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MECHANICAL PROPERTIES OF SANDWICH LAMINATES COMPOSITE ON PLYWOOD AND GLASS FIBERS

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ABSTRACT

The reinforcement of solid wood and wood-based composite materials is not a new idea, but there have been very few studies about reinforcing plywood with glass fiber composite. In this study, woven glass fibers were used on both outer surfaces of plywood sandwich laminates composite with the help of epoxy resin to improve mechanical properties of standard plywood laminated. The vacuum bagging technique was applied to fabricate plywood sandwich laminate composite test samples with three different thicknesses which is 3 mm, 5 mm and 9 mm, and their mechanical properties were analyzed using tensile and surface roughness tests for different cutting speed parameters of laser cut machine. The collected data were analyzed using analysis of variance (ANOVA), and the microscopic investigation was performed to examine the cross-section structure of ruptured surfaces and its failure morphology during cutting process.

Keywords: plywood, glass fiber, mechanical properties, laser cut machine.

1. INTRODUCTION

The wood-based composites sector plays an important role in national economies in many countries. Plywood is one of the wood-based composite that widely used for different applications, such as construction, furniture manufacturing, means of transportation, packaging, decorative purposes, and many others. According to Sankar and Sajan [1], the global plywood market was valued at USD 71870 million in 2019 and it is expected to reach USD 84430 million by the end of 2026. Plywood has several advantages such as low density, good thermal insulation and sound insulation. However, it also has disadvantages, such as high variability, and low strength, which diminish the physical and mechanical properties of plywood. Usually, plywood is typically produced from fast-growing forest plantations, giving it undesirable characteristics such as dimensional instability and susceptibility to biological degradation and therefore, making it unsuitable for outdoor and long-term use [2, 3, 4]. To resolve this issue, the combination of synthetic fibers with wood-based composites such as plywood was found to be a good alternative reinforcing material due to an increase in its strength.

In recent years, many researchers have studied the physical and mechanical characteristics of the combination of wood-based composites such as plywood and synthetic fibers. Ismail *et al.* [5] evaluated the formaldehyde emission and some mechanical properties such as shear strength, bending strength and modulus of elasticity of plywood panels manufactured from rotary cut veneers having different moisture content by using urea-formaldehyde and modified urea formaldehyde by melamine. Pavlo *et al.* [6] evaluated some of the physical and mechanical properties of plywood manufactured from compressed veneer of birch (*Betula pubescens*) and alder (*Alnus glutinosa*) using a cold rolling process. An experimental investigation was presented by Choi *et al.* [7] on the effect of buckling load to the plywood reinforced with glass fiber composite materials with various composite thicknesses. Yuan *et al.* [8] investigated plywood composites laminated with carbon fiber paper in terms of electromagnetic shielding. They discovered that carbon fiber paper is a potential material for industrially producing hardwood composites with high shielding effectiveness. Bal *et al.* [9] analyzed on the physical and mechanical properties of the reinforcement of plywood with glass fiber fabric using various tests. The mechanical properties, such as density, moisture content, water absorption, bond strength and screw-holding capability, as well as the thermal and sound insulation properties of the carbon fiber composite plywood were analyzed [10]. Flexural properties, water absorption, density, cutting force, and tensile shear strength of the reinforcement layer between plywood panels and carbon fibers were tested and evaluated by Auriga *et al.* [11].

The cutting process plays an important role in achieving the quality of finishing composite materials, especially on the tool geometry, machining conditions, or parameters applied to the machine. According to Sekhar and Singh [12], output responses of various machining processes are mainly determined by cutting conditions. Then the tool geometry, machining conditions and parameters impact machinability profoundly. Ramesh *et al.* [13] analyzed the drilling machine characteristics of the glass-sisal-jute fibers reinforced hybrid composites by varying the cutting speed, feed rate, and tool geometry. The effects of the production parameters on thrust force and surface roughness of metal matrix composites drilled with different feed rate was presented by Salur *et al.* [14]. Maneiah *et al.* [15] optimized the input process parameters such as feed rate, stand of distance and abrasive flow rate for surface roughness during abrasive water jet machining of aluminum or magnesium hybrid metal matrix composites using Taguchi approach. Furthermore, the effects of the machining parameters and the kinematics of material removal during end milling of kenaf, jute and rice husk reinforced polypropylene composites has been

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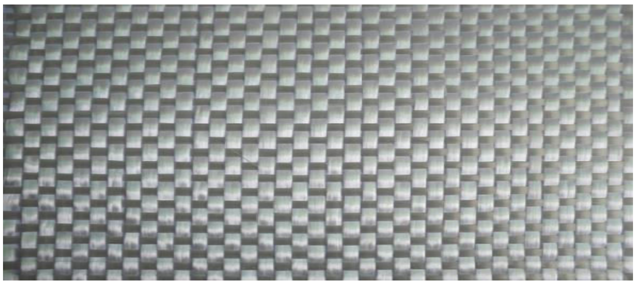
analyzed using a two-factor and three-level experimental plan [16].

This study is aimed to analyze the mechanical properties of plywood sandwich laminate composites and the effects of laser cut machine cutting speed parameters. Three different cutting speed parameters were used to determine the effects of production parameters on the surface roughness. At the same time, the mechanical properties of plywood sandwich laminate composites were investigated based on the tensile test. Finally, the experimental results were interpreted and presented via statistical analyses

2. MATERIALS AND METHODS

In this study, plywood and woven glass fiber were used for laminate preparation with the help of epoxy resin, as shown in Figure-1. These materials were purchased from a local company, and their mechanical properties are shown in Table-1.

(a)



(b)

(c)

Figure-1. (a) Plywood. (b) Woven glass fiber. (c) Epoxy resin.

Table-1. Mechanical properties of plywood, woven glass fiber and epoxy resin.

Properties	Plywood	Glass Fiber	Epoxy Resin
Density (g/cm3)	1.38	2.54	1.2
Modulus of elasticity (GPa)	8.55	75	2.7
Specific Gravity (gm/cc)	0.6	2.5	-
Poisson's ratio	0.22	0.22	0.4

Hybrid laminates of plywood and woven glass fibers in sandwich form were prepared by the usual hand lay-up technique. The woven glass fibers are placed on both outer surfaces (face skin) and the plywood is placed on the middle (core) of plywood sandwich laminates composite as shown in Figure-2. Next, the vacuum bagging technique was used to cure the sandwich laminates of plywood and glass fibers. Three groups of sandwich laminate composite samples with different thicknesses (i.e. 3 mm, 5 mm and 9 mm) were prepared. The fabricated composites were cut using a Laser Cutting Machine FO MII 3015 N to obtain the dimensions of the specimen for mechanical testing as per standard. The cutting parameters of the laser cut machine used in this study are shown in Table-2.

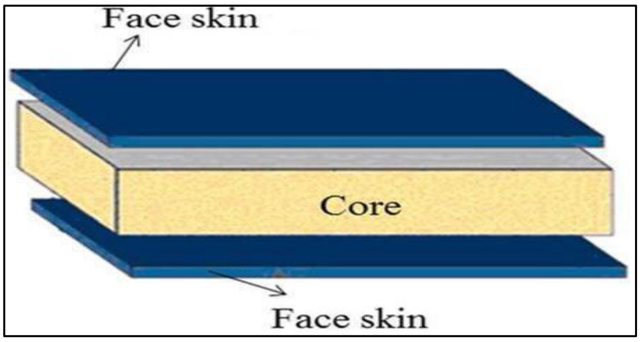


Figure-2. Plywood sandwich laminates composite.

Table-2. Cutting parameter of laser cut machine.

Parameter	Level 1	Level 2	Level 3
Cutting speed (mm/min)	2000	2500	3750
Gas pressure (Mpa)	0.5	0.5	0.5
Gas type	Co2	Co2	Co2
Nozzle gap (mm)	1	1	1
Power (W)	1000	1000	1000
Nozzle diameter (mm)	2	2	2

The specimens of plywood sandwich laminate composites were prepared for the tensile test as per the ASTM D3039 standard size. This test was performed using the universal testing machine. The elongation of the specimen during the test was recorded. The test was repeated seven times for each specimen thickness, and the results were analyzed using one-way analysis of variance (ANOVA).

The specimens of plywood sandwich laminate composites were prepared for the surface roughness test. This test used a microcomputer-based viewing device to analyze scattered light patterns from the surface to obtain the parameter of ruggedness. Reading was taken three times for each specimen, and three specimens were chosen for each thickness and laser cut machine cutting speed parameters. Therefore, a total of nine results were obtained from the surface roughness test for each thickness of plywood sandwich laminate composites.

To investigate the surface roughness of plywood sandwich laminate composites after the cutting process using a laser cut machine, few selected samples were chosen to capture real cross-sections images of the specimens using microscope Nikon ECLIPSE LV100. The tested samples were analyzed to capture the heat-affected zone.

3. RESULTSANDDISCUSSIONS

3.1 Tensile Strength of Plywood Sandwich Laminates Composites

To investigate the mechanical properties of the experiment, tensile test is performed to get the tensile strength and elongation of plywood sandwich laminate composites with three different thicknesses such as 3 mm, 5 mm, and 9 mm. Then, ANOVA was applied to analyze the tensile strength and elongation of the materials as shown in Tables 3 and 4, respectively. The results presented that the tensile strength and elongation of plywood sandwich laminate composites for all different thicknesses were significant since the value of significant is smaller than the significant cut-off level which is $\alpha = 0.05$. The variation of tensile strength and elongation for various thicknesses of plywood sandwich laminate composites is shown in Figures 3 (a) and 3 (b), respectively. The results showed that the value of tensile strength for plywood sandwich laminate composites with a thickness of 3 mm is greater than the other composites with different thicknesses (i.e. 5 mm and 9 mm) (Figure-3 (a)). Comparatively, the highest thickness (9 mm) had the lowest value of tensile strength (Figure-3 (a)). However, the plywood sandwich laminate composites with a thickness of 3 mm and 9 mm have the highest and lowest value of elongation, respectively, as presented in Figure-3 (b). This observation suggested that the tensile strength of the plywood sandwich laminate composites become weaker as thickness increases.

Table-3. ANOVA of tensile strength for plywood sandwich laminate composites with different thicknesses.

Source of Variation	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	11530.22	2	5765.11	234.19	1.30184×10^{-13}
Within Groups	443.09	18	24.61		
Total	11973.32	20			

Table-4. ANOVA of elongation for plywood sandwich laminate composites with different thicknesses.

Source of Variation	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	303.15	2	151.57	106.03	1.099×10^{-10}
Within Groups	25.73	18	1.42		
Total	328.88	20			

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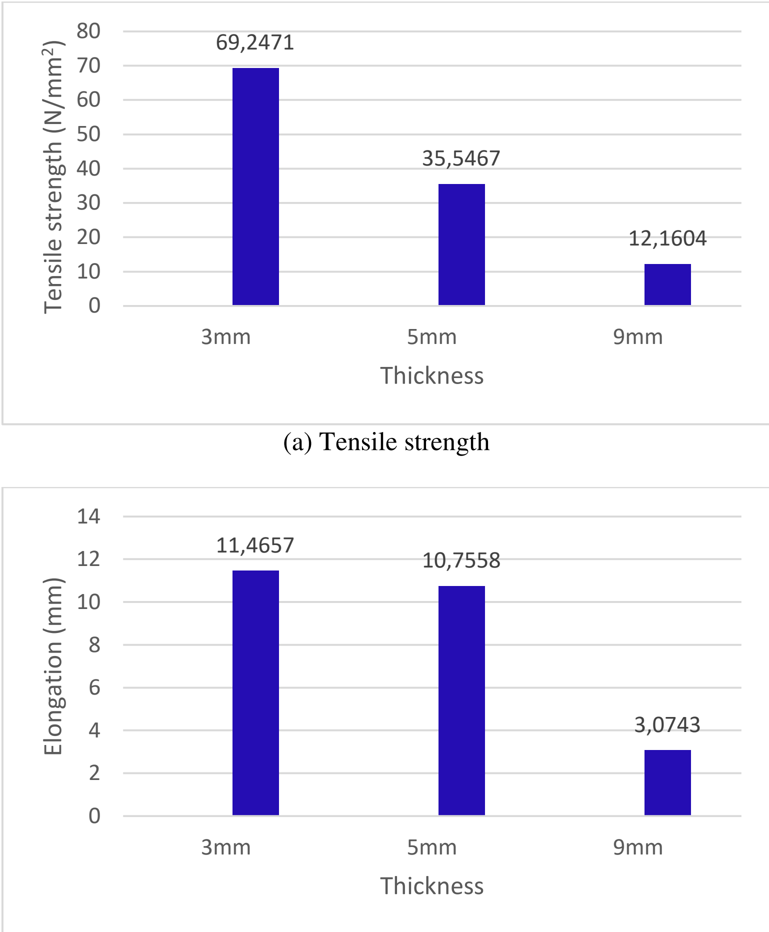

(a) Tensile strength

(b) Elongation

Figure-3. Tensile strength and elongation for various thicknesses of plywood sandwich laminate composites.

3.2 Surface Roughness of Plywood Sandwich Laminate Composites

Three different cutting speed parameters for the laser cut machine were applied (i.e. 2000 mm/min, 2500 mm/min and 3750 mm/min) with a 1 mm nozzle gap, and carbon dioxide gas was used. The relationship between surface roughness of plywood sandwich laminate composites and three different cutting speed parameters for 3 mm, 5 mm, and 9 mm thicknesses was analyzed using ANOVA as shown in Tables 5, 6 and 7, respectively. The results indicated that the laser cut machine cutting speed parameters for plywood sandwich laminate composites with the 3 mm and 9 mm thicknesses were not significant since the value of significant is larger than the significant cut-off level $(\alpha = 0.05)$ as presented in Tables 5 and 7, respectively. However, the laser cut machine cutting speed parameters for plywood sandwich laminate composites with a 5 mm thickness were significant since the value of significant is smaller than the significant cut-off level $(\alpha = 0.05)$ as presented in Table-6. This observation indicated that all the surface roughness of plywood sandwich laminate composites has equal average even though the laser cut machine cutting speed parameters are different, and this condition is applied to 3 mm and 9 mm of thicknesses.

Table-5. ANOVA for surface roughness of plywood sandwich laminate composites with a thickness of 3 mm.

Source of Variation	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	52.92	2	26.46	2.14	0.139164284
Within Groups	296.33	24	12.34		
Total	349.25	26			

Table-6. ANOVA for surface roughness of plywood sandwich laminate composites with a thickness of 5 mm.

Source of Variation	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	30.54	2	15.27	6.26	0.006474069
Within Groups	58.52	24	2.43		
Total	89.07	26			

Table-7. ANOVA for surface roughness of plywood sandwich laminate composites with a thickness of 9 mm.

Source of Variation	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	0.81	2	0.41	0.13	0.878581574
Within Groups	75.43	24	3.14		
Total	76.25	26			

The relationship between surface roughness of plywood sandwich laminate composites and three different types of thicknesses (i.e. 3 mm, 5 mm and 9 mm) for 2000 mm/min, 2500 mm/min and 3750 mm/min laser cut machine cutting speed parameters was analyzed using ANOVA as shown in Tables 8, 9 and 10, respectively. The results presented that the thicknesses for plywood sandwich laminate composites with a 2000 mm/min laser cut machine cutting speed parameters were significant since the value of significant is smaller than the significant cut-off level $(\alpha = 0.05)$ as presented in Table-8. However, the thicknesses for plywood sandwich laminate composites with the 2500 mm/min and 3750 mm/min laser cut machine cutting speed parameters were not significant since the value of significant is larger than the significant cut-off level $(\alpha = 0.05)$ as presented in Tables 9 and 10, respectively. This observation indicated that all the surface roughness of plywood sandwich laminate composites has equal average even though the thicknesses are different, and this condition is applied to 2500 mm/min and 3750 mm/min of laser cut machine cutting speed parameters.

Table-8. ANOVA for surface roughness of plywood sandwich laminate composites with 2000 mm/min cutting speed parameters.

Source of Variation	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	40.36	2	20.18	9.63	0.00084977
Within Groups	50.28	24	2.09		
Total	90.64	26			

Table-9. ANOVA for surface roughness of plywood sandwich laminate composites with 2500 mm/min cutting speed parameters.

Source of Variation	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	1.49	2	0.74	0.41	0.67084404
Within Groups	43.93	24	1.83		
Total	45.42	26			

Table-10. ANOVA for surface roughness of plywood sandwich laminate composites with 3750 mm/min cutting speed parameters.

Source of Variation	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	88.53	2	44.27	3.16	0.06044637
Within Groups	336.07	24	14.01		
Total	424.61	26			

3.3 Microscopic Cross-Section Capture Image


(a) 3 mm


(b) 5 mm


(c) 9 mm

Figure-4. Capture image of plywood sandwich laminate composites with 2000 mm/min laser cut machine cutting speed parameters.


(a) 3 mm


(b) 5 mm


(c) 9 mm

Figure-5. Capture image of plywood sandwich laminate composites with 2500 mm/min laser cut machine cutting speed parameters.


(a) 3 mm


(b) 5 mm


(c) 9 mm

Figure-6. Capture image of plywood sandwich laminate composites with 3750 mm/min laser cut machine cutting speed parameters.

The real cross-section capture image of plywood sandwich laminate composites for three different thicknesses by applying 2000 mm/min, 2500 mm/min and 3750 mm/min laser cut machine cutting speed parameters are presented in Figures 4, 5 and 6, respectively. Microscopic cross-section capture image showed that the worst heat affected zone existed on the plywood sandwich laminate composites with the 3750 mm/min laser cut machine cutting speed parameters for all types of thicknesses as showed in Figure-6. The heat-affected zone existed at the middle of the sandwich laminate composite, which is located at the plywood specimen part but not at the glass fiber specimen part. Therefore, it is obvious that a faster cutting speed parameter of the laser cut machine would result in a bigger area on the heat-affected zone.

4. CONCLUSIONS

In this study, the mechanical properties and the effects of laser cut machine cutting speed parameters on various thicknesses of plywood sandwich laminate composites have been investigated. The study pointed out that plywood sandwich laminate composites result in a decrease in tensile strength and elongation as thickness increases. Besides, based on ANOVA results, laser cut machine cutting speed parameters for the plywood sandwich laminate composites with the highest and smallest thicknesses (i.e. 3 mm and 9 mm) were not significant. Whereas, the slowest laser cut machine cutting speed parameters (2000 mm/min) were significant. The microscopic investigation of the surfaces of composites with a faster cutting speed parameter revealed that the existence of a heat-affected zone.

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