TECHNICAL NOTE: EFFECTS OF POLYURETHANE RESIN ON THE PHYSICAL AND MECHANICAL PROPERTIES OF WOOD FIBER/PALM KERNEL SHELL COMPOSITE BOARDS

Faizatul Azwa Zamri
Research Engineer
System Engineering and Energy Laboratory
Kuala Lumpur University MSI (Malaysian Spanish Institute) Malaysia
Kulim Hi-Tech Park, 09000 Kulim Kedah, Malaysia
E-mail: faizatulazwa.zamri08@s.unikl.edu.my

*Walter Charles Primus**
Dr/Senior Lecturer
Department of Basic Science and Engineering
Faculty of Agriculture, Science and Technology
University Putra Malaysia Bintulu Campus
97008 Bintulu, Sarawak, Malaysia
E-mail: walter@upm.edu.my

Abdul Halim Shaari
Professor
Physics Department
University Putra Malaysia
43400 Serdang, Selangor, Malaysia
E-mail: ahalim@upm.edu.my

Aaliyawani Ezzerin Sinin†
Department of Basic Science and Engineering
Faculty of Agriculture, Science and Technology
University Putra Malaysia Bintulu Campus
97008 Bintulu, Sarawak, Malaysia
E-mail: aaliyawanisinin@gmail.com

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Abstract. This article investigates the effect of polyurethane (PU) resin as a binding agent for wood fiber (WF) and palm kernel shell (PKS) composite board in terms of physical and mechanical properties. A series of fiberboard samples consisting of WF/PKS at a ratio of 85/15 with different percentages of PU adhesive (40%, 50%, and 60%) have been fabricated. The results showed that flexural modulus, flexural strength, tensile modulus, tensile strength, and hardness of the boards were increased with the increase in PU adhesive percentage. The effects of the binder were also explained in terms of porosity and surface morphology. Based on the results, the board met the Japanese Industrial Standard A 5905 for type 5 and can be classified as medium-density fiberboard, which could potentially be used in the decoration application. Replacing formaldehyde with PU resin as a binding agent in fiberboard composites is one way of avoiding health issues.

Keywords: Composite, WF, oil PKS, PU adhesive, mechanical properties.

INTRODUCTION

The demands on wood products keep increasing with the increase in population, but the supply of wood resources is limited. This forces the wood

* Corresponding author
† SWST member

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industry to find alternative resources to replace the existing wood fiber (WF) with other lignocellulose materials or blend to produce composite products. Fiberboard composite can be categorized into hard, medium, and low based on its density. The medium-density fiberboard (MDF) is made from lignocellulosic fiber combined with a synthetic resin or other suitable bonding systems that are combined together under heat and pressure. It is denser than plywood or particleboard (Mahzan et al 2011) makes the MDF industry growth tremendously because of the wide range of application as construction materials, furniture, interior design, and packaging materials.

Nowadays, the WF is obtained from both fresh and recycled wood material and mixed with a variety of agricultural waste such as palm kernel shell (PKS). In the polymer composite industry, PKS from oil palm fruit is widely used as a biodegradable filler because of its good mechanical and physical properties (Jain et al 2013). Despite having a high rupture force (~3000 N to ~4000 N), PKS also possesses ~11% to ~28% of porosity (Dagwa and Ibhadode 2008; Davies 2012; Edmund et al 2014). These properties also make PKS suitable for bonding with any binder and fiber.

Presently, few types of binders such as urea–formaldehyde (UF) resin, phenolic resin, melamine resin, and isocyanates are commonly used in fiberboard composites. The awareness of health hazard and environment pollution produced from the existing MDF using related formaldehyde resin and isocyanates reveals nontoxic resins are more favorable in making composite materials. A number of research on PKS as reinforcement in the polymer composite have been reported to have good mechanical properties such as in recycled polyethylene/PKS (Olumuyiwa et al 2012), polyester/PKS (Shehu et al 2014), polypropylene/PKS (Jain et al 2013; Ong et al 2016), and low-density polyethylene/PKS (Salmah et al 2011). Mahzan et al (2011) used PU as the resin in MDF composite material using recycled rubber and coconut coir, and show the mechanical properties met the requirement for application. PU is a polymer composed of organic units joined by carbamate (urethane) links. Most PUs are thermosetting polymers that do not melt when heated, but thermoplastic PUs are also available (en.wikipedia.org/wiki/Polyurethane). Table 1 shows the basic physical and mechanical properties of PU.

Their excellent mechanical properties, stability, as synthetic bone and good biocompatibility give them a special place in medicine (O'Neill et al 2012). In terms of cost, the PU price is a bit higher than that of the UF, melamine formaldehyde, and melamine–UF, but it is more readily available in the market. Although PU has been used widely as a binder in many composite materials, the compatibility of PU mixed with PKS and WF to produce composite product are not yet being reported. Therefore, this article reports the effect of Pu on the mechanical properties of WF/PKS composite.

MATERIALS AND METHODS

A fiberboard composite consisting of WF, PKS, and PU adhesive as a binder, as shown in Fig 1,

Table 1. Properties of polyurethane.

S. No.	Properties	Unit	Range
1	Specific gravity	—	1.1-1.46
2	Density	kg/m^3	1125
3	Tensile strength	MPa	18
4	Tensile modulus	GPa	0.8-1.1
5	Compressive strength	MPa	90-250
6	Flexural strength	MPa	30
7	Flexural modulus	GPa	1.2-1.5
8	Shrinkage	%	0.004-0.008

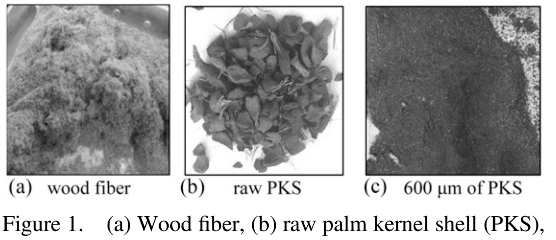

Figure 1. (a) Wood fiber, (b) raw palm kernel shell (PKS), and (c) 600 μm of PKS.

was prepared according to a wet-process method. The PU adhesive used in this fiberboard was bought from RS online store at a low cost. First, the WF was sieved using a 2.0-mm sieve to obtain WF of even WF dimension and then sprayed with distilled water before the mixing process; meanwhile, PKS was washed using a detergent to minimize the oil residue and then dried at 140°C for 30 min in an oven. After cooling, PKS was ground using a kernel grinder model IKA MF 10 Basic (IKA@Works, Sdn Bhd, Rawang, Selangor, Malaysia) and sieved to obtain 600 μm particles.

An amount of PU (40%, 50%, and 60% from the total mass of WF/PKS) was added into 85% of WF and 15% of PKS composition before mixing homogeneously using a mixer for 30 min. After that, the mixed compound was placed into the mold, where a plastic cover was placed on the top and bottom mold, and sprayed with WD-40 lubricant (WD-40 Company, San Diego, CA) to avoid the sample sticking on the mold surface. The sample inside the mold was preheated in the oven at a temperature of 140°C for 30 min. Then, the sample inside the mold was directly pressed at 15 MPa using a mechanical press and further heated at 140°C for 1 h. Finally, the heated sample was taken out from the oven and left for 24 h for further curing. Then, the molded composite was removed from the sample and stored at room temperature for 2 d for conditioning. The dimensions of samples prepared are 10.5 cm width, 13.0 cm length, and approximately 0.3 cm thickness, as shown in Fig 2.

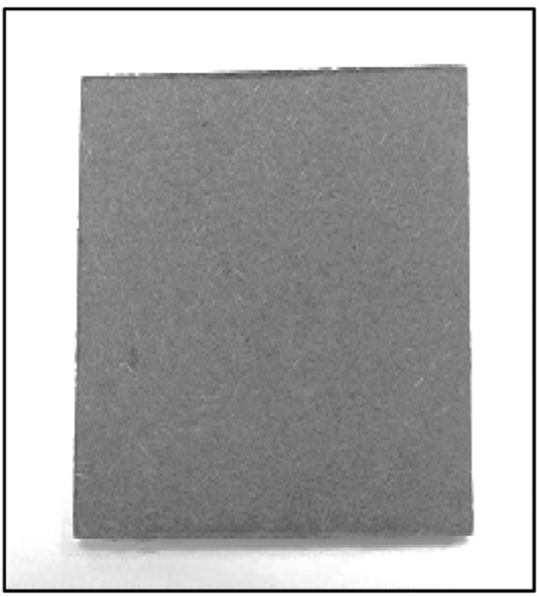

Figure 2. The fiberboard composite.

The density measurement was performed according to the Japanese Industrial Standard (JIS) A 5905 (JIS A 5905 2003). The particle density of the fiberboard samples was determined using the helium psychometric test model AccuPcy II 1340 Micromeritics equipment (Micromeritics Instrument Corporation, Norcross, GA). Microstructure observation on the fracture surface was carried out using a scanning electron microscope (SEM-CARL ZEISS MA10, Carl Zeiss Microscopy GmbH, Oberkochen, Germany). The mechanical properties of the WF/PKS composite board were measured using flexural, tensile, and hardness tests. Flexural and tensile tests were conducted using a universal testing machine from HAIDA equipment and TM2101 software (HAIDA International, Dongguan City, Guangdong Province, China). The flexural modulus and flexural strength values were obtained from the flexural test. The tensile test was carried out to obtain tensile modulus and tensile

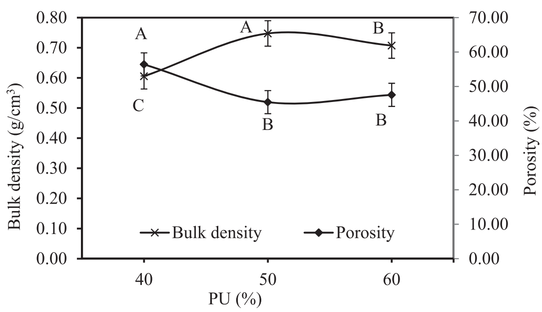

Figure 3. Bulk density and porosity of WF/PKS composite board for different polyurethane (PU) contents. Different alphabets indicate significant difference between means using Tukey's Honestly Significant Difference (HSD) test at $p \leq 0.05$. The error bars are the ±SE or triplicates.

strength properties. The sample dimension used for flexural test is 50 mm × 130 mm and 20 mm × 130 mm (width × length) for tensile test. The gauge length of the test piece is 80 mm. The crosshead speed was set up to 10 mm/min according to the JIS A 5905 fiberboard standard for MDF or insulating board. Hardness test was carried out using INOVA Rockwell Hardness tester model CV-600MBDL/S (CV Instruments, Bradford, West Yorkshire, United Kingdom). Rockwell hardness values were obtained from the average of four readings.

RESULTS AND DISCUSSION

Physical Properties

For the determination of physical properties of the WF/PKS composites, the bulk density, porosity, and surface morphology were measured and observed. Figure 3 shows that density of the WF/PKS composite generally increases with an increase in PU but decreases with 60% PU composition. This is because excessive amount of PU causes low compactness of composites and high porosity in the composite. The density value obtained for 40% was 0.61 g/cm^3, 0.75 g/cm^3 for 50% of PU addition, and 0.71 g/cm^3 for 60% PU addition of the composite board. According to the JIS A 5905 fiberboard standard, the density values obtained were within the density range of MDF. In addition, the porosity determined using Eq 1,

$$\text{Porosity}\,(\%) = 1 - \frac{\text{Bulk Density}}{\text{Particle Density}} \times 100, \tag{1}$$

shows the samples were improved with the increase in PU in the composite. The highest porosity value was 56.41% obtained from 40% of PU. Meanwhile, the porosity percentage for samples with 50% and 60% of PU content was 45.45% and 47.57%, respectively. This is due to the fact that increases of resin content cause more uniform particle surface coated by adhesive. Furthermore, the board density increased, resulting in increases of particle surfaces due to increasing wood compression (Krzysztof et al 2013). In addition, the study on physicomechanical properties of MDF panels made from kenaf (*Hibiscus cannabinus* L.) bast fiber shows the resin type and content are closely related to mechanical properties (Ali et al 2014). Therefore, it is expected that increasing PU content resulted in improving mechanical and physical properties of the MDF.

The fracture surface of WF/PKS in Fig 4 shows the less pores observed with PU increment. This supports the low density and high porosity obtained with a low PU content. The existence of pores in the composite could be due to the insufficient PU content to cover and fill the space between WF, PKS, and WF/PKS, resulting in high compressibility and producing less compact composite. The nonexisting pores between fibers

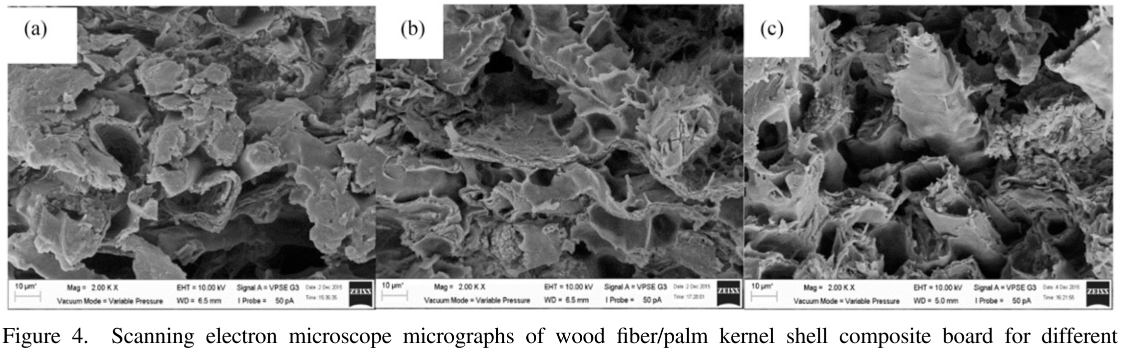

Figure 4. Scanning electron microscope micrographs of wood fiber/palm kernel shell composite board for different polyurethane contents. (a) 40%, (b) 50%, and (c) 60%.

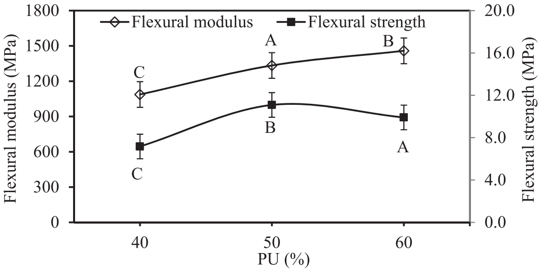

Figure 5. Flexural properties of wood fiber/palm kernel shell composite board for different polyurethane (PU) contents. Different alphabets indicate significant difference between means using Tukey's HSD test at $p \leq 0.05$. The error bars are the ±SE or triplicates.

suggest a good adhesive bonding between fibers. Therefore, it is expected that these results will affect the mechanical properties of the composite boards.

Mechanical Properties

Figure 5 shows the variation of flexural properties as a function of PU content. It can be seen that the flexural modulus increase with increasing PU content, whereas the flexural strength of the composite board increases ~4 MPa from 7.2 MPa for 40% PU to 11.1 MPa for 50% PU, before slightly decreasing to 9.9 MPa at 60% PU. These results have been expected because the flexural properties are related to the density of the MDF shown in Fig 1. As the density of the MDF increased, the number of interbonds between fibers increased, resulting in the enhancement of bending properties (El-Kassas and Mourad 2013).

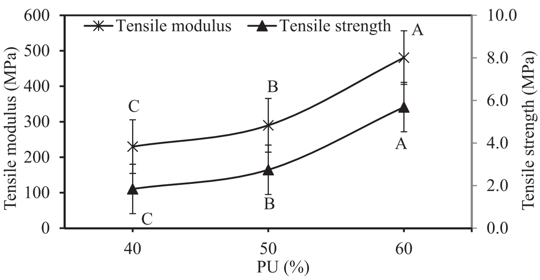

Figure 6. Tensile properties of wood fiber/palm kernel shell composite board for different polyurethane (PU) contents. Different alphabets indicate significant difference between means using Tukey's HSD test at $p \leq 0.05$. The error bars are the ±SE or triplicates.

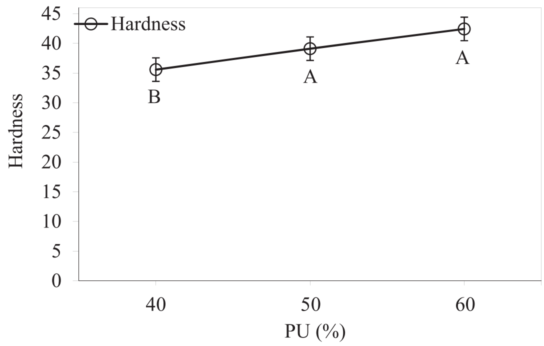

Figure 7. Hardness of wood fiber/palm kernel shell composite board for different polyurethane (PU) contents. Different alphabets indicate significant difference between means using Tukey's HSD test at $p \leq 0.05$. The error bars are the ±SE or triplicates.

In Fig 6, the tensile properties of the WF/PKS composite board also show improvement with PU addition content. The tensile modulus increases with increasing PU. The tensile strength of the fiberboard with 40% PU is 1.8 MPa and increases almost 4-fold to 5.7 MPa. This is a common observation where board properties improve with increasing adhesive level (Ye et al 2007; Akgul and Camlibel 2008; Park et al 2012). Generally, the mechanical properties of wood-based particleboard and MDF are strongly dependent on the average density (Halvarsson et al 2008). The increased number of fiber-to-fiber contact point leads to an interbond between resinated fibers, resulting in an increase in the density of the MDF. Besides that, higher bonding areas in the MDF allow higher tensile stresses in the fiber to reach

Table 2. Mechanical properties of wood fiber/palm kernel shell composite board for different PU compositions.

	PU (%)		
Mechanical properties	40	50	60
Flexural strength (MPa)	7.17	11.09	9.91
Flexural modulus (MPa)	1087.05	1333.69	1458.13
Tensile strength (MPa)	1.84	2.74	5.69
Tensile modulus (MPa)	229.88	289.88	480.69
Hardness	35.58	39.11	42.44

PU, polyurethane.

the breaking strength (Akgul and Camlibel 2008; Halvarsson et al 2008).

Figure 7 shows the increase in PU composition from 40% to 60% improved the hardness of WF/PKS composite from 35.6 to 42.4. This trend is similar to the results of flexural modulus, tensile modulus, and tensile strength, except flexural strength. The discontinuity of the fiber/PKS reduced as the PU content exceeded the optimum composition, resulting in ultimately poor physical fiber-to-fiber contact, hence reducing the strength of composites (Lee et al 2006). Besides that, the density of the WF/PKS composites was increased by increasing the PU content, resulting in harder surface. The hardness test is also reflex to the material's strength, ductility, and wear resistance, which can be used to determine the application of the materials.

The values of the mechanical properties are listed in Table 2. Based on JIS A 5905 standard, the fiberboard composite produced is classified based on its flexural strength. The composite boards with 40%, 50%, and 60% of PU addition were found to meet the minimum requirement of board type 5 because the flexural strength is within the range of 5-15 MPa. In addition, the composition also met the minimum standard requirement of flexural modulus for board type 5, which was greater than 800 MPa.

CONCLUSIONS

The physical and mechanical properties of the fabricated WF/PKS composites for different PU composition were measured. The MDF with 85% of WF, 15% of PKS as reinforcement, and PU as adhesive possesses good physical and mechanical properties. As the PU content increases from 40% to 60%, the flexural, tensile, and hardness properties of the fiberboard also increase. However, the increase in the PU content from 50% to 60% shows slight depreciation in flexural strength. The optimum properties of MDF were made from 15% of PKS reinforcement using 60% of PU. However, the WF/PKS composite boards with 40% and 50% PU produced also met the minimum requirement of JIS A 5905 fiberboard standard for type 5 based on the flexural strength results, which could potentially be used in the decorative application.

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