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EFFECT OF BIOCOMPOSITE MATERIALS TO ENHANCE DURABILITY OF SELECTED WOOD SPECIES (INTSIA PALEMBANICA MIQ, NEOBALANOCARPUS HEIMII, SHOREA PLAGATA) IN MALAYSIA

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ABSTRACT

The purpose of this study is to improve the recent technology which only used the solid wood as a product like bridge, water tanks, furniture, and others that might have some lacking. It is also to determine the wood properties in terms of durability in mechanical properties when combining with wood composite materials. Recent studies show that the wood itself have some disadvantages of wood properties, which covers the solid wood will get moulds, easily broken, not flexible, not durable because of termite attacks, and others. In those researches, they stated that the disadvantages of using wood fibers are their low bulk density, low thermal stability, high tendency to absorb moisture, and susceptibility to biological degradation. Thus, this research study aims an innovation, which is to determine and compare the impact of different wood composites when laminating with different type of solid wood, so that it can be applied to the industry when the durability is enhanced. In order to get most accurate result, this study used SolidWorks simulation software to predict the suitability of bio composite materials. Method used in the experiment is by using Charpy impact test, to figure out the energy needed to fracture the samples. The energy then is converted to Force (N) to find the stress value. The value also needed to be included as parameters like force and type of woods in simulation design. Combination of Merbau wood and plywood is determined as the most effective bio composite material because the value increase up to 41.57%. SolidWorks simulation also had predicted the value well with the percentage difference only from 1.14% until 23.24% from the experimental design.

Keywords: bio-composites, durability, mechanical properties, impact test.

INTRODUCTION

Bio composite material

Bio-composites are composite materials that consist of biodegradable matrix and bio-degradable natural fibers as reinforcement. The development of bio-composites has attracted great interest due to their environmental benefit and improved performance. Application of bio composites in building industry can be classified into two main groups: Structural and nonstructural bio composites (Rowell, 1995).

A structural bio-composite can be defined as one that is needed to carry a load in use. For instance, load bearing walls, stairs, roof systems, and subflooring in building industry are examples of structural bio composites. Structural bio-composites can range widely in performance from high to low performance materials, while a nonstructural bio composite can be defined as one that is not needed to carry a load during service. In terms of the reinforcement, this could include plant fibres such as cotton, flax, hemp and the like, or fibres from recycled wood or waste paper, or even by-products from food crops (Mallick, 1997).

Malaysia has vast amounts of untapped natural fibre materials available from the agricultural sector and natural products such as thermoplastics and other semiconductor materials (Mazlan *et al*., 2013; Mazlan *et al*., 2014). Beside that wood particles, and textiles are used to make the products like ceiling tiles, furniture, windows, doors, and so on. These fibre and biomass materials range from rice husks, coconut trunk fibres, kenaf to oil palm biomass.

Wood Composite

a) MDF Board

The MDF industry currently has 15 plants with a total annual installed capacity of 2.9 million cubic meters. In 2011, exports of MDF from Malaysia amounted to RM1.1 billion. The industry has started utilizing *Acacia mangium* 6 and mixed hardwood to produce MDF as alternatives to rubber wood. Currently, Malaysia is the world's third largest exporter of MDF, after Germany and France. MDF for Malaysia has attained international standards such as BS, Asia-Pacific: Japan Australia and New Zealand (JANS), and EN standards. A number of companies have also ventured into the production of laminated or printed MDF.

Minimum property requirements for MDF are specified by the American National Standard for MDF, ANSI A208.2 - 2002 (CPA 2002). Medium-density fiberboard is frequently used in furniture applications. Apart from that, it is also used for interior door skins, moldings, flooring substrate, and interior trim components (Cai *et al.*, 2006; Youngquist *et al.*, 1993).

b) Chipboard

Particleboard has become one of the most popular wood-based composite materials for integrating decoration because of its low density, good thermal insulation, sound absorption, and wonderful machining properties. The primary lignocellulosic material used in the particleboard industry is wood. The increased demands of raw materials in wood panel, pulp and paper manufacturing have led to worldwide shortages of forest resources. Over the past decades, many non-wood lignocellulosic biomasses, including bamboo, wheat straw, cotton stalks, bagasse, rice straw, sunflower stalk, and kenaf stalk, have been conducted to produce particleboard or other end-products (Papadopoulos *et al*., 2004; Biswas *et al.*, 2011; Wang & Sun, 2002; Heslop, 1997; Mohammad *et al*., 2011; Bektas *et al*., 2005; Guler and Ozen, 2004; Kalaycioglu & Nemli, 2006).

c) Plywood

Plywood has been introduced in its application in 1865, since the plywood manufacturing sector began to rapidly developing era, focusing on making buildings and making the walls of the first aircraft using plywood (Sen *et al.*, 2011). According to Khalil and Hashim (2004), plywood is a flat panel made of veneer layers from either a soft or hard wood; these layers are arranged perpendicularly using odd numbers and resin spread on these layers. It is stacked together by using a clamp or pressing machine to form a panel. Each of the layer is identified with a different name; for example, the outer layer is the face, the inner layer is the middle or the core, and the wood grain layer that is at a right angle with both the face and back side is known as the cross layer.

However, plywood has advantages not found in other materials which including being lightweight, easy to use, and robust, having smooth surface textures, reduced shrinking and expansion under certain conditions (Saville, 2008).

Wood-based industry in Malaysia

Industry of wood in Malaysia has become wider year by year. It is because Malaysia has been a great major involved in exporting the wood to other countries. Most forests plantations in Malaysia are growing rubber, heaveawood, acacia, laran and khaya (source: MTIB, 2011). There are seven forest plantations in Peninsular Malaysia, eight in Sarawak and four in Sabah. Apart from that, there are land areas under cash cropping include oil palm, rubber, cocoa, and coconut plantations. Natural fibres such as rice husk, kenaf, coconut coir, oil palm biomass as raw materials to supplement wood from the natural forest for utilization of wood based and bio composite industries. Those fibres are extracted from rubber, oil palm, and coconut do provide raw materials to wood-based industry as R&D into the use of such materials have proved successful in their usage in Medium-Density Fibreboard (MDF), plywood and even in furniture manufacturing. Wood is often perceived as a non-durable material because it can be susceptible to decay and termite attack and others (Greg *et al.*, 2002).

Properties of *Intsia palembanica miq*

The Standard Malaysian Name for the timber of *Intsia* spp., principally *I. palembanica* (Leguminosae). Vernacular names applied include *merbau ipil* (Peninsular Malaysia) and *ipil laut* (Sabah) for *I. bijuga*. Major species include *I. bijuga* and *I. palembanica*. The sapwood is pale yellow to light buff and is sharply differentiated from the heartwood, which is yellowish to orange-brown when fresh, darkening to brown or dark red-brown on exposure.

Also known as Kwila (Australia); Merbau (Brunei); Krakasprek (Cambodia); Vesi (Fiji); Besi kesia, Ipil, Kayu besi and Merbau (Indonesia); Tat-takun (Myanmar); Komu (New Caledonia); Bendora and Kwila (Papua New Guinea); Ipil, Ipil laut and Malaipil (Philippines); Ifilele (Samoa Islands); Lumpha, Lumphor thale, Lum-por and Maka-mong (Thailand); and Gonuo (Vietnam).

a) Density and Natural Durability

The timber is a Heavy Hardwood with a density of 515 - 1,040 kg/m3 air dry. The natural durability for the timber of Merbau is classified as durable under exposed conditions. The classification is based on the standard graveyard tests of untreated specimens of dimension 50 x 50 x 600 mm conducted at the Forest Research Institute Malaysia (FRIM). Two such tests were conducted on the species *I. palembanica*. In the first series of such tests, the average service life for 14 test specimens was 5.5 years (Foxworthy and Woolley, 1930). It is then continued with the second test, and the average service life for 60 specimens was 6 years (Jackson, 1965).

b) Principal Uses

Merbau is a very attractive wood, with its growth ring figure and deep colour. The timber is suitable for interior finishing, panelling, mouldings, office fittings, flooring (heavy traffic), superior joinery, cabinet-making, musical instruments, ornamental items and carvings. The timber is widely used for the manufacture of reproduction antique furniture and strip flooring in the country. It is also suitable for heavy construction, power transmission poles, railway sleepers, decking, columns (heavy duty), door and

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window frames and sills, fender supports, staircase (apron lining, rough bracket, baluster, balustrade, carriage, handrail, newel, riser, stringer, tread, bullnose, round end and winder), heavy duty furniture, tool handles (impact) and pallets (heavy permanent type).

METHODS AND MATERIALS

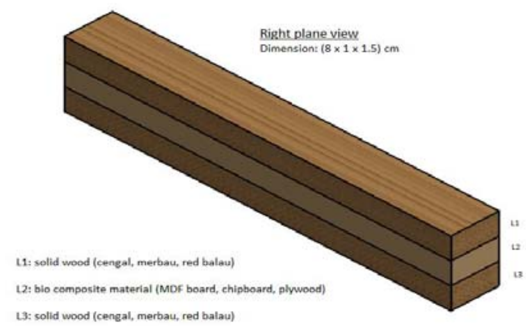
Materials

Bio composites are composites that are based on wood and non-wood materials, which are commonly used by furniture manufacturers in variety of applications (Suhaily *et al*., 2012). In this study, the materials that used for bio composite materials are MDF board, chipboard, and plywood. The mechanical properties of each bio composite material are known and this research focused on the main materials. According to Khalil (2011) the mechanical, physical, and chemical properties of these renewable resources are similar to those of wood, and they maybe suitable for raw materials wood based-panels. While optional in wood is focused only on three types of wood in terms of durability which comprising of *Neobalanocarpus heimii*, *Intsia Palembanica miq*, and *Shorea plagata.* Mechanical properties in terms of durability that measured in this study had used Charpy impact test as the equipment in this research. This test is available at UMK Jeli Campus.

Model Description

a) Top plane view (unit in cm)

b) Front plane view (unit in cm)



c) Isometric view

This product design is (80 x 10 x 15) mm with each 5 mm of the length consist of bio composite material that is laminated with solid wood. This design is then brought to selected wood factories to cut into pieces, according to the measurements provided. The prepared samples are then brought to laboratory for further analysis.

Parameters in Measuring Wood

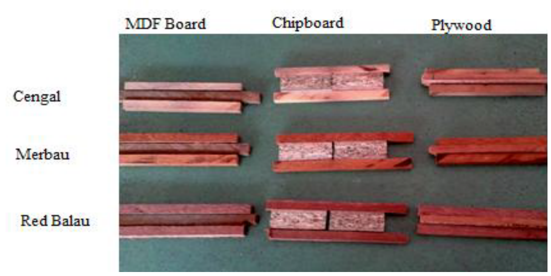


Figure-1. Panel A.

Preparation of Sample

For the three (3) types of solid woods, the wood samples are obtained from local factories. While the wood composites such as MDF board, chipboard and plywood, they are taken from the shop around Kelantan and Terengganu. This study used Charpy Impact Test as a method to measure the mechanical strength by energy, after the sample is prepared. The method used to prepare the sample is by combined each of the composite material with each different wood by using glue. Glue or resin named Urea formaldehyde Resin (UF) is used in this study to laminate the wood samples with wood composite materials. As the UF resin is a polar adhesive, it needs to wet the fibers to achieve adequate bonding and to then develop bonds (Ayrilmis *et al.*, 2009).

According to Podgorski (1996), new bonds are responsible for the changes in structural parameter of the resin by producing high molecular weight structures, polar or bulk constituents. Due to the degradation, the in homogeneity of the aged sample has increased (Vlad-Cristea *et al*., 2012). The thickness of the wood is constant, and the materials that this study used come in different types.

Impact Test

Charpy Impact is a single point test that measures a materials resistance to impact from a swinging pendulum. Charpy impact is defined as the kinetic energy needed to initiate fracture and continue the fracture until the specimen is broken. The values obtained can be used for quality control or to differentiate general toughness. This test is currently available at UMK Jeli Campus. For the test procedure, the specimen is mounted horizontally and supported unclamped at both ends. The hammer is released and allowed to strike through the specimen. If breakage does not occur, a heavier hammer is used until failure occurs.

The specimen size is 80 x 15 mm by thickness. The specimens can be either notched or unnotched. For the data produced, impact energy is expressed in Joules (J), by dividing impact energy in joules by the area under the notch to calculated impact strength. The higher the resulting number produced, the tougher the materials.

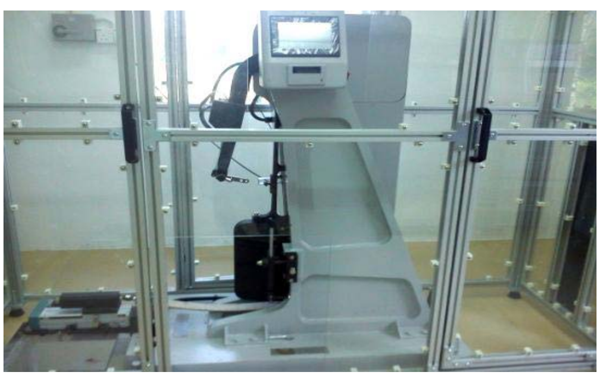


Figure-2. Charpy Impact Test.

RESULT AND DISCUSSIONS

In Figure-3 below shows the result of bio composite materials in Newton (N) unit. This graph had shown the relationship between bio composite materials and Force (Newton) when using Charpy Impact Test. From the chart, the solid wood itself got the range from 170 N to 500 N. The most suitable combination of solid wood and wood composite material goes to Merbau wood laminated with plywood, while the most unsuitable combination goes to Chengal wood laminated with chipboard or particleboard, because the value is decreasing dramatically when combined. Clearly it shows that the Red Balau wood itself does not need any additional material because the durability of wood species is in the highest state. The energy value reduced when adding another composite as a layer in solid wood.

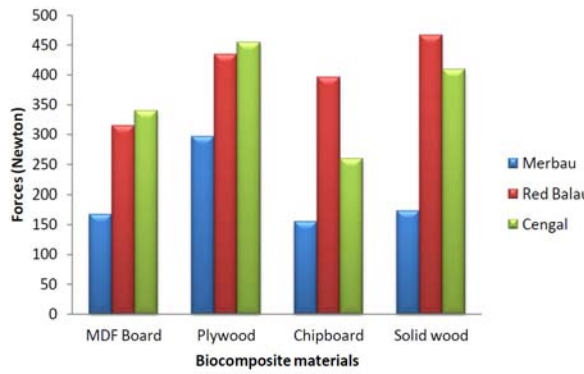


Figure-3. Relationship between bio composite materials and Force (N) using Charpy Impact.

The Figure-4 shows the stress value obtained from the experiment, using the formula given. All of the energy in Joule unit are converted to Force (N) and are divided to area in meter square. So, clearly it shows that certain woods do not need to add any composite to enhance their durability. For an example, the value of stress of Red Balau is decreasing when laminate with wood-composite. It means that this type of wood do not suitable for adding other composite as its hardness value also decreasing. For Cengal wood, the stress value is reducing when adding wood composites such as MDF Board and chipboard, while the stress value of this wood is slightly increase when adding plywood. Lastly, Merbau wood had dramatically increase changes in stress value when adding plywood panel product. But, for others type of panel products, the stress values are slightly reducing. In conclusion, the value of stress of Merbau has a huge change when plywood is applied to this type of solid wood. Saville (2008) has concluded that plywood has advantages not found in other composite materials which including being

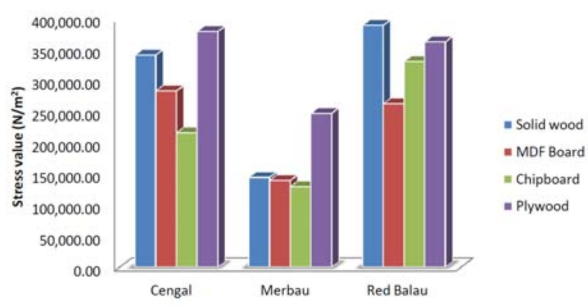


Figure-4. Stress value of Bio Composite materials in Experimental.

Simulation Design

This figure 5 depicts the final product of the wood sample when undergo the SolidWorks simulation.

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The parameters such as forces, type of woods, and bio composites are added before run the simulation. By using the steps that are listed in this study, this study could predict the displacement and stress value that matched with the experiment.

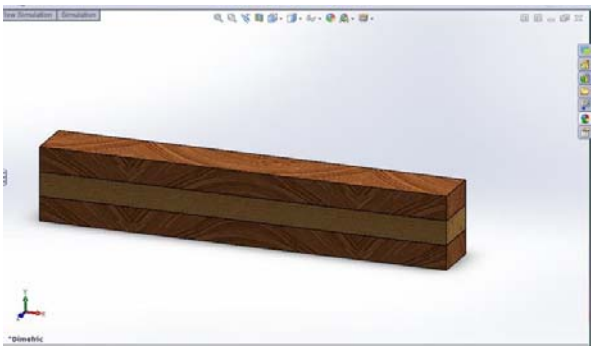
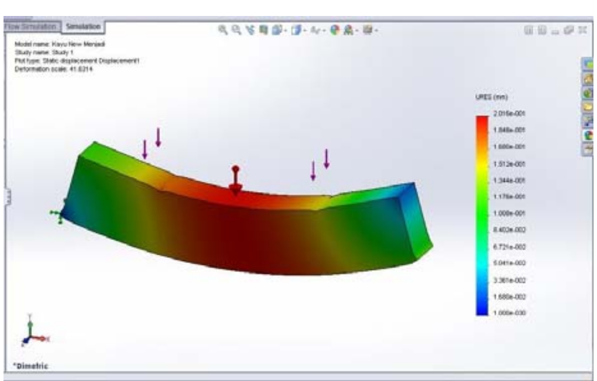


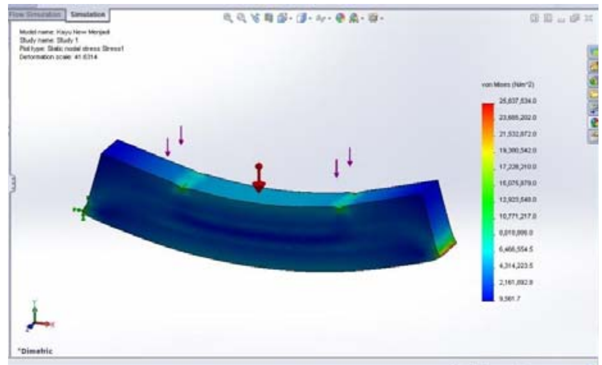
Figure-5. The bio composite material that is ready to undergo simulation.

Figure-6(a) shows the result of SolidWorks simulation which consists of two (2) parts that are displacement analysis and stress analysis. For part A, displacement means the difference between a later position of a thing and its original position. In physics, the linear or angular distance in a given direction between a body or a point and a reference position, is known as displacement.

While the second Figure-6(b) depicts the result from SolidWorks simulation which is stress analysis. Stress analysis in this state means the general term used to describe analyses where the results quantities include stresses and strains. It is also can be known as structural analysis. While in continuum mechanics, a physical quantity that expresses the internal forces that neighboring particles of a continuous material exert on each other is called as stress. When the stress increases, the hardness also increases.



a) Displacement Analysis



b) Stress Analysis

Figure-6 (a-b). Displacement and Stress Analysis.

Table-1. Stress Analysis of Solid wood.

Solid wood	Force (N)	Average Stress (N/m^2)
Chengal	409.3	586,434.5
Merbau	173.3	187,298.6
Red Balau	466.7	537,978.5

Table-2. Stress Analysis of bio-composite materials.

Biocomposite materials	Force (N)	Average Stress (N/m^2)
A1 Cengal + MDF Board	340.0	447,612.8
A2 Cengal + Chipboard	259.3	371,518.0
A3 Cengal + Plywood	454.7	653,191.0
A4 Merbau + MDF Board	167.3	239,702.5
A5 Merbau + Chipboard	155.3	222,509.8
A6 Merbau + Plywood	296.7	255,103.5
A7 Red Balau + MDF Board	315.3	452,938.0
A8 Red Balau + Chipboard	396.7	567,264.5
A9 Red Balau + Plywood	434.7	622,826.5

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Comparison Stress Analysis between Experiment and Simulation

Referring to table 3, the figure 7 depicts the comparison between the stress value that calculated by using formula and the analysis of stress displayed by the SolidWorks simulation. The pink color is the value level of the stress that is calculated by using given formula. While the papyrus color, it shows the average stress tabulated by simulation.

The graph shows that Red Balau has the highest value in experimental and simulation design with the value of 388, 916.67 N/m2 and 507,978.5 N/m2 respectively. It is because of the force obtained is the highest. However, the high value of bio composite material is according to the high value from force (N). So, if the value of force (N) is high, so the level of stress analysis in simulation also high. Some of the bio composite materials do not follow this hypothesis.

Table-3. Comparison of Stress Analysis between Experiment and Simulation.

Bio composite materials	Force (N)	Stress Value (N/m^2)	Average Stress (N/m^2)
Chengal	409.3	341,083.33	436,434.50
Merbau	173.3	144,416.67	177,298.6
Red Balau	466.7	388,916.67	507,978.5
A1 Cengal + MDF Board	340.0	283,333.33	367,612.8
A2 Cengal + Chipboard	259.3	216,083.33	281,518.0
A3 Cengal + Plywood	454.7	378,916.67	478,191.0
A4 Merbau + MDF Board	167.3	139,416.67	179,702.5
A5 Merbau + Chipboard	155.3	129,416.67	142,509.8
A6 Merbau + Plywood	296.7	247,250	250,103.5
A7 Red Balau + MDF Board	315.3	262,750	302,938.0
A8 Red Balau + Chipboard	396.7	330,583.33	367,264.5
A9 Red Balau + Plywood	434.7	362,250	452,826.5

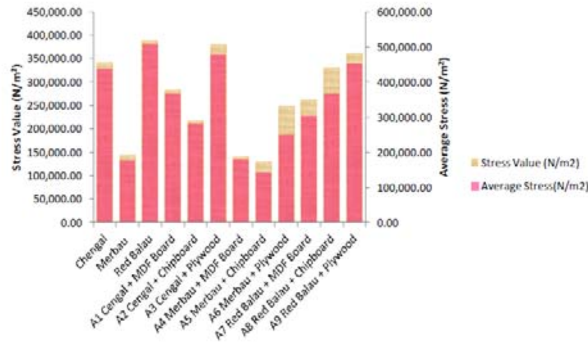

Figure-9. Comparison Stress analysis of Bio Composite Materials.

Somehow, the bio composite material of Merbau wood laminated with plywood had shown only slight difference changes between stress value from experiment and simulation. It shows the smallest gap, which about 1.14% increase that is calculated by the given formula. So here concludes that, the SolidWorks simulation and experiment do puts good correlation because it produce narrow gaps that contribute only 1.14-23.24% percent of difference.

In a conclusion, this SolidWorks simulation is one of the correct tools to measure out the value of stress and displacement in order to get most accurate result. As for its advantages, it includes it can reduced and save cost by only predicting the value instead of using the real solid wood to test and determine its properties

CONCLUSIONS

The different type of mechanical wood properties (*Neobalanocarpus heimii*, *Shorea plagata, and Intsia palembanica miq)* is categorized as durable in Malaysia. The samples such as Chengal wood, Merbau wood, and Red Balau wood are chosen based on their mechanical properties such density and natural durability.

After done with the experiment by using Charpy Impact Test, this method had determined the most suitable bio composite materials with different type of wood, which is combination of Merbau wood with plywood as a bio composite material. Thus, by adding the wood composite and laminate with solid wood, the durability of wood can be increased by 41.57%.

In getting the most accurate result, simulation software is used to predict the result. Without causing or using much cost, SolidWorks simulation is used in this research study. The result shows the percentage differences is only 1.14% up to 23.24%. Hence, this software can predict the value well including generate more analysis such as stress, displacement, strain and others properties

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