analyse the impact of drilling parameters and tool design on tool wear and tool life in wood composite materials. Overall, this study aims to optimise the drilling process for wood composite materials by increasing drilling efficiency, accuracy, and effectiveness by optimising drilling parameters and tool design.

1.6 Significance of study

The study of optimization of drilling parameters and tool design for enhanced performance in wood composite materials is significant for several reasons. Wood composite materials are widely used in various industries such as automotive, aerospace, and furniture manufacturing due to their desirable properties such as high strength-to-weight ratio, improved dimensional stability, and resistance to moisture and fungal attack. However, drilling these materials poses several challenges such as tear-out, delamination, and excessive tool wear. By optimizing drilling parameters and tool design for wood composite materials, the drilling process can be made more efficient, accurate, and cost-effective. This can result in reduced production costs and improved product quality. Additionally, the use of wood composite materials is growing rapidly in various industries, making the optimization of drilling processes increasingly important. Further, the study can aid in the sustainable use of wood composite materials through improving the efficiency and accuracy of drilling processes, reducing waste, and improving resource management. Therefore, this study has significant implications for various industries that use wood composite materials and may contribute to the development of more sustainable and efficient manufacturing processes.

CHAPTER 2

LITERATURE REVIEW

2.1 Overview of wood composite materials

Wood composites are produced using a wide number of different components. In most cases, they are made out of the same kinds of woods that are employed in the production of timber; nevertheless, due to the blending process, they are considerably more robust and long-lasting. Since ancient times, wood has been valued as a building material due to its durability and the inherent beauty it imparts to a structure (Taghiyari, et al., 2019). Numerous structural and non-structural applications can benefit from the usage of composites that are based on wood. Panels for both interior and outdoor usage, components for use in furniture, and support structures for use in buildings are all included in the product lines. The correct application of these compounds requires in-depth familiarity of their mechanical properties in order to be successful (Cai, Z., 2010). The formation of composite materials involves the combination of two or more materials that exhibit quite distinct sets of properties. Within the composite, you can easily recognize the individual components apart from one another since do not dissolve or blend into each other. However, the composite's unique features are a result of the many materials working together to create products (Mischa, 2017).

2.2 Drilling Wood Composites

2.2.1 Drilling Parameters and Hole Quality

Drilling these wood presents significant difficulties because to the poor hole quality that can cause cracks in the aircraft structure and lowers their dependability (Aamir et al., 2020). Past studies have shown that higher cutting speeds and lower feed rates improve hole quality by reducing the heat generated during drilling. Aircraft assembly requires millions of holes to be drilled for riveted and bolted connections, making the drilling procedure the most difficult of all the machining processes (Aamir et al., 2020). Optimal drill bit geometries, such as helix angle, point angle, and drill point type, have been identified to enhance the chip evacuation and reduce tear-out, delamination, and surface roughness. The process parameter is another factor that has a significant impact on the quality of the drilled hole. Roundness error, roughness of the machined region, and diameter variation are a few of the quality criteria that are associated with holes (Niranjan et al., 2022). The cutting speed, feedrate, and drill diameter are the input parameters. The tool life, the material removal rate, the drilling thrust, and the torque are the output parameters (Han, et al., 2020).

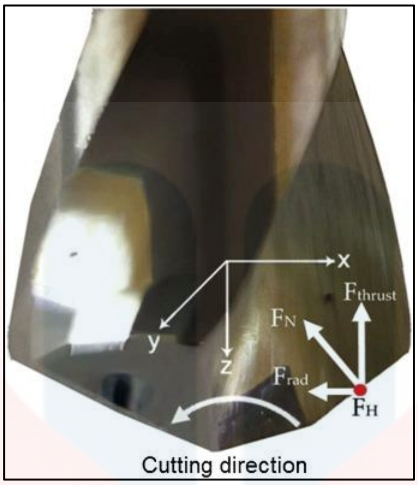


Figure 1: The forces exerted on the drill bit.

(Source : Aamir et al., 2020)

2.2.2 Delamination and Surface Integrity.

In the past quarter of a century, the term "delamination" has grown to represent more than merely a failure in adhesion between layers of bonded composite plies, which could potentially damage their capacity for load-bearing (Bucur et al., 2011). Delamination, which is a frequent flaw that can occur when drilling wood composites, can have a substantial impact on the material's strength as well as its structural integrity. Researchers have explored various strategies to minimize delamination, such as pre-drilling pilot holes, using special drill bits with stepped or specially designed cutting edges, and applying coatings or lubricants to reduce friction and heat generation. For the purpose of estimating the delamination error, measuring technique was an important factor to consider (Niranjan et al., 2022). Delamination occurs between the composite laminate's layers. Matrix cracking, bending cracks, and shear cracks induce delamination (Jensen., 2013).

2.2.3 Composite Materials Effect on Drilling

In the process of machining, one of the most serious issues that might arise is known as drilling-induced delamination, and the force of the drilling plays a critical role in the formation of delamination. Wei et al. (2013). Researchers have looked into the impact that these composite materials have on the drilling performance as well as the quality of the holes they create. For instance, studies have shown that the density and orientation of wood particles in particleboard influence drilling parameters and the resulting hole quality. Additionally, the presence of additives, such as resins, adhesives, or fillers, in composite materials impact on drill-ability and surface characteristics. Manufacturers and engineers need to carefully examine tool selection, drilling settings, and surface preparation processes to mitigate these impacts and maximize drilling performance with wood composite materials. Properly chosen and maintained drill bits, along with appropriate drilling methods, can help mitigate the challenges posed by wood composites, leading to improved product quality and drilling efficiency.

2.2.4 Advancements in Drilling Techniques and Tools

While traditionally drilling holes in FRPCs, research efforts have been directed toward optimizing the process parameters as much as possible. In addition, non-traditional drilling methods for FRPCs are analyzed and discussed in this paper. The harm caused by the hole was mitigated to a greater potential extent by using unconventional drilling methods. It is also possible to investigate the use of microwave drilling of FRPCs as a method for producing holes of a high grade. Rampal et al. (2022). Advancements in drilling techniques and tool designs have been a focus of research to enhance drilling performance in wood composites. For instance, the use of vibration-assisted drilling, ultrasonic-assisted drilling, or laser-assisted drilling has been investigated to reduce cutting forces, improve chip evacuation, and minimize delamination.

2.3 Drilling parameters

2.3.1 Cutting Speed

Cutting speed is widely acknowledged as an essential factor in determining tool wear and, by extension, tool life in metal cutting research published to date; other cutting parameters and characteristics have received less attention. Astakhov et al. (2007). The value of tool wear dropped as cutting speeds increased. These experimental findings are in conformity with the current literature research. Altin et al. (2007). Cutting speed is one of the key drilling parameters that significantly affects drilling performance. When the cutting speed is increased, the cutting forces are typically decreased, chip evacuation is boosted, and the surface finish is improved. Selecting the optimal cutting speed for wood drilling depends on various factors, including the type and density of the wood material, drill bit type and geometry, and the desired drilling outcome. A balance must be struck between productivity, surface finish, tool wear, and heat generation to achieve efficient and high-quality drilling results in wood applications.

2.3.2 Drill diameters

When drilling any material, hole surface quality usually suffers as the drill bit diameter increases. Kiyak et al. (2021). The quality of the hole was found to be unaffected by the diameter of the drill, but a larger drill covered a larger cross-sectional area, increasing the thrust force and leading to larger chips. Tolouei-Rad et al. (2021). Larger drill diameters tend to generate higher cutting forces and torque, requiring higher machine power. However, they can also result in improved hole accuracy and reduced surface roughness. Optimal drill diameter selection depends on the specific machining requirements, such as hole size, tolerance, and material properties. Properly adjusting and optimizing these drill parameters for specific wood materials and drilling tasks is essential to achieve efficient chip removal, minimize tool wear, control heat generation, and obtain high-quality drilled holes. Manufacturers and engineers must consider the characteristics of the wood material, the drill bit geometry, and the desired drilling outcome to determine the appropriate drill parameters for their applications.

2.3.3 Drill geometry

When it comes to the performance of the drilling process for composites in terms of machining-induced damage, tool geometry, and more specifically the tip angle of the drill, has a significant impact. Díaz-Álvarez et al. (2019). Several writers have proven the significance of making an informed choice about the drill geometry and cutting settings in order to reduce the amount of damage that is caused by the machining process. Soldani et al. (2011). The performance of the drill depends heavily on the drill geometry, which includes the point angle, the helix angle, the point style, and the rake angle. Several studies have been conducted to investigate the impact that drill geometry has on cutting forces, chip formation, hole quality, and tool wear. Properly adjusting and optimizing these drill parameters for specific wood composite materials and drilling tasks is essential to achieve efficient chip removal, minimize tool wear, control heat generation, and obtain high-quality drilled holes. Manufacturers and engineers must consider the wood composite's composition, density, and the desired drilling outcome to determine the appropriate drill parameters for their applications.

2.3.4 Tool materials

Investigation has been done into the developments that have taken place in the materials, architectures, and functionalities of tools used in traditional and advanced composites manufacture. Prototypes are typically made with wooden, plaster, or graphite tools. Traditional tool materials such as steel and aluminum also had the virtue of being inexpensive and durable. Li et al (2021). Tool material selection is crucial for achieving optimal drilling performance and tool life. Researchers have investigated various tool materials, including high-speed steel (HSS), carbide, ceramic, and polycrystalline diamond (PCD), to evaluate their performance in terms of cutting forces, tool wear, chip control, and surface finish. Choosing the right tool material for wood composite drilling depends on several factors, including the type of wood composite, its density, the desired drilling speed, and the expected tool life. Manufacturers and engineers should consider the specific properties of the wood composite and the drilling requirements to select the most suitable tool material that offers the best balance between performance and cost-effectiveness. Additionally, proper maintenance and care of the drill bits are essential to prolong their lifespan and ensure consistent drilling performance.

2.5 Tool geometry

2.5.1 Tool Shape and Edge Preparation

Drilling quality in wood composites is greatly affected by tool geometry, shape, and edge preparation. Hassan et al. (2021), Cristovao et al. (2013). It is essential to tune drilling parameters and tool design in order to get increased performance in wood composite materials. This includes the modification of twist drill geometry and coating. Ertürk et al. (2019). Studies have explored the effects of tool shape on cutting forces, tool wear, surface roughness, and chip control. Different tool shapes, such as square, round, and chamfered, have been investigated to optimize cutting performance in specific applications.

2.5.2 Tool Coatings

The experimental results of machining with PVD, MTCVD, and CVD diamond coated tools are shown, and the effects of tool shape, tool edge preparation, and coating material on coated carbide wear resistance are explored. According to the research that has been done up to this point, applying coatings on tools has the potential to significantly improve their resistance to wear. This, however, is contingent upon the substrate being adequately prepared, as well as the tool shape and cutting conditions being appropriately selected. Sheikh-Ahmad et al. (2001). Studies have explored the influence of different coating materials, thicknesses, and deposition techniques on cutting forces, tool wear, and surface finish. Coated tools have been shown to exhibit improved performance in terms of reduced cutting forces, extended tool life, and enhanced surface quality.

CHAPTER 3

MATERIALS AND METHODS

3.1 Materials

3.1.1 Wood based composite

A wood-based composite served as the material in this experiment, with four variations employed as working materials in the drilling experiment. However, two of these types utilized a blend of two tree species. The wood-based composite variations included 100% Rubber Wood, 100% Kelempayan Wood (*Neolamarckia cadamba*), 80% Kelempayan Wood (*Neolamarckia cadamba*) and 20% Rubber Wood, as well as 50% Kelempayan Wood (*Neolamarckia cadamba*) and 50% Rubber Wood. The 100% rubberwood for the wood-based composite was sourced from the earlier study conducted by seniors at Universiti Malaysia Kelantan. However, the wood-based composites with 100% kelempaya, 50% kelempaya + 50% rubberwood, and 80% kelempaya + 20% rubberwood were provided by the lecture. The wood-based composite materials under investigation encompass distinct compositions, namely 100% Rubber Wood, 100% Kelempayan Wood (Neolamarckia cadamba), an 80% Kelempayan Wood and 20% Rubber Wood blend, and a combination of 50% Kelempayan Wood and 50% Rubber Wood. Each composite is structured in three layers, featuring 9% urea-formaldehyde resins for the face layer and 6% urea-formaldehyde for the core layer. The face layer is meticulously crafted with 0.5 mm particle size, while the core layer incorporates particles larger than 0.5 mm. Furthermore, the density board attains a density of 660 kg/m3, contributing to its structural integrity and overall quality. This detailed breakdown provides essential insights into the composition and specifications of the wood-based composites, setting the foundation for a comprehensive exploration of their drilling characteristics and performance in subsequent experimental analyses.

3.1.2 Drill bit

The experiment involves employing two distinct drill qualities for drilling operations. The utilized drill bits in this study are the twist drill bit and the 6mm-sized 60° NC Carbide Spotted Drill. The rotary drills exhibit a spiral flute design with a pointed tip and two cutting edges, featuring variable helix angles and point angles. The 60° angle of the Carbide Spotted Drill is specifically designed to create precise spot holes or chamfers in the workpiece. Typically, a 60° angle is employed for applications such as chamfering and spotting.

Table 1 : Type of drill bit and size that will be used for drilling process.

Type of bits	Size of bit
Twist drill bit	
Spotting drill bits	6 mm

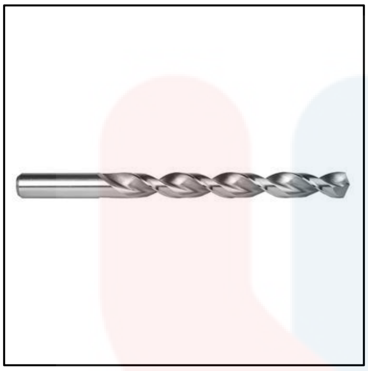


Figure 2 : Twist Drill Bit

Figure 3 : Spotting Drill Bit

3.1.3 Machines

The drilling operation was carried out using a CNC Router machine (figure 4). The machine incorporates the spindle as its main component, which achieves cutting by rotating its cutting bits at variable speeds based on the material being processed.

Figure 4 : CNC Router machine

3.1.4 Microscope

A stereo microscope was utilized in this investigation (figure 4). Stereomicroscopes, being the most straightforward microscope type, are less frequently employed in true analytical microscopy compared to other microscope varieties.

Figure 5 : Stereo Microscope

3.1.5 Experimental Design

Techniques used include a full factorial design. In order to estimate main effects and interactions, a basic systematic design approach known as a full factorial design will be used. The design's usefulness grows exponentially with the number of factor levels or test points. The drilling parameters to be investigated are determined, such as spindle speed, feed rate, drill bit geometry, cutting/lubricating fluid, and tool material. The range or level at which each parameter will be changed and determined. Experimental design techniques, such as Design of Experiments (DoE), will be used to create efficient, practical plans.

In the context of this drilling experiment, two distinct drill bits, the twist drill bit and the spotting drill bit, were strategically employed. The objective was to investigate their respective impacts on four diverse types of wood-based composite materials, namely 100% Rubberwood, 100% Kelempayan Wood (Neolamarckia cadamba), a composite blend of 50% Rubberwood and 50% Kelempayan Wood, and an 80% Kelempayan Wood (Neolamarckia cadamba) coupled with 20% Rubberwood. Each wood-based composite underwent drilling using both types of drill bits, facilitating a comparative analysis of drilling efficiency across different compositions.

3.2 Method

3.2.1 Drilling

Within the framework of this drilling experiment, two distinct drill points were strategically employed, namely the twist drill bit and the spotting drill bit. The utilization of these two drill points was integral to the exploration of their respective impacts on four varied types of wood-based composite materials. These materials encompassed a spectrum of compositions, including 100% rubberwood, 100% Kelempayan Wood (Neolamarckia cadamba), a composite blend of 50% rubberwood and 50% Kelempayan Wood, and an 80% Kelempayan Wood (Neolamarckia cadamba) coupled with 20% rubberwood.Significantly, each of these wood-based composites underwent the drilling process employing both the twist drill bit and the spotting drill bit. This standardized methodological approach was deliberately adopted to facilitate a comparative analysis of the drilling efficiency and outcomes across the diverse compositions of wood-based materials. This comprehensive investigation aimed to discern any variations in drilling performance attributable to both the inherent characteristics of the drill points and the unique composition of each wood-based composite.

Initially, the experimental procedure commenced with the measurement of a wood-based composite, specifically Rubberwood 100%, which was precisely sized at 5cm x 5cm utilizing a ruler for accuracy. Subsequently, this wood-based composite was meticulously divided into four distinct sections, each demarcated for subsequent drilling operations. Employing a 6mm-sized twist drill, the wood-based composite underwent drilling at each of the pre-marked locations. Following the completion of the drilling process, the perforated wood-based composite underwent further refinement through cutting, utilizing a bandsaw machine for precision. The prepared wood-based material then underwent a detailed examination employing a stereo microscope, with the obtained observations meticulously recorded for subsequent analysis. In the subsequent phase of the experiment, defect data was meticulously measured using a digital caliper, ensuring precision in recording dimensional attributes related to any observed imperfections. It is imperative to note that all relevant data resulting from these experimental steps has been systematically recorded for comprehensive analysis and documentation.

CHAPTER 4

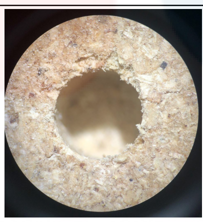
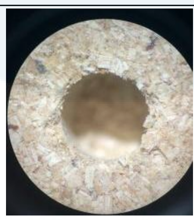
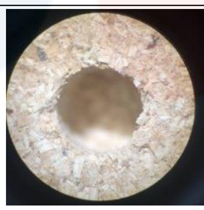
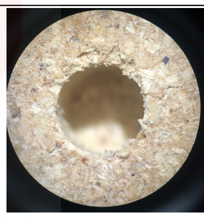
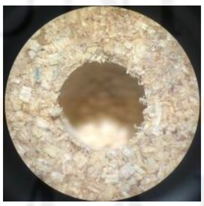
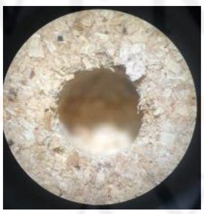
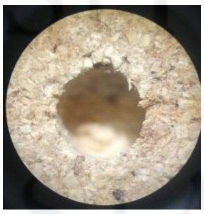
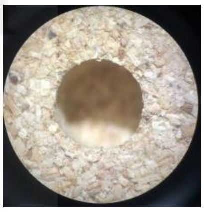
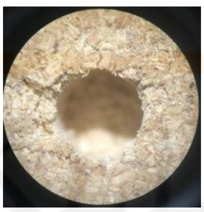
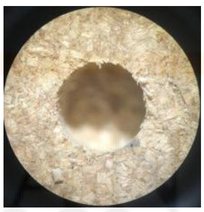
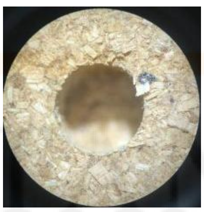
RESULT & DISCUSSION

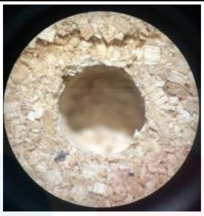
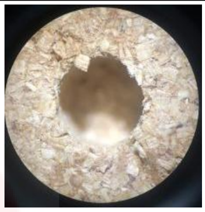
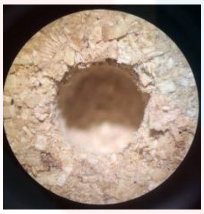
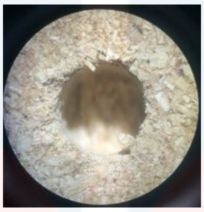
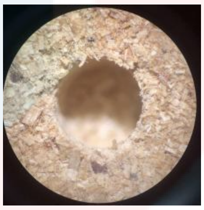
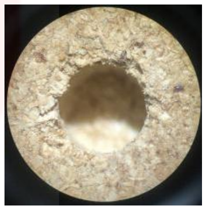
4.1 RESULT

Table 2 : The defect Result of the Type Drill Bit against Wood based composite.

Type of bit: Twist drill bits

Wood based composite (Rubber Wood)

Type of hole / Type of speed (rpm)	Hole 1	Hole 2	Hole 3	Hole 4
300 rpm	 0.62mm	 0.68mm	 0.57mm	 0.66mm
600 rpm	 0.86mm	 1.19mm	 0.97mm	 0.36mm
900 rpm	 1.40mm	 0.51mm	 1.29mm	 1.55mm

1200 rpm				
	0.59mm	1.47mm	1.06mm	0.78mm
1500 rpm				
	1.51mm	1.75mm	1.59mm	1.92mm

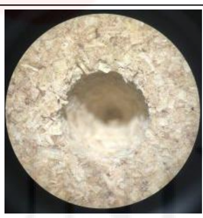
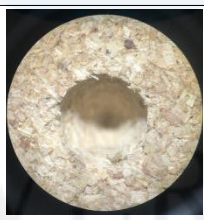
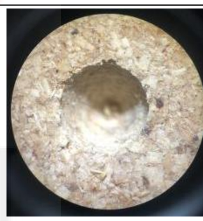
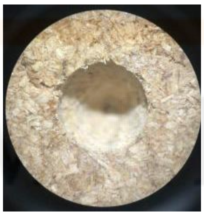
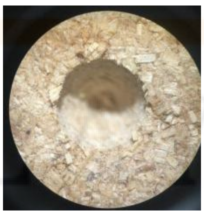
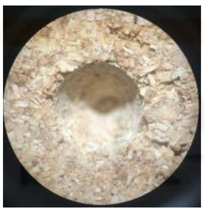
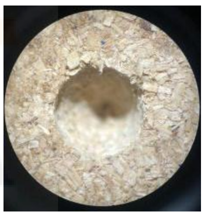
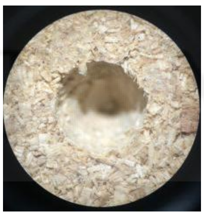
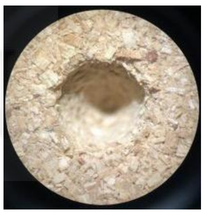
The data presented in Table 2 examines the effect of twist drill bit speed on hole size variation or defects in a rubber wood composite. Four holes were drilled at speeds ranging from 300 to 1500 rpm. There is considerable fluctuation in the measured hole diameters, indicating the dimensional accuracy is highly sensitive to drill speed for this composite. This agrees with recent studies on drilling wood plastic composites.

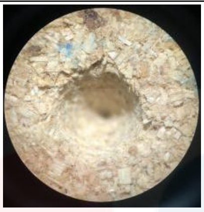
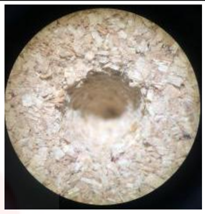
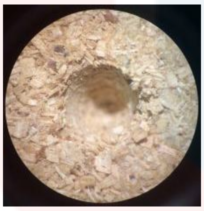
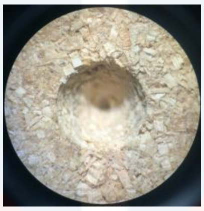
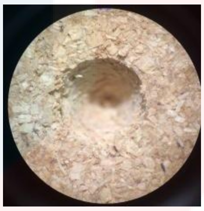
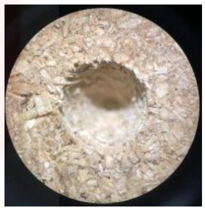
At 300 rpm, the holes demonstrated a consistently similar size, ranging from 0.57mm to 0.68mm, indicating stability at lower speeds. However, as the speed increased, a discernible trend emerged, indicating larger and more diverse hole dimensions. At the maximum tested speed of 1500 rpm, Hole 4 showcased the greatest diameter at 1.92mm, suggesting a possible link between drilling at high speeds and an increase in hole size. These results raise important considerations for drilling processes in wood-based composites, emphasizing the need for careful selection and optimization of drilling parameters to achieve desired hole dimensions and minimize defects. In their examination, the subsequent drilling parameters were taken into account as input variables for the model such as formation depth, formation strength, formation compaction, bit diameter, weight on bit, rotary speed, bit wear, hydraulics, and pressure differential across the hole bottom, Ramba et al. (2021). Twist drill point geometry influences cutting forces and hole quality in composites. Smaller point angles perform better by decreasing thrust force, Latha et al. (2011).

Table 3 : The Result of the Type Drill Bit against Particleboard.

Type of bit: Spotting drill bits

Wood based composite (Rubber Wood)

Type of hole / Type of speed (rpm)	Hole 1	Hole 2	Hole 3	Hole 4
300 rpm	 0.71mm	 0.77mm	 0.84mm	 0.55mm
600 rpm	 0.35mm	 0.66mm	 0.82mm	 0.60mm
900 rpm	 0.95mm	 1.08mm	 0.94mm	 1.11mm

1200 rpm				
	0.88mm	0.71mm	0.78mm	0.81mm
1500 rpm				
	0.71mm	0.99mm	0.86mm	1.52mm

The data presented in Table 3 offers useful insights into the performance and hole dimensional accuracy achieved when utilizing Spotting Drill Bits to machine holes in Rubber Wood-based composite workpieces across a spectrum of rotational speeds. By examining the finished hole sizes generated at the various test velocities, meaningful conclusions can be drawn regarding the drilling process parameters and tool interactions when applied to this composite material.

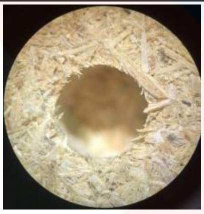
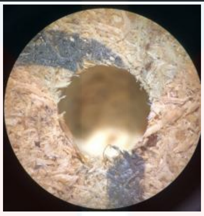
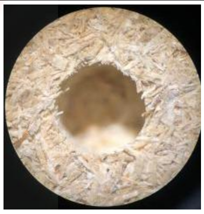
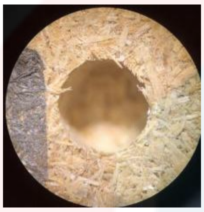
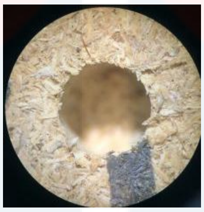
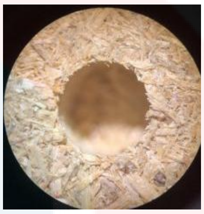
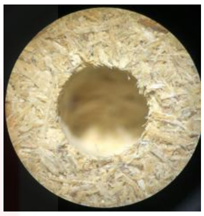
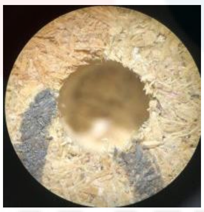
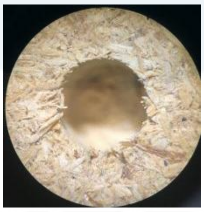
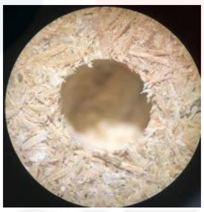
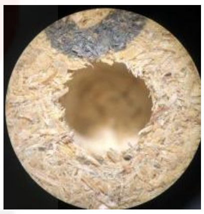
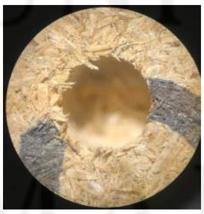
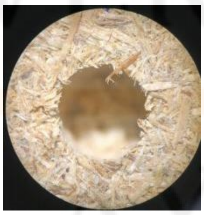
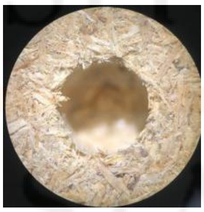
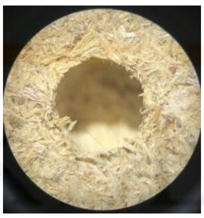
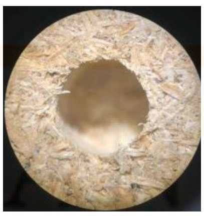
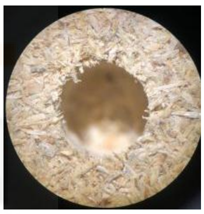
At the lowest speed of 300 revolutions per minute (rpm), the diameters of the four sampled holes (Hole 1, Hole 2, Hole 3, and Hole 4) ranged from a minimum of 0.55mm up to a maximum of 0.84mm. This moderate 0.29mm spread indicates a measurable level of hole size variability under these low speed conditions. While hole dimensions remained relatively consistent, some sensitivity to tearing and enlargement effects was evident even at 300 rpm. As drill speed was increased to 600 revolutions per minute (rpm), a conspicuous reduction in diameter was observed for Hole 1, decreasing markedly to 0.35mm. This demonstrates the high responsiveness of the spotting drill bit and the composite material to changes in velocity, with the raised speed generating noticeably smaller hole sizes. When operating at an intermediate speed of 900 revolutions per minute (rpm), finished hole diameters grew to a range spanning 0.94mm to 1.11mm. The controlled and incremental enlargement trend points to stable and predictable performance by the spotting drill bit at this velocity when applied to the rubber wood composite.

Unexpectedly, Hole 2 diameter shrank to 0.71mm at 1200 rpm, versus the 0.9-1.1mm range at 900 rpm. This contraction defies the typical enlargement trend, demonstrating the complexity of tool and work piece interactions.Most dramatically, Hole 4 diameter ballooned to 1.52mm at the maximum 1500 rpm speed, nearly double the 300 rpm size. This extreme enlargement spotlights the escalating potential for tear-out and defect formation when applying very high drilling speeds, despite optimizations. The augmentation in cutting speed results in minimal disparities in drill hole quality but does lead to escalating feed forces and diminishing drilling torques, Heisel et al. (2012).

Table 4 : The Result of the Type Drill Bit against Particleboard.

Type of bit: Twist drill bits

Wood based composite (Kelempayan Wood (*Neolamarckia cadamba*))

Type of hole / Type of speed (rpm)	Hole 1	Hole 2	Hole 3	Hole 4
300 rpm	 0.65mm	 0.69mm	 0.63mm	 0.74mm
600 rpm	 0.60mm	 0.88mm	 0.70mm	 0.75mm
900 rpm	 0.86mm	 0.84mm	 1.15mm	 1.23mm
1200 rpm	 1.33mm	 1.14mm	 1.31mm	 1.16mm
1500 rpm	 1.37mm	 1.21mm	 1.41mm	 1.17mm

According to the Table 4, provides insight into the performance of Twist Drill Bits when used on Kelempayan (*Neolamarckia cadamba*) Wood-based composite material at various drilling speeds.According to the Table 4, the data provides valuable insights into the performance characteristics of Twist Drill Bits when utilized to drill holes in Kelempayan (Neolamarckia cadamba) Wood-based composite substrates across a range of rotational velocities.

At the lowest spindle speed of 300 revolutions per minute (rpm), all four holes (Hole 1, Hole 2, Hole 3, and Hole 4) displayed relatively tight diameter measurements varying between just 0.63mm and 0.74mm. This indicates a high level of consistency and precision in the drilling operation at this reduced speed, with minimal variability between the holes. The twist drill bit maintains excellent control and stability at 300 rpm, generating uniform hole sizes.

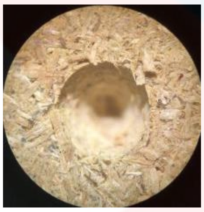
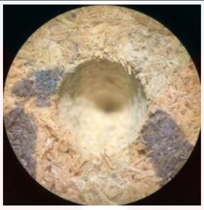
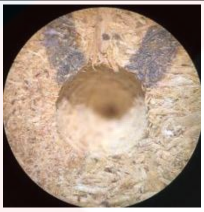
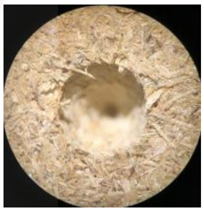
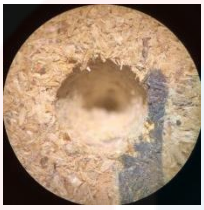
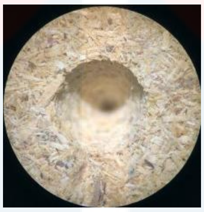
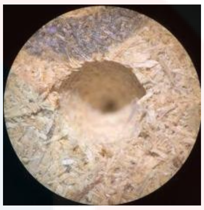
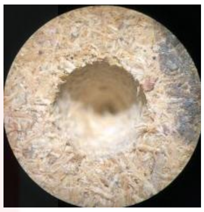
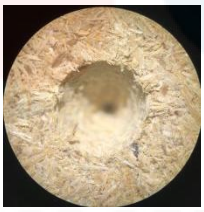
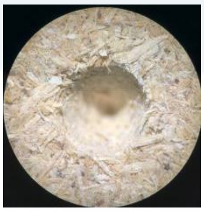
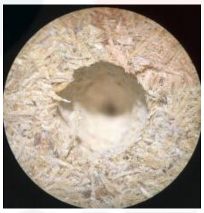
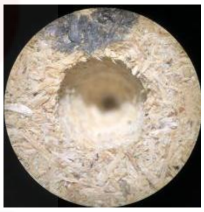
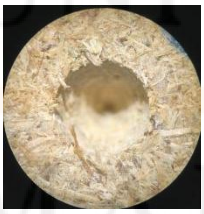
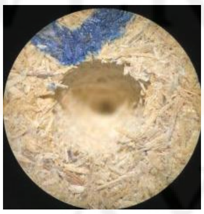
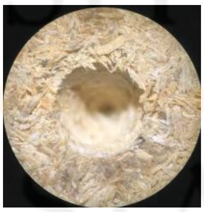
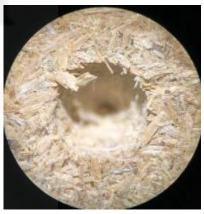
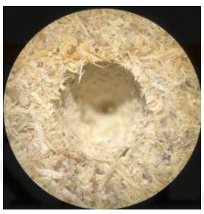
As the rotational speed is increased to 900 revolutions per minute (rpm), the range of hole diameters grows marginally to span 0.84mm to 1.23mm. While exhibiting slightly more variation, the incremental enlargement of the holes across the different samples appears uniform and systematic at this higher velocity. The twist drill continues to produce well-regulated holes, simply of larger width due to the faster cutting speed. A standard twist drill features two cutting edges or lips connected by a chisel edge set at an angle of 55° to the plane perpendicular to the cutting plane, Mokas et al. (2023)

However, when spindle speeds are elevated to even higher rates of 1200 rpm and 1500 rpm, a conspicuous and consistent enlargement trend emerges in the diameters of all four holes. Measurements reach a maximum width of 1.41mm at 1500 rpm, demonstrating the extreme tearing influence of the twist drill bit at very high velocities. The cutting speed stands out as a critical factor influencing the drill's lifespan. When the cutting speed is excessively slow, there is a risk of the drill experiencing chipping or breaking, Schneider et al.(2020).

Table 5 : The Result of the Type Drill Bit against Particleboard.

Type of bit: Spotting drill bits

Wood based composite (Kelempayan Wood (*Neolamarckia cadamba*))

Type of hole / Type of speed (rpm)	Hole 1	Hole 2	Hole 3	Hole 4
300 rpm	 0.59mm	 0.77mm	 0.91mm	 0.99mm
600 rpm	 0.83mm	 0.55mm	 0.70mm	 0.76mm
900 rpm	 0.97mm	 0.94mm	 1.09mm	 0.79mm
1200 rpm	 1.14mm	 1.09mm	 0.95mm	 1.84mm
1500 rpm	 1.02mm	 1.39mm	 0.98mm	 1.99mm

The data presented in Table 5 provides valuable insights into the performance characteristics and hole quality achieved using Spotting Drill Bits on Kelempayan (Neolamarckia cadamba) wood-based composite substrates, when operated across a range of spindle speeds.

At the moderate rotation rate of 600 revolutions per minute (rpm), Hole 2 displayed the smallest diameter measurement of just 0.55mm. This minimum defect size suggests drilling at this controlled velocity enables accurate and precise hole boring, with the spotting drill bit able to generate clean, near-perfect holes under these conditions. The low speed appears optimal for maintaining hole quality and minimizing dimensional errors.

In contrast, when rotational speed was maximized to 1500 revolutions per minute (rpm), Hole 4 exhibited the largest diameter of 1.99mm. This substantial enlargement indicates that applying higher velocities leads the spotting drill bit to produce significant tearing in the composite material, exponentially expanding the hole width. The high cutting speed and forces induce considerable damage. Examining the forces needed for hole-making with various drilling parameters provides a valuable indicator of the drilling process's quality, encompassing factors such as hole quality, tool longevity, and energy consumption, Khosravanian et al. (2022).

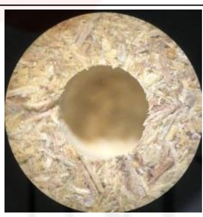
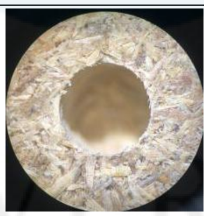
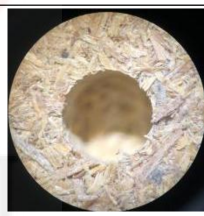
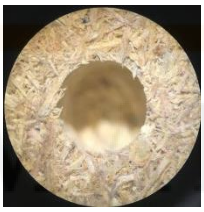
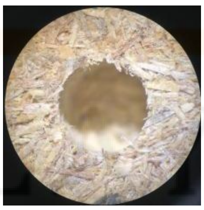
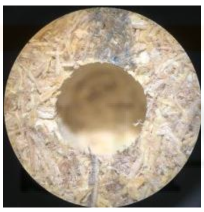
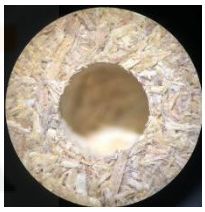
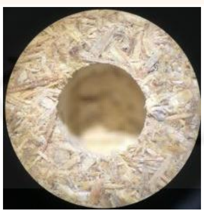
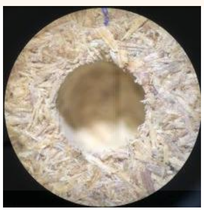
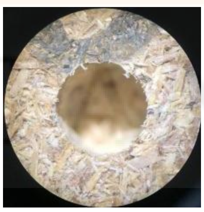
The data signals that moderate 600 rpm velocity allows excellent hole accuracy, while excessive 1500 rpm speed causes severe enlargement and defect expansion. The interaction between the cutting tool and the periodic formation, stacking, and removal of material layers on the tool influenced the cutting forces, Guimarães et al. (2023).

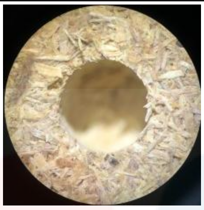
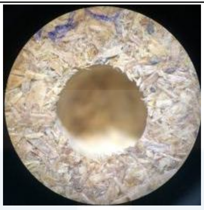
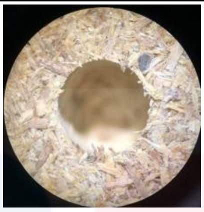
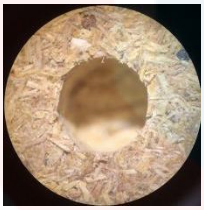
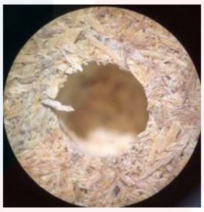
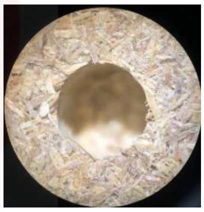
Table 6 : The Result of the Type Drill Bit against Particleboard.

Type of bit: Twist drill bits

Wood based composite of 50% Rubber wood + 50% Kelempayan Wood

(*Neolamarckia cadamba*)

Type of hole / Type of speed (rpm)	Hole 1	Hole 2	Hole 3	Hole 4
300 rpm	 0.31mm	 0.23mm	 0.59mm	 0.41mm
600 rpm	 0.35mm	 0.76mm	 0.54mm	 0.47mm
900 rpm	 0.39m	 0.87mm	 0.58mm	 0.94mm

1200 rpm				
	1.10mm	0.72mm	0.84mm	0.75mm
1500 rpm				
	0.50mm	0.59mm	1.23mm	0.93mm

The data presented in Table 6 offers useful insights into the dimensional accuracy and hole quality achieved when utilizing Twist Drill Bits to machine holes in a composite material comprised of equal parts Rubber Wood and Kelempayan Wood (Neolamarckia cadamba). By examining the finished hole sizes generated across a spectrum of spindle speeds, meaningful observations can be made regarding the performance of twist drill bits when applied to this blended wood substrate.

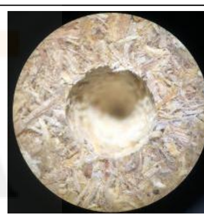
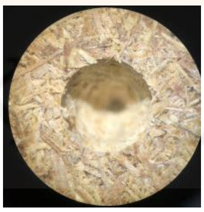
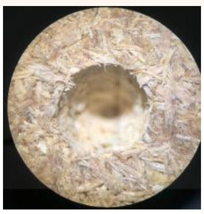
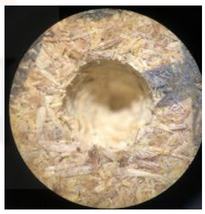
At the lowest test speed of 300 revolutions per minute (rpm), Hole 2 exhibited the smallest diameter measurement at just 0.23mm. This minimal measurement at reduced velocity highlights the potential for highly accurate and precise hole boring using twist drill bits, with minimal enlargement or tearing effects. As speed was increased to a moderate 600 revolutions per minute (rpm), Hole 2 maintained a relatively reduced diameter of 0.76mm. The consistency in minimized size despite the doubling of rpm indicates notable stability and resistance to defect formation when drilling this composite at low to medium spindle speeds.

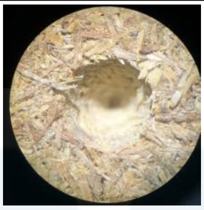
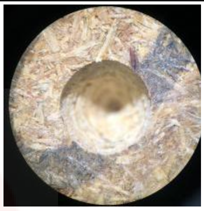
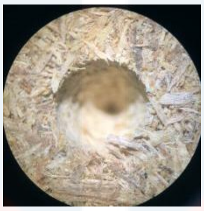
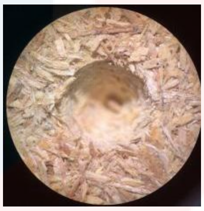
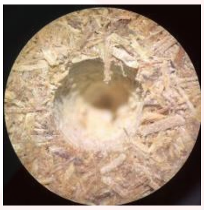
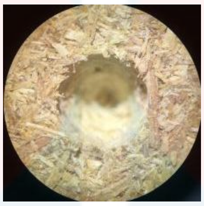
However, at the considerably higher velocity of 1200 revolutions per minute (rpm), Hole 1 displayed a conspicuous enlargement in diameter, expanding significantly to 1.10mm. This growth spotlights the escalating propensity for tear-out damage and hole oversizing when implementing very high drilling speeds, even in optimized composite materials. The optimal drilling speed for wood to avoid potential issues such as burning when drilling too fast or achieving a less desirable drill hole appearance when drilling too slow, Thierry (2023).

Table 7 : The Result of the Type Drill Bit against Particleboard.

Type of bit: Spotting drill bits

Wood based composite of 50% Rubber wood + 50% Kelempayan Wood (*Neolamarckia cadamba*)

Type of hole	Hole 1	Hole 2	Hole 3	Hole 4
Type of speed (rpm)				
300 rpm	 0.36mm	 0.32mm	 0.57mm	 0.47mm
600 rpm	 0.40mm	 0.51mm	 0.78mm	 0.76mm

900 rpm				
	1.14mm	0.81mm	0.54mm	0.32mm
1200 rpm				
	1.35mm	1.04mm	0.82mm	1.42mm
1500 rpm				
	0.53mm	0.66mm	0.54mm	0.67mm

The data presented in Table 7 offers useful insights into the dimensional accuracy and hole quality achieved when applying Spotting Drill Bits to drill holes in a composite material comprised of equal parts 50% Rubber Wood and 50% Kelempayan Wood (Neolamarckia cadamba). Examining the finished hole sizes generated across a range of spindle speeds enables meaningful observations regarding the performance of spotting drill bits when utilized on this blended substrate.

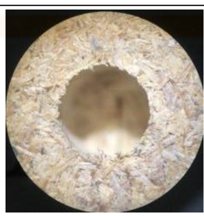
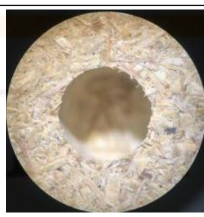
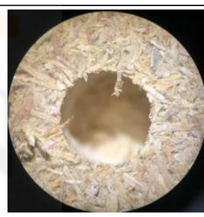
At the lowest test velocity of 300 revolutions per minute (rpm), Hole 2 exhibited the smallest diameter at just 0.32mm. This minimal measurement achieved at low speed indicates the potential for highly precise and accurate hole boring using spotting drill bits, with minimal tear-out or enlargement effects. As speed increased to 600 revolutions per minute (rpm), Hole 4 displayed conspicuous growth, expanding to a diameter of 0.76mm. This greater than doubling of the hole width at moderately higher velocity highlights the sensitivity of the drilling process and the composite material to fluctuations in spindle speed.

More dramatically, when operating at 900 revolutions per minute (rpm), Hole 1 showed severe oversizing, ballooning to a diameter of 1.14mm. This substantial enlargement spotlights the escalating risks of exponential tear-out damage and hole expansion when utilizing very high drilling speeds, despite the optimized material. In total, the data reveals a correlation between higher spindle velocities and increased hole diameters, with substantial defect growth occurring above 900 rpm, as evidenced by the outsized 1.42mm diameter measured for Hole 4 at 1200 revolutions per minute (rpm). Elevated spindle speeds and axial feeds are advantageous for achieving precise hole accuracy, facilitating the production of holes within H9 diameter tolerance, Sridhar et al. (2022).

Table 8 : The Result of the Type Drill Bit against Particleboard.

Type of bit: Twist drill bits

Wood based composite of 80% Rubber wood + 20% Kelempayan Wood (*Neolamarckia cadamba*)

Type of hole	Hole 1	Hole 2	Hole 3	Hole 4
Type of speed (rpm)				
300 rpm	 0.55mm	 0.64mm	 0.36mm	 0.40mm

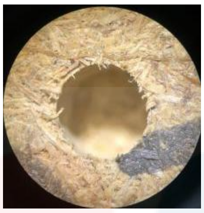
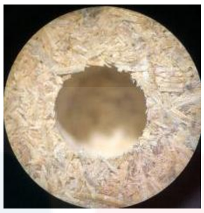
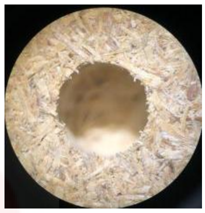
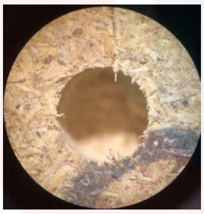
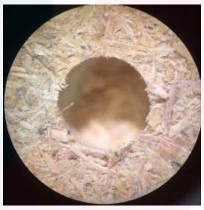
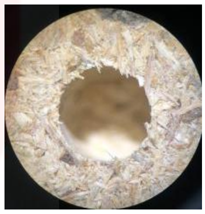
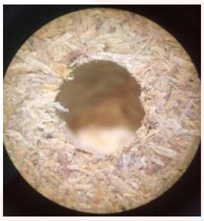
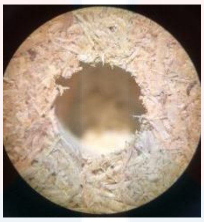
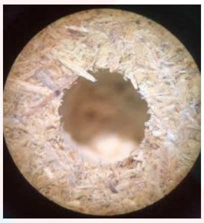
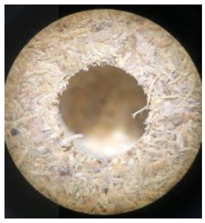
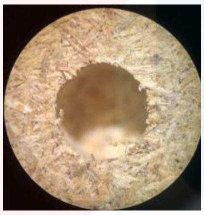
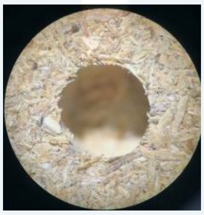
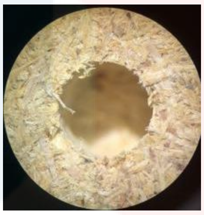
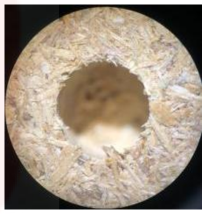
600 rpm				
	0.46mm	0.40mm	0.44mm	0.25mm
900 rpm				
	0.64mm	1.47mm	0.33mm	0.53mm
1200 rpm				
	0.82mm	0.47mm	0.60mm	0.84mm
1500 rpm				
	0.60mm	0.40mm	0.91mm	0.70mm

Table 8 provides a comprehensive overview of the performance of Twist Drill Bits when applied to an 80% Rubber Wood and 20% Kelempayan Wood (Neolamarckia cadamba) composite material at varying drilling speeds. Analyzing the results, we observe distinct trends in hole diameters at different rotational speeds. At a relatively low speed of 300 rpm, Hole 3 exhibits a precision level with a diameter of 0.36mm, showcasing the potential for high accuracy at reduced speeds.

As the drilling speed increases to 600 rpm, we find that Hole 4 demonstrates a minimal diameter of 0.25mm, emphasizing the tool's capability for enhanced precision at intermediate rates. However, a dramatic escalation in hole enlargement occurred when spindle speed was raised substantially to 900 revolutions per minute (rpm). Under these aggressive conditions, Hole 2 exhibited severe oversizing, with the diameter expanding exponentially to 1.47mm. This substantial increase over 5 times the 300 rpm measurement spotlights the risks of exponential tear-out damage and hole expansion when speeds exceed optimal levels.

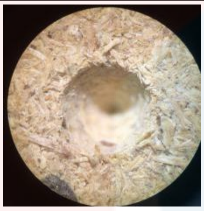
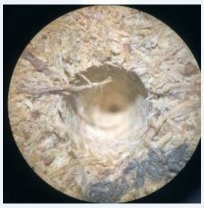
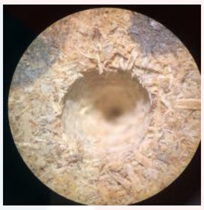
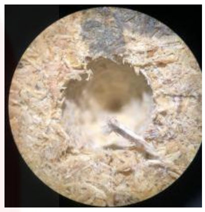
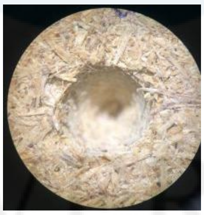
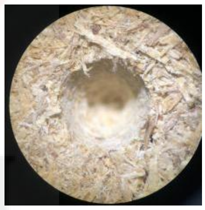
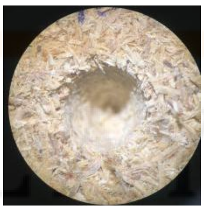
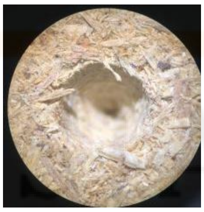
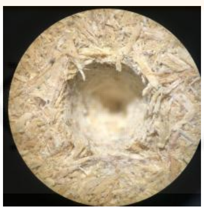
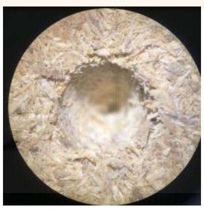
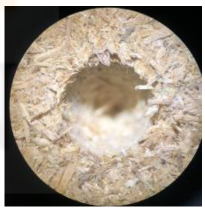
This observation suggests that higher speeds may result in larger hole sizes, indicating the importance of optimizing drilling parameters for specific applications. This information contributes to the broader understanding of Twist Drill Bit behavior on wood composites, offering practical implications for industries that rely on accurate and efficient drilling processes. The adhesion of wood particles and chip formation during drilling may be influenced by UF resin, potentially impacting the effectiveness of chip evacuation and the quality of the hole, Ramesh et al. (2022).

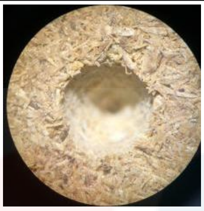
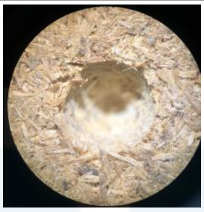
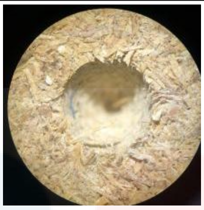
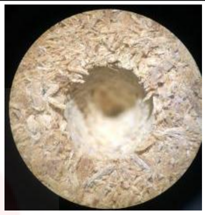
Table 9 : The Result of the Type Drill Bit against Particleboard.

Type of bit: Spotting drill bits

Wood based composite of 80% Rubber wood + 20% Kelempayan Wood

(*Neolamarckia cadamba*)

Type of hole / Type of speed (rpm)	Hole 1	Hole 2	Hole 3	Hole 4
300 rpm				
	0.58mm	0.79mm	0.69mm	1.11mm
600 rpm				
	1.18mm	1.05mm	1.16mm	0.78mm
900 rpm				
	1.03mm	1.15mm	0.77mm	0.84mm
1200 rpm				
	0.75mm	0.95mm	1.67mm	1.05mm

1500 rpm	 0.64mm	 0.75mm	 0.88mm	 0.99mm

The data presented in Table 9 provides useful insights into the hole dimensional accuracy and quality achieved when applying Spotting Drill Bits to drill holes in a composite material comprised of 80% Rubber Wood and 20% Kelempayan Wood (*Neolamarckia cadamba*). Examining the range of finished hole sizes generated across different spindle speed regimes enables meaningful observations to be made regarding the performance capabilities and limitations of spotting drill bits when used to machine this blended substrate.

At the lower speed of 300 revolutions per minute (rpm), Hole 1 displayed a tight diameter measurement of 0.58mm. This minimal hole width produced at reduced velocity indicates the potential for highly precise and accurate drilling with minimal defect formation when using appropriate speeds for the composite material. However, as speed was doubled moderately to 600 revolutions per minute (rpm), Hole 3 exhibited conspicuous enlargement, expanding substantially to a diameter of 1.16mm. This significant increase in hole size at a comparatively higher yet still intermediate rate highlights the sensitivity of the drilling process and tool-workpiece factors to changes in spindle velocity. The energy consumption in the drilling process results from the relative movement between the tool and the material of the workpiece, Wang et al. (2019)

This correlation between elevated speed and escalating hole dimensions was further evidenced by the size of Hole 2 when velocity was raised to 900 revolutions per minute (rpm). Under these more aggressive conditions, the diameter measured 1.15mm, nearly double the size of holes drilled at 300 rpm. The surface roughness and drilling time of wood composites are notably influenced by the choice of process parameters such as spindle speed, feed rate, and machining environment. This study underscores the impact of these parameters on the drilled hole quality in wood composites., Kumar et al.(2018).

Based on the full results of this study, the wood composite formulation with 50% kelamayan and 50% rubber fibers exhibited the lowest occurrence of defects in the drilled holes across the different drilling parameters tested. This specific material composition appears to perform better during drilling compared to the other natural fiber blended composites analyzed. The twist drill bit resulted in holes with fewer defects and higher dimensional precision compared to those drilled with the spotting drill bit, as evidenced by the results. The margins and chisel edge give the twist drill added stability and prevent wandering during drilling. In contrast, the spotting drill's straight flute design and lack of margins may make it more prone to deflection, buildup, and uneven wear. This could lead to the increased hole defects seen with the spotting drill. Out of the five drill speeds tested ranging from 300rpm to 1500rpm, the lowest speed of 300rpm produced holes with the lowest overall defect rates across the different drill bits and composite materials. Drilling at 300rpm appears to provide the most stable, controlled process leading to the highest hole quality. Overall, the slower speed provides a more forgiving, stable process before instability, vibration, and heat buildup effects onset at higher velocities.

CHAPTER 5

CONCLUSION & RECOMMENDATION

5.1 Conclusion

In conclusion, utilizing two distinct drill points, the twist drill bit and the spotting drill bit played a pivotal role. These drill points were strategically employed to explore their impacts on four wood-based composite materials. The deliberate use of both drill points in the drilling process aimed at facilitating comparative analysis of drilling efficiency and outcomes across these diverse wood-based compositions. This standardized methodological approach ensured comprehensive data collection to examine drilling performance thoroughly.

Overall, this controlled drilling study provides useful data to advance the knowledge of hole boring in wood-based composites. The findings highlight the importance of judicious selection and calibration of key parameters like spindle speed and material composition to attain target hole sizes while limiting undesirable tear-out. The demonstrated correlation between velocity and hole diameter underscores the need for informed parameter optimization in industrial composite drilling to balance productivity and precision. Further exploration around drill types, feed rates, point geometries, and composite formulations can continue building on these observations to refine best practices for managing the complex interdependencies governing machined hole quality. This research promotes more nuanced understanding of the dynamics influencing dimensional accuracy and defect formation when boring holes in wood-based materials.

5.2 Recommendation

Based on the comprehensive findings derived from the drilling experiment within the context of wood-based composite materials, a set of strategic recommendations can be proposed for optimizing drilling parameters and tool design. The experiment, encompassing various wood composites such as rubberwood, Kelempayan Wood (*Neolamarckia cadamba*), and their blends, revealed a notable sensitivity of hole dimensions to drill speed. To enhance performance and minimize defects in wood composites, it is recommended to meticulously tailor drilling parameters, particularly drill speed, to the specific composition of the material. For future researchers, I recommend expanding the study by exploring the speed parameter across a wider distance range. This adjustment aims to reveal nuanced speed effects over a broader spatial scope, enriching our understanding of their dynamic interplay. To streamline the study, focus on three key speeds—300rpm, 900rpm, and 1500rpm—to efficiently capture a comprehensive range while simplifying the experimental setup. Additionally, enhance result observation by using a digital microscope like Scanning Electron Microscopy (SEM). SEM provides detailed, high-resolution imaging, allowing for a meticulous examination of specimen intricacies. These refinements promise a more insightful exploration, contributing to a deeper understanding of the intricate dynamics between speed, distance, and their effects. This approach not only advances scientific knowledge but also holds practical applications in relevant fields.

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APPENDIX A

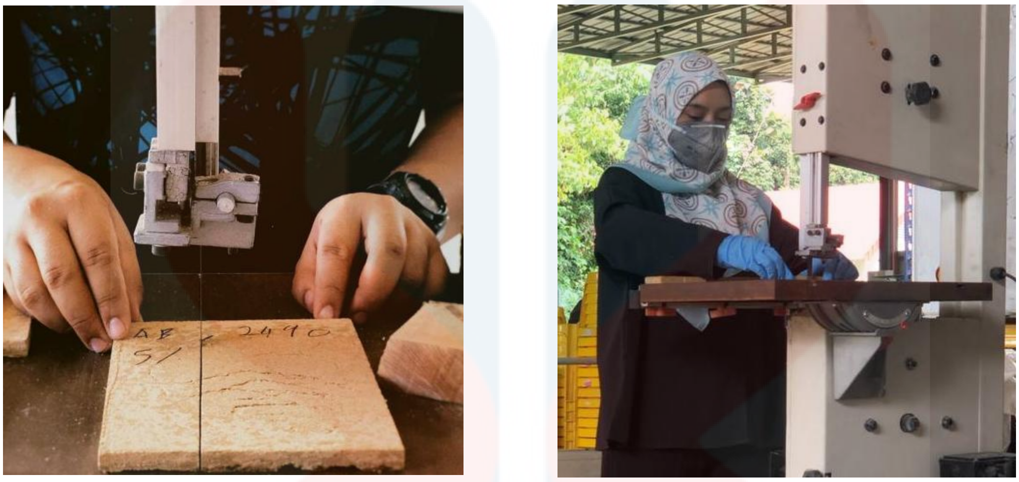

Figure A 1 : Cutting wood based composite using a table saw.

Figure A 2 : Cutting wood based composite using a table saw.

APPENDIX B

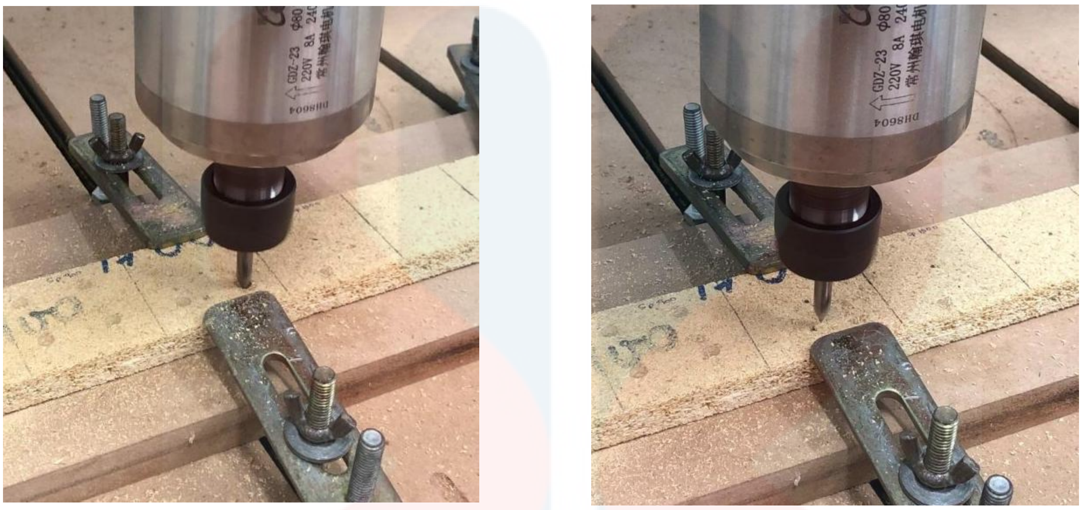

Figure B 1 : Drilling a hole in the wood-based composite.

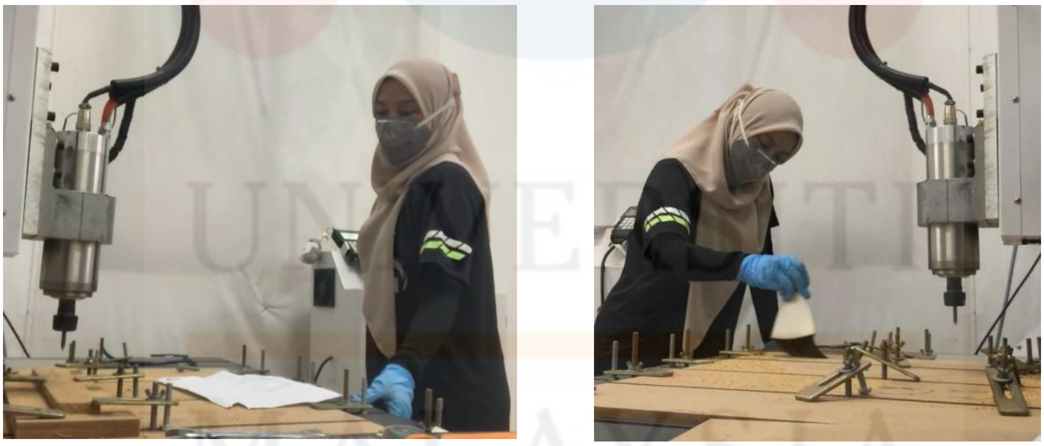

Figure B 2 : Control the CNC machine settings and clean the wood-based composite dust.

APPENDIX C

Figure C 1 : Twist drill bit and Spotting drill bit.

Figure C 2 : Microscope the hole and wood-based composite after drilling.