Mechanical Science Reports

Powder bio-composite: Initial development of naturally binding Trembesi-Tapioca blends for floor applications

Wisnu Suganda[a], Hudah Alfian[b], Sri Mulyo Bondan Respati[c], Muhammad Dzulfikar[d]
[a,b,c,d]Universitas Wahid Hasyim
Semarang, Indonesia

Email of the corresponding author: dzulfikar@unwahas.ac.id

Abstract

Floor material technology has progressively advanced from conventional bare wood to the recent bio-composite floors. Designing materials have suitable mechanical properties and targeted deformation behaviour is the key to the development of bio-composite materials for flooring applications. A series of naturally binding Trembesi-Tapioca blends was developed to obtain mechanical properties of hardwood and suited to resist impact deformation. Three naturally blended with volume ratio of Trembesi-Tapioca Matrix (Tr-TM) ranging between 40:60 and 60:40 was compared in this study. Their macrostructure, mechanical properties and fracture behaviour were carefully investigated. Results show that their macrostructure is mainly composed of gum part, with the appearance of particulate strongly blended. The flexural modulus and flexural strength of blends were comprised between 137 MPa and 6.06 kN/mm2 for Tr60TM to 142 MPa and 6.27 kN/mm2 for Tr40TM. The average flexural strength of bio-composite was balanced between softwood and hardwood. All blends show similar deflection values. Among the blends studied in this work, the Tr40TM blend shows the highest impact value.

Keywords: bio-composite floor, powder, Tr-TM blends, resin gum, mechanical properties, flexural

1. Introduction

Flooring, lamination of the field with cement, synthetic grass, or parquet, is common for home appliances or sports fields [1], [2]. In the 1990s, critical discussion about the preservation of natural resources and recycling led to a renewed interest in natural, renewable materials [3]. Floor material technology has progressively advanced from conventional bare wood to the recent bio-composite floors.

Recently, many composite developments use sawdust as a result of waste from the wood-cutting or sawmill industry. Wood waste in the form of sawdust and wood chips originating from the furniture industry or sawmills accumulates a lot and eventually is simply burned away. In the future, it is expected that wood waste in the form of powder, which has been produced by the wood industry, can be utilized.

The use of powders in composites has been widely practiced, such as using teak wood powder with several volume fraction variations using the ASTM D309-00 and ASTM D790-99 methods, which were tested for bending and tensile strength. A comparison of bending strength was also carried out between composites made from teak sawdust and paper with a damar gum binding matrix as a hybrid composite material [4], [5], [6].

There are many types of binder matrices or polymers derived from nature, and in their developmental stages for polymers in composites have many advantages and disadvantages [7], [8], [9], [10], [11]. However, natural polymers are rarely used because they easily change their properties when subjected to high heat.

Trembesi wood (*Samanea saman*) is a furniture material that can grow quickly. Trembesi tree trunks are very straight, reaching a height of 20 meters, which is very much liked by wood craftsmen [12]. The characteristics of trembesi wood are dark brown with black lines. Making furniture with this wood is often used as a substitute for teak wood, which grows for a long time [4], [12]. So many sawmills produce this trembesi sawdust.

Physical and mechanical properties of particle board using resin adhesive and meranti wood waste with powder type. Specimen production follows SNI Standard No. 03-2105-2006 through the pressurized printing method of 1.33 MPa. The wood particles used are sized (0.315-5 mm), mixed with a weight percentage of resin of 5%, 10%, 15% and 20%. The heating temperature is 150 ºC for 15 minutes. From the test, it was found that the highest tensile strength was 0.516 MPa with a density value of 0.989 g/cm^3. These results were obtained from specimens that had an adhesive composition of Damar to Meranti wood particles with a ratio of 20:80, with a density value of 0.989 g/cm, while for weight gain and thickness development, the values were 42% and 27% lower than other test specimens. The modulus of elasticity for the same composition is 1642 MPa. Based on the percentage, the higher the use of Damar will be obtained, the higher the value of tensile strength, modulus of elasticity and density [13]. Meanwhile, the value of water content and thickness expansion decreased [14].

The purpose of this study was to determine the flexural strength and the impact energy of the bio-composite containing trembesi powder with a natural binder (matrix) of gum resin and tapioca starch [15], [16], [17]. Therefore, the selected blends containing 40-60 volume % TM (tapioca matrix) were evaluated for their potential as bio-composite floor materials.

2. Methods

Research variable

In this study, the independent variable in the form of volume fraction was used, namely the ratio of powder sawdust with a binder mixture of gum resin and tapioca flour, including the following:

1. Composition A, which consists of 40% Trembesi wood powder and 60% natural matrix from gum resin and tapioca flour;
2. Composition B, which consists of 50% Trembesi wood powder and 50% Natural Matrix from gum resin and tapioca flour;
3. Composition C, which consists of 60% Trembesi wood powder and 40% natural matrix from gum resin and tapioca flour;

Research Steps

1. Literature and Field Studies
   Conducted a literature search and references regarding the development of natural composites, sawdust as reinforcement, natural binders such as tree sap and tapioca flour.
2. Preparation of Tools and Materials
   The materials prepared in this research are sawdust, tapioca flour, and damar sap. Moreover, this research conducted bending tests and impact tests equipment to examine the materials' specimens.
3. Mixing ingredients
   The material mixing was conducted on the binding matrix between the gum resin and tapioca flour. It is conducted by heating the ingredients to melt and stirring evenly. Furthermore, the binder is in liquid form and depicted in Figure 1.

4. Specimen Making
   The specimen was divided into two parts, namely, for the bending test using standard ASTM D3039 sizes according to Figure 2 and impact tests using ASTM A370 sizes according to Figure 3 [18]. Other specimens are made as follows:

Figure 1. Boiling gum resin

a. Sieve Trembesi sawdust using a 50 mesh sieve.
b. Heat the gum resin with a gas stove until it melts as shown in Figure 1.
c. Mixing gum resin and tapioca flour 60% by volume and trembesi wood powder 40% by volume.
d. Put the mixture into the mould.
e. Repeat steps 3-4 for a mixture of sap resin and tapioca flour, 50% by volume and 50% trembesi sawdust. As well as for a mixture of sap resin and tapioca flour, 40% by volume, and 60% trembesi sawdust.
f. Refrigerate for 3-5 hours so that the specimen hardens.
g. Release from the mould, and the specimen is ready to be tested.

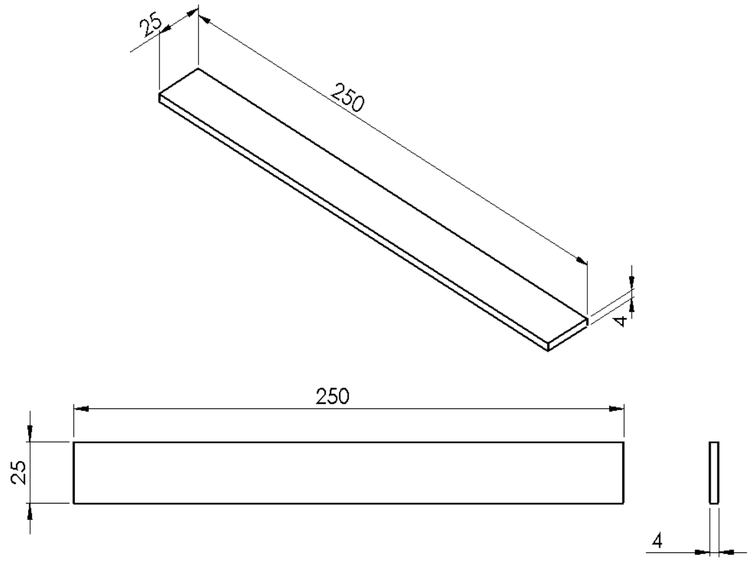


Figure 2. ASTM D3909 Standard Bending Test Mold Size

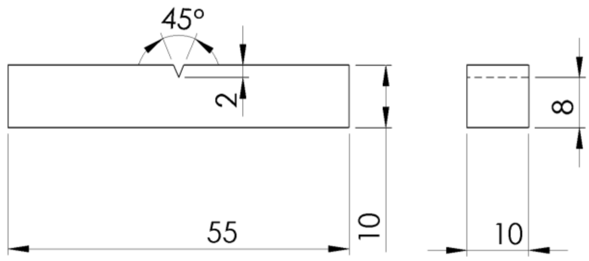


Figure 3. Dimensions for ASTM A370 Standard Impact Test

5. Testing
   The bending specimen was moulded according to the ASTM D3909 standard. The three-point flexure tests were carried out using a universal testing machine (Gotech GT-7001-LC10). The tests were conducted at room temperature. For each specimen, the force–deflection curve was recorded.
   Impact energy was measured by a testing machine (Gotech GT 7045-MD) following ASTM A370 Charpy test standard. The failure mechanism was identified by visual inspection after the completion of the test.
6. Data Analysis
   The analysis shows the results of the bending test and impact test. Moreover, the strength values of the resulting stresses were also obtained. Therefore, it can be selected based on the optimal and best strength value of the composite to be potentially used as a futsal field floor.

3. Results and Discussion

Bending (flexural) Strength

The experimental data obtained from the three-point flexural tests are presented in the form of force–deflection curves F(δ). Figure 4 shows the force–deflection curves for the bio-composite specimens for different values of (P:M) ratio. Based on the results obtained in Table 1, the first can be discussed, namely the effect of the composition on the maximum load or force during the bending test where when the composite composition A averaged from 2 specimens of 685 kgf, for composite B it was 703 kgf and for composite C it was 710 kgf. Figure 5 is a graph of the comparison of the maximum load value to the composition. The highest value was obtained for composite composition C, namely 60% trembesi sawdust, 40% gum resin and tapioca flour. So that when the percentage of trembesi sawdust is increased, the force generated to bend the specimen will be greater. According to refs [11], [12], [13]. The flexural modulus was calculated in each case by equation (1), taking into account the force F and deflection δ corresponding to the initial linear slope of the force–deflection curve. The values of the flexural strength were, in turn, determined by using equation (2), wherein deflection δmax corresponds to maximum force Fmax applied to the specimen. From the classical beam theory, the maximum normal stress σx max at the outer surfaces of the specimen of the rectangular cross-section for the three-point flexure test is given by equation (3).

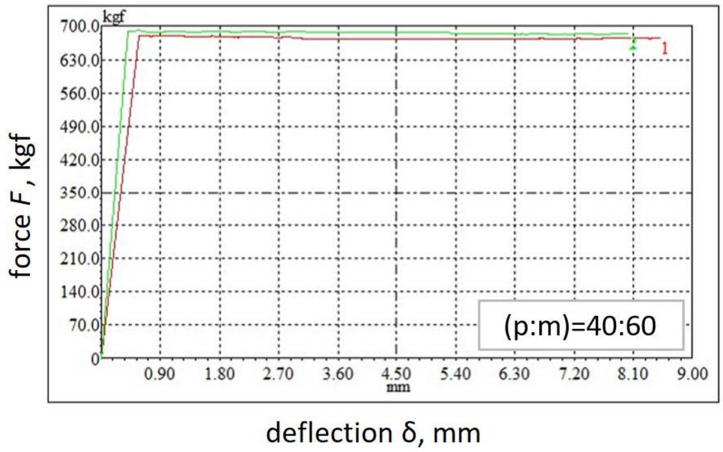
$$\mathrm{E}_f = \frac{F}{\delta} \cdot \frac{L^3}{4\,\mathrm{b}\,\mathrm{d}^3} \qquad (1)$$

$$\sigma_f = \sigma_x^{max}.\left[1 + 6\left(\frac{\delta_{max}}{L}\right)^2 - 4\left(\frac{d}{L}\right)\left(\frac{\delta_{max}}{L}\right)\right] \ldots (2)$$

$$\sigma_x^{max} = \frac{3\,F_{\max}\mathrm{L}}{2\ \mathrm{b}\ \mathrm{d}^2} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$$

Table 1. Bending (Flexural) strength calculation results (values in brackets represent one standard deviation)

Bio-composite	Particle: matrices Volume ratio	Maximum force, F_{max} [kgf]	Deflection, δ [mm]	Flexural modulus, E_f [MPa]	Flexural strength, σ_f [kN/mm^2]
A	40:60	685	8.28 (0.25)	137.1 (1.1)	6.06 (5)
B	50:50	703	8.11 (0.02)	140.5 (0.2)	6.21 (1)
C	60:40	710	8.18 (0.09)	142.0 (0.4)	6.27 (2)



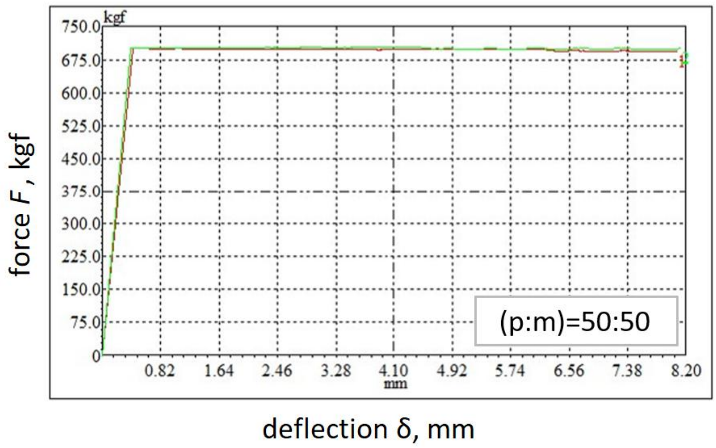


Figure 4. Flexural force–deflection responses of the biocomposite specimens for various values of (particle:matrices) ratio

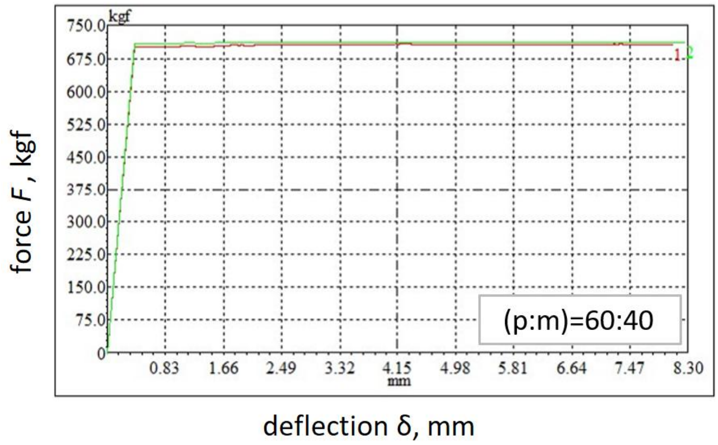


Figure 4. Flexural force–deflection responses of the bio-composite specimens for various values of (particle:matrix) ratio (continuation)

The deflection value shown in Table 1 was obtained for the biocomposites A, B, and C in order with an average of 8.28 mm, 8.11 mm, and 8.18 mm. So that when the percentage of trembesi sawdust is greater, the deflection value is smaller because the more reinforcement in the composition, the less flexible it is.

Figure 5 is a graph of the flexural modulus. The resulting flexural modulus for biocomposite A, with an average of 2 specimens, was 137 MPa, for biocomposites B and C it was 141 MPa and 142 MPa. So it is said that when the composition of sawdust is getting bigger, the modulus of elasticity increases and the composite gets stiffer.

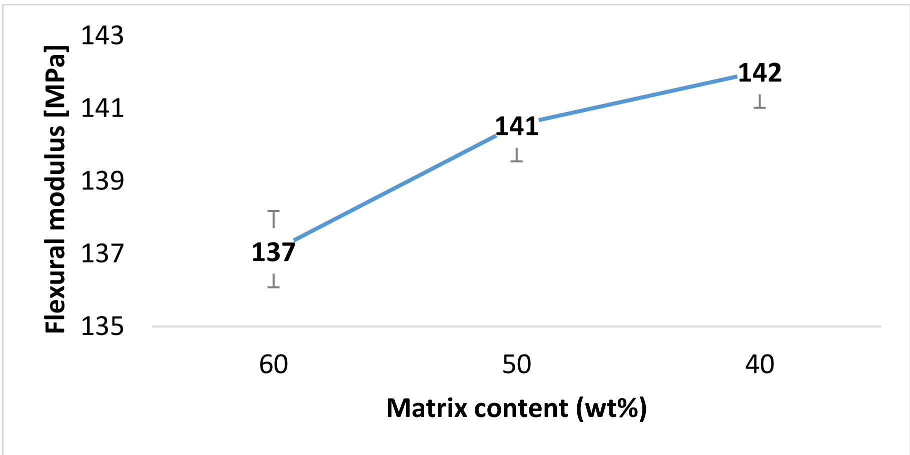


Figure 5. Graph of the flexural modulus of the biocomposite

With the calculations that have been done, the flexural strength on the composite is obtained for biocomposite A of 6.06 kN/mm^2, for biocomposite B of 6.21 kN/mm^2 and biocomposite C of 6.27 kN/mm^2. The greatest value for flexural strength occurs in the effect of the presence of sawdust composition, which is getting bigger, will increase the value of the flexural strength, so that the composite is stronger and more resistant to deflection. The graph in Figure 6 shows the potential of the flexural strength Tr-TM bio-composite between softwood and hardwood. This present study was then connected with past data originating from wood handbook [14].

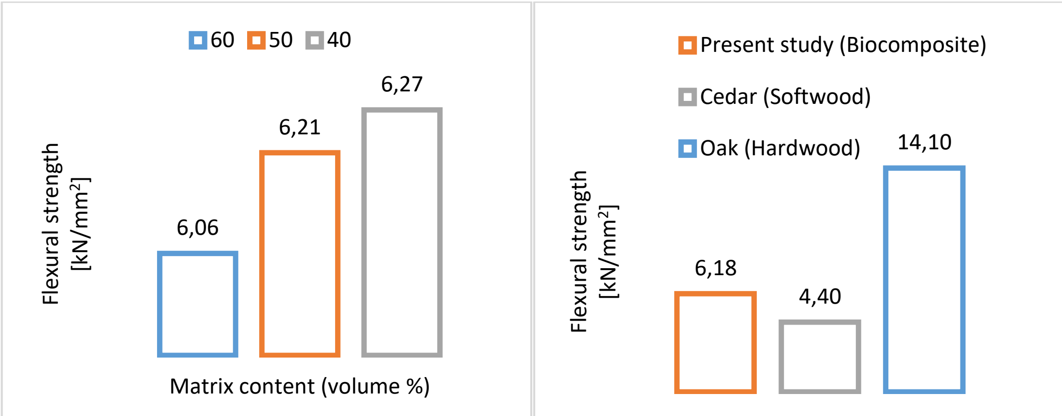


Figure 6. Graph of flexural strength on composite composition

Impact Strength

The impact value for all blends derived from the calculation is presented in Table 2. According to references [15], the impact value was calculated in each case by equation (4), taking into account the energy Es and cross-sectional area A corresponding to the machine–specimen specification.

$$\mathrm{H}I = \frac{E_s}{\mathrm{A}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (4)$$

Tapioca-damar gum (Kopal) resin composition slightly increased the impact value potential of Tr-60TM blend. While it decreased the impact potential of Tr-50TM blend.

Table 2. Impact calculation results

Bio-composite Volume ratio	Specimen	A [cm^2]	Es [Joule]	HI [J/cm^2]	HI average [kJ/m^2]
A (40:60)	A1	1.29032	0.41	0.3177	3.68 (0.50)
	A2	1.29032	0.54	0.4185	
B (50:50)	B1	1.29032	0.50	0.3875	3.56 (0.31)
	B2	1.29032	0.42	0.3255	
C (60:40)	C1	1.29032	0.44	0.3410	3.60 (0.19)
	C2	1.29032	0.49	0.3797	

Cross-sectional area (A), impact energy (Es), impact value (HI), and average impact value (HI average). Standard deviation in parentheses

Figure 7 shows the fracture surfaces of biocomposite specimens. The mode of fracture was brittle (in which the fracture surface becomes fibrous). The appearance of the failure surface indicates that the impact energy has a small value. This could be due to the irregularity of the composition of the wood particle in the fractured section during the impact test. So the values obtained are different.

A1 & A2 (40:60)

B1 & B2 (40:60)

C1 & C2 (40:60)

Figure 7. Photograph of fracture surface of biocomposite Charpy V-notch specimens tested at indicated particulate:matrices (p:m) volume ratio.

Figure 8 shows the value of the impact on the composition of the bio-composites that have been tested.

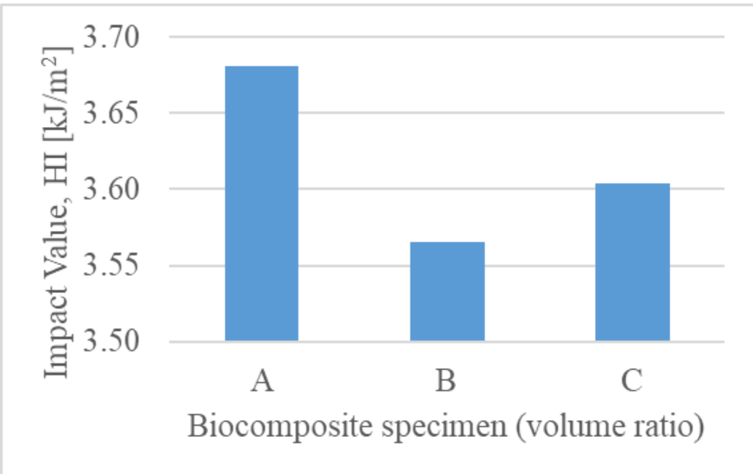


Figure 8. The value of the impact energy of the biocomposite

The impact value from testing of natural composites showed that the highest strength to receive a more optimal impact energy was composition A of 3.68 kJ/m^2. The value of the impact value in each composition, the resulting difference is not significant, so that it can be said that it is almost the same in each of these biocomposites.

4. Conclusion

Three binary Tr-TM blends, Tr60TM, Tr50TM, and Tr40TM, were designed to meet the requirements of bio-composite field floor application. They were produced through the powder moulding route, followed by a series of meshing, heating, mixing and moulding cycles resulting in hard solid material. Tr40TM has the highest flexural strength of the others. The deflection of these powder moulded blends was similar. The bio-composite naturally maintained its flexural modulus at around 140 MPa. Brittle fracture slightly increased the impact value of Tr60TM while for Tr50TM was decreased. Based on mechanical, flexural, and impact properties, the Tr40TM showed good characteristics as required for bio-composite field floor applications. Therefore, these naturally blended are recommended to be further studied.

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