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Preliminary Investigation of Delamination Factor for Drilling Wood Plastic Composites (WPC)

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Abstract. This study examines the effect of the delamination factor on wood composite drilling. Drilling is one of the most important machining operations in the manufacturing process, operating in a variety of ways to make life better every day. The preliminary experiment focuses on the implementation of three drilling strategies to determine the most appropriate for drilling composite and to identify the effect of the machining parameters of wood plastic composite (WPC) drilling. The CNC machining centre is used at the factory of the local company to assist them in the provision of certain production inputs. It is observed that the single step drill peck is the best suited strategy for drill WPC with less delamination at the entrance and exit holes compared to the other two methods, 2-peck and 4-peck drills. Hole tends to create a peel-up and to force the delamination down heavily along the hole edge when using the 4-peck process while the least peel-up pattern happens when using a single-step method. The findings also show a large amount of peel-up delamination as the feed rate increases. Therefore, the final results are also useful in understanding the relationship between the drilling parameters and the cutting experiments.

1. Introduction
Composite materials are a mixture of two components: a matrix material that transmits mechanical strength, and a material that retains a composite strain. The material's accelerated development started in the second half of the twentieth century. Beginning in the 1980s, modern vehicles and aircraft became widely used in the defence field because they were items of better value than previous models. Rather of dealing with population and rising production costs, recombination of natural fibers is used in advanced composite technology [1, 2].

The main concern is how the delamination element will have an effect on wood plastic composites (WPC) during the drilling process. Demands are rising between industries as an alternative to other solid-wood composites. In addition, several wood product engineers are now expected to fill the gap. Nevertheless, drilling is always the most challenging process [3].

WPC is a mixture of a thermoplastic matrix and bits of wood, until it is usually recycled polyethylene or polypropylene, and the latter is reclaimed, e.g. sawdust and wood shavings. In the manufacture of WPCs, wood contaminants, e.g. sawdust, wood shavings or wood powder, are mixed in their final state with thermoplastic polymer and thermoformed (or thermoformed) melt, either as a continuous extrusion profile or as a 3-D injection moulding type. WPCs have expanded their market share as a key building feature in recent decades [4].

The purpose of this study is to provide the latest data required to check the best-suited drilling technique and to define new machining parameters for wood plastics composites (WPCs) drilling. In fact, this research will help companies to identify appropriate and insufficient drilling tools, handle less waste and reduce extra expenses when buying supplies and equipment. For more detailed features, a new wider approach will be focused such that less time is spent on studying how to drill wood plastic composites. This appeal can be partially explained by the fact that WPCs are competitively alternative choice compared to tropical hardwoods and are known to be less maintenance than conventional wood products. Using WPC, it is also possible to create more specific shapes than other solid wood products.

2. Materials and Methods

The research takes part two important phases of experimental testing. Phase 1 investigated preliminary drilling in order to identify the most suitable drilling strategy on WPC. While phase 2 is to study the effect of drilling operation parameters on WPC. The following paragraphs detail the workpiece material, tooling, equipment utilized in the experiments together with a brief description of procedure.

The workpiece material used was the 12 mm thick wood plastic composites supplied by eco-tourism-based company, Homestay Jeli, located in Ayer Puteh, Jeli, Kelantan, Malaysia. Due to the new construction site, the manufacturer had experienced some contaminants, so there are minimal tests to determine detailed specifications of the products. The materials were cut in 5 x 15 cm blocks using handsaw at the Universiti Malaysia Kelantan, Jeli Campus carpentry workshop.

This study focused on only one form of drill bit (Type: WC – coated carbide; Diameter: 8mm; Number of flutes: 2; Helix angle: 35°; Point angle: 118°; Chip flute length: 75mm). It is the type of tool commonly used in the furniture industry to drill composite material based on the recommendation of the local wood furniture company, Nik Lah Sdn. Bhd. located in Kota Bharu, Kelantan, Malaysia. The selected machining parameters were based on a literature review study and Table 1 shows the matrix table of cutting speed and feed rate parameters for both drilling strategies, i.e. 2- and 4-peck drilling.

Drilling samples were conducted in dry conditions. All phase needed to use WC drill bits to complete the study. Three drilling strategies consisting of peck drilling of 2 and 4 pecks as well as single stage drill. Holes shown were drilled accordingly, meaning the first hole was drilled with the lowest feed and the lowest speed, while the last hole was drilled with the highest feed and highest speed. The table also shows the combination of feeds and cutting speeds, where each hole was drilled to confirm that cutting parameters affect hole quality.

Table 1. Cutting speed and feed rate parameters

Feed Rate (mm/rev) / Cutting Speed (m/min)	0.090	0.10	0.20
80	H3	H6	H9
64	H2	H5	H8
40	H1	H4	H7

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A high-speed CNC drilling machine with the fastest spindle speed of 39000RPM was used for this experimental work for drilling WPC. Hole damage includes fiber pull-out, delamination, fiber-matrix de-bonding, heat damage and cracks were investigated. The literature review revealed that the one-dimensional delamination factor (Fd) as shown in equation (1) is the most widely applied tool used to measure the amount of damage to composite materials produced by a hole. As introduced by Chen [5], this method was used to measure the maximum diameter of the damaged zone or delamination around the hole, with the center point of the diameter of the damage being at the center of the hole. Holes were analyzed using the laboratory's digital microscope at the Universiti Malaysia Kelantan.

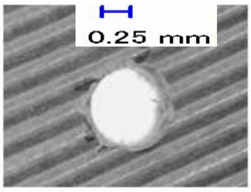
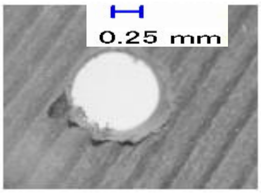
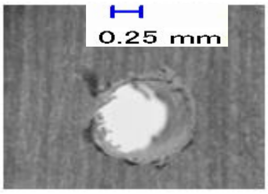
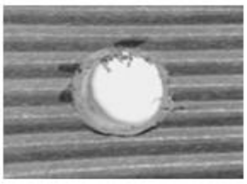
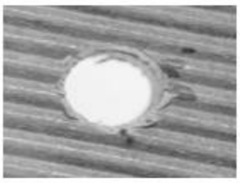
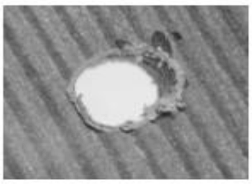
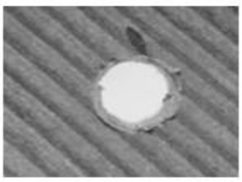
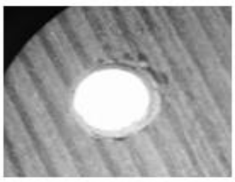
$$F_d = \frac{D_{max}}{D_0} \tag{1}$$

3. Results and Discussion

3.1 Phase 1: Preliminary drilling to determine the most suitable strategy

This section documents the early experiments conducted to establish the relationship between cutting parameters (i.e. feed rate and cutting speed) and hole size, which has a distinctive impact on surface cut size in wood plastic composite drilling. At this point, the evaluation focused only on the delamination factor in order to determine the best drilling. Table 2 shows an example of matrix table results for 2-peck drilling strategy. The blue ink marker had nothing to do with these experiments because the content had been left behind by the company.

Table 2. Example of 2-peck drilling strategy

Feed Rate (mm/rev) / Cutting Speed(m/min)	0.09	0.10	0.2
	H3	H6	H9
80			
	H2	H5	H8
64			
	H1	H4	H7
40			

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Visible damage was seen and observed in all the holes made, substantially peel-up and push-down delamination. Figure 1 shows an example of the damage to the hole entry. The damage to the hole was severe for the 4-peck drilling as the drilling stage rose during the drilling process. The question over consistency can easily be seen as a distinction between the two approaches, which were one-step and two-step drilling. Depending on the results, the most severe damage happened in the hole entries.

Although the delamination at the hole entries was commonly shown to be greater than the damage done at the hole exits, a closer examination of the hole defect exits, such as delamination and fiber overhangs in the table, shows that comparable harm was found, i.e. harm in a particular area, in the main case. In this sense, some of the affected thermal regions were thought to have specific lines radially spreading in these areas, where the high thermal conductivity of plastic composites, in comparison to the nearest matrix, permitted the heat generated during the cutting process to disperse inside the fibers. With the 2-peck drill, hole 2 has more delamination found on the front side relative to hole 1. Though Hole 3 had exactly the same peel-up delamination as Hole 2. An increase in cutting speed for the same feed rate of 0.09 mm was observed impacting the opening side of hole 1, hole 2 and hole 3.

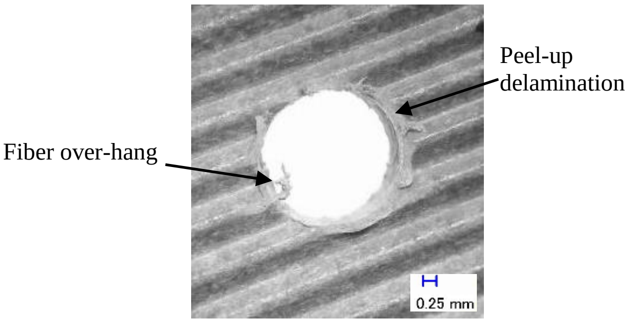

Figure 1. Example of hole 8 (H8) of the 4-peck drilling strategy

While input hole 6 was more impacted, more peel-up delamination as feed rate increased to 0.1 mm per rev relative to hole 4 and hole 5. As for the last three holes, hole 8 was a bit oval but still comparable in peel-up delamination to hole 7 and hole 6. There was a small variation in the consistency of the hole as various feed rates were added. Groovy substance surface structures are an apparent source of delamination. This groovy structure was initially designed to provide a grasping function when binding to some other type of material, but when it comes to drilling, it can cause a drill bit to travel faster than normal to create a hole, resulting in either mild or extreme delamination in the early and final drill.

In the meantime, the 4-step drilling has nonetheless achieved the worst outcome relative to other techniques. Some holes in the 4-peck drilling were very poorly delaminated. Many of the holes have one or both of them peel-up and push-down delamination. Because of the drilling process, the fiber was pulled up and down, causing the hole to be used as peel-off. The same combination of feed and pace was used to investigate all final holes in this technique as single-peck and 2-peck drill, which still gives a more severed result.

As a result, 2-peck and 4-peck drilling provided a lot of heat created during drilling, as the tool needed to emerge two to four times faster than single-step drilling, where there was less contact time between the tool and the workpiece [6]. It means that the efficiency of the hole was not quite dependent on the cutting criteria, but should not be affected by the advancement of the tool 's wear. As a result, the single-peck drilling procedure was found to be the safest tool to be used for drilling the WPC surface.

3.2 Phase 2: Effect of operating parameters

An analysis on the hole entry damages was conducted to observe the delamination factor. Images recorded can confirms the relations of feed, cutting speed and quantity of damages to entry and exit holes. Each holes were drilled by the one same drill bit, and it resulted in a significant amount of peel-up delamination as the feed rate was increased. In the meantime, the use of same feed rate with increasing speed happened to reduce the peel-up delamination. The drilling process becomes technically more challenging as the surface of material is created in groovy structures, not as flat structures as normal WPC surface had. The thickness became greater as the composite resisted the fibre from bending. The effect can be seen as the damage surrounding and along the hole edge (peel-up, push-down, fibre uncut). The cutting parameters also affected the hole quality. The main idea of this occurrence is the optimization of the force peeling as the vital role in hole damage. In normal practice, torque and the thrust force are the components for the peeling force [7]. It is obvious since they are usually related to the initial of delamination. The highest delamination factor (Fd) ratio was 1.29 for hole 9 (H9) of 4-peck drilling, while the lowest Fd ratio was 1.13 for hole 3 (H3) of single-step drilling.

During early process, the peeling force should be avoided by managing the cutting parameter. It is said that delamination at the entry hole was hugely affected by the feed rate, as much that as an increase in feed rate would bring to an increase in the delamination fact [6]. Even the slightest wear would cause the decrease of quality of cut, so the actual tool wear amount should be kept in small range.

As for the exit damages, it is observed that there was less total damage occurred. There were not much damages to be called severe such as fibre uncut or delamination. But other researchers had different ideas as past studies found [1, 6, 7, 8] that the damage was highly occurred at hole exit and mostly of them observed more views and attention to the push-out delamination. In addition, the alteration of the speed at the cutting or feed rate appears to have an obvious lesser effect on the damage to the exit hole than the entrance hole. As for that, the main focus of this study was on the best suitable form of drilling, along with the least damage occurred either at the exit or entry hole. Peel-up damage seems to be the major damage observed at each holes compared to damage from push out since the strategy requires the drill bit to be pull out and push in for a few times inside the composite.

With addition of the groovy structure presence at the top surface of the wood plastic composites, making the drilling resulted in more variable ways to be recorded. Not to forget that the structure of wood plastic composite is a mixture of wood and plastic, making it far stronger and durable combination compared to when they are not combined together, suited with their various functionality across the globe. Moreover, as the drill bit entered the workpiece, it was assumed that a steady increase of thrust force occurred before it reached a constant value then it settled down once drill had penetrated the surface layer. The mechanism was always aligned with the steady drilling through the thickness of the workpiece. Then, it was followed by a steep drop as tool passed through the downward side. This was confirmed by other researchers as well [6, 8].

4. Conclusions and Future Work

The goal of this preliminary experiment was to include the latest data needed to review the best-adapted drilling methodology and to identify new machining parameters for wood composite plastics (WPCs) drilling. Single-peck drilling strategy was the appropriate strategy for drilling wood plastic composites. While 2-peck drilling strategy can be an easier form of drilling, with less delamination occurring at the bottom of the hole after the full hole has been drilled compared to a 4-peck drilling strategy. The machining parameters had an impact on the quality of the hole, especially in the hole entries. Delamination is a crucial element in drilling, because it can render the materials not stable enough to be used. Moreover, the use of the same feed rate with rising speed had been shown to increase the peel-up delamination.

Tool performance is also an important consideration to prevent further delamination around the hole bottom. Wood plastic composite is a combined material which possesses upgraded mechanical properties and now is widely preferred by many wood-based products companies in terms of wall building, paneling and many other exterior functions.

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