Physical Properties of Bio-Composite Board Reinforced with Shell Particle and Coconut Fiber

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Abstract. The properties of the particles which have best binding capacity with the matrix can be combined with the properties of the fibers which give the composite strength. The use of shell particles and coconut fiber together as a composite reinforcement provides a variety of new physical properties that are different from its constituents. Therefore, the variation in weight fraction of the two fibers as reinforcement is interesting to study. The bio-composite board was made to use open mold process. The bio-composite board reinforced with shell particles and coconut fiber has a density of $0.938 \leq \rho \leq 1.020 \text{ g/cm}^3$. The greatest water content reaches 5.43%. The immersion time of 24 hours, water absorption of this bio-composite board is in the range of 1.95% to 3.38%, and the largest thickness swelling reaches 2.86%. Bio-composite board which is composed of 40% by weight of coconut fiber has a density of 1.111 g/cm$^3$. Water content reaches 5.90%. Water absorption capacity and thickness swelling of 4.08% and 3.12%, respectively. While the bio-composite board which is composed of 40% by weight of shell particles has a smaller density, moisture content, absorption capacity and thickness expansion, namely 0.901 g/cm$^3$, 4.13%, 1.61% and 1.18%.

1. Introduction

Innovations in the field of composite materials make natural fibers attractive for researchers. Its use as a composite reinforce is very potential. One of these natural fibers is coconut shell and coir. Coconut shells and coir are renewable, renewable raw materials. It is environmentally friendly, biodegradable, abundant, renewable, inexpensive, and has a low density. Polymeric composites reinforced with natural fibres have been developed in recent years. It shows significant potential for various engineering applications due to their intrinsic sustainability, low cost, low weight and mechanical strength. The coconut coir reinforced composites were applied to noise reducing materials, ebonite rubber, and technical material [1]-[3]. Also, the coconut shell particle can be applied as fillers for property development in natural rubber compound [4].

Coconut shell is a layer of coconut which layer sequence is after the fiber layer shell. Its volume fraction is about 15-19 % of the coconut volume fraction with 3-5 mm thickness. It has a density of 0.65 g/cm$^3$ and contains 8.00% water, 26.60% cellulose, and 29.40% lignin [5]. Coconut fiber is composed of 75% fiber and 25% cork. The fiber has a diameter of 0.1-1.5 mm, and contains 35% - 45% lignin and 23% -43% cellulose. The capacity of water holding reaches 3 times of its volume fraction. Coconut fiber is durable, high buoyancy, non-flammable and excellent insulation against temperature and sound [6]. Maximum water absorption in the coconut fiber reaches 180%. Its density is 1.2 g/cm$^3$ [7].
Several studies on the physical properties of coconut fiber composites or coconut shell powder have been conducted by previous researchers. The density of coconut shell particle reinforced composites with 200-800 μm size decreased with the increasing of particle volume fraction, namely 1.288-1.171 g/cm³ [8]. Tensile property and modulus of elasticity reduces with the increase of wt% of shell particle namely 25.20 MPa and 654.00 MP for 35 wt% shell particles. Particles size, density and light absorbance of of uncarbonized coconut shell nanoparticles was studied in ref [9]. The results of these studies indicated that density of the uncarbonized coconut shell nanoparticles obtained at 70 hours of milling are 0.65 g/cm³. Average particles size at 16, 46 and 70 hours of milling are 119.2 nm, 72.1 nm and 49.85 nm respectively. a decrease in particle size is accompanied by a decrease in the maximum absorbance wavelength when milling lasts up to 70 hours. Another case with the research conducted in ref [10], composites with coconut fiber reinforcement were successfully made with various fiber volume fractions. The tensile and impact strengths depend on the volume fraction of the fiber. Based on ref [11], the natural fibers as reinforcing polymer composites stated that the mechanical strength of coconut fibers can compete with the technical fibers. The results of these studies indicated that density, ultimate strength, modulus of elasticity and % elongation of particle composite depend on wt% of shell particle and particles size. Composite of coconut fiber can made in various fiber volume fractions.

Coconut fiber as a reinforcing element greatly determines the physical and mechanical properties of the composite. Fiber will be able to continue the load distributed by the matrix [12]. Shell particles and coconut fiber, which is combined with a polymer as a matrix, will produce alternative composites that are very beneficial to the industrial application. It is expected to produce maximum composite physical properties to support the application of alternative composites.

Composite physical properties is largely determined by the fiber, matrix and the volume fraction of its constituents [13]. The addition of a wetting agent is needed to wet the fibers. Interaction between particles or fibers can occur if there is contact between the wetting agent and the fiber surface. Wetting agent functions as a matrix. The matrix will bind the fibers into a structural unit, protect the fibers from external damage, transmit, or transfer external loads to the shear plane between the fibers and the matrix. Composite quality is influenced by the type of matrix used [14]. The unsaturated polyester resin matrix is a liquid. This resin is easy to handle, fast curing, perfect dimensional stability, good physical and electrical properties, easy to colour and modify. Unsaturated polyester resin has a density of 1.2 g/cm³ to 1.5 g/cm³, and the water absorption at immersion for 24 hours at temperature of 20⁰ ranges from 130% to 180%. Research conducted by BPPT Jakarta on the quality of tensile strength in matrix-reinforced composite structures (epoxy, polyester, vinyl ester) with natural fibers (abaca, hemp, kenaf, and pineapple fibers). The matrix with 40% -50% by volume fraction of unsaturated polyester resin has the highest tensile strength qualities. This resin is suitable for composites was made by casting method in open mould. Methyl Ethyl Ketone Peroxide (MEKP) is a hardener catalyst. MEKP is the result of the reaction of methyl ethyl ketone with hydrogen peroxide. The addition of this catalyst helps the resin hardening process. The time it takes for the resin to turn into plastic depends on the amount of catalyst mixed. The more catalyst you add, the faster the curing process. The addition of excessive catalyst results in a brittle material or burnt resin. The alkaline treatment of the fibers removes the ineffective fiber constituents, dirt and foam adhering to the fibers, increases the adhesion of the fiber and matrix interfaces and obtains mechanical bonding [15].

Physical testing is an initial test before further testing is carried out. Unlike the mechanical test, the physical test reflects properties that are not related to the influence of external forces. The result of physical testing has a big effect on the strength and appearance of the resulting composite board. Composite board density is defined as mass per unit volume. Density is determined by the mass of the fibers and the matrix as a constituent of the composite. Water content reflects the amount of water remaining in the cell cavity and voids trapped in the crystal structure. The amount of water contained in the fiber, resin, and humidity in the surrounding air affects the moisture content in the composite. The amount of water that can be absorbed by the cell cavities and voids is called water absorption capability.
Variations in composite research can be done by making a combination of coconut shell particles and coconut fiber as a bio-composite reinforcement. This aims to get a new composite from the best combination of characteristics of each constituent component. This research is a preliminary study to describe the physical properties of the bio-composite board. The physical properties studied were density, water content, water absorption capacity, and thickness swelling.

2. Experiment

2.1 Preparation

Coconut shells and dried coconut fibers were chosen as bio-composite reinforcement. The separation of the coconut fiber from the cork is done using natural brushing techniques. The coconut shell is cleaned with sandpaper with the aim of removing the sticky cork. Next, immersion in 5% NaOH solution for 2 hours. Coconut shell particles with ≤ 74 μm size were obtained by filtering using a 200 mesh sieve. The fibers were chosen to be the same size and cut to a length of 3 cm.

2.2 The Making of Bio-composite

The bio-composite was made by lay-up hand method. The volume fraction ratio of fiber and matrix used is 40%:60%. The ratio of the weight fraction of the coconut shell particles and fiber are as follow, namely; 0%: 40%, 10%: 30%, 20%: 20%, 30%: 10%, and 40%: 0%. The unsaturated polyester resin matrix used was Yukalac type BQTN-EX 157. The density of this resin is 1.215 g/cm³ with a water absorption capacity of 0.188%. The hardening of the resin using a MEKP catalyst was 3% of the volume of the resin used. Coconut fibers are arranged in a random fiber model in a mold. The coconut shell particles are mixed with unsaturated polyester resin.

Pressure is applied to the fibers until the thickness of the bio-composite board reaches 1 cm. The bio-composite board is allowed to dry. To get a stable condition, the bio-composite board is left to stand for 14 days. The test sample is 3x10x1 cm in size.
2.3 Testing

The test of bio-composite board density was carried out in dry air and volume conditions. The water content test was carried out by heating at 100°C for 6 hours. The moisture content was determined by the mass under dry air conditions and the mass after heating. The water absorption of the test sample was carried out by immersion method for 24 hours. The water absorption capacity of the bio-composite board was determined by the mass under dry air conditions and the mass after immersion. The mass of the test sample was measured with the Ohaus digital balance.

![Mass measurement](image1)
![Thickness measurement](image2)

The thick swelling test used the immersion method. The test sample was immersed for 24 hours. The thickness swelling is determined from the thickness of the test sample at a certain point under air-dry conditions and the thickness after immersion. The thickness of the test sample was measured by using a measuring instrument in the form of a screw micrometer.

3. Results and Discussion

The 5% NaOH treatment for 2 hours changed the color of the shell and coconut husks from pale yellowish brown to dark brown. Research by M Leena [16] also showed similarity in color to coconut fibers after soaking with NaOH. The measured average density of coconut fiber was 1.125 g/cm³.

![Density of bio-composite board](image3)

The bio-composites filled with only coconut shell particles had a density of 0.901 g/cm³, and those filled with only coconut fiber had a density of 1.111 g/cm³.
The combination of unsaturated polyester resin with a density of 1.215 g/cm$^3$, coconut shell particles with a density of 0.65 g/cm$^3$, and coconut fiber with a density of 1.125 g/cm$^3$ resulted in a composite with a density of 0.938 < $\rho$ < 1.020 g/cm$^3$. This value is smaller than the density of composites made from coconut fiber alone or greater than the density of composites made from coconut shell particles. The difference in density between coconut shell particles, unsaturated polyester resin, and coconut fiber resulted in a combined density. The addition of 10% coconut shell particles weight fraction accompanied by the 10% decrease in coconut fiber decrease the density of the composite. The decrease of density is shown in Figure 6. The greater the weight fraction of the high density fibers in the fixed composite volume, the higher the density of the composite. The density of the bio-composite board produced was ≥ 0.90 g/cm$^3$.

The bio-composite board filled only with coconut shell particles had the lowest water content, namely 4.13%. The highest water content, namely 5.90%, is on the bio-composite board which is only filled with coconut fiber. The bio-composite board with variations in the weight fraction of coconut shell and coconut shell particles has a water content of 4.71% to 5.43%, as shown in Figure 8. The water content of the bio-composite board decreases with increasing weight fraction of coconut shell particles on the constant volume of the bio-composite.

![Figure 7. The Bio-composite](image)

![Figure 8. Water content of bio-composite board](image)

The fiber weight fraction which is greater than shell particles contain a larger number of cell cavities and voids. The damaged fiber shape can create voids. Voids are also formed because air is trapped between fibers and particles that are not properly attached. Voids and cell cavities become free water reservoirs due to trapping of water vapor in them. The addition of coconut shell particles reduces the water content shown in Figure 8. The resin, the shell particles and fibers in small volume fraction can coats the composite perfectly. Shell particles are evenly distributed in the fiber arrangement. Water vapor from the outside environment cannot enter the composite.
By soaking for 24 hours, the bio-composite board with 10% weight fraction of coconut shell particles and 30% weight fraction of coconut fiber has a water absorption capacity of 3.38%. This value is smaller than the bio-composite board which is only filled with 40% coconut husk or greater than the bio-composite board which is only filled with coconut shell particles. The longer the immersion time, the greater the water absorption capacity of the bio-composite board, as shown in Table 1.

Table 1. The water absorption capacity of the bio-composite board

| Weight fraction (%) | Coconut shell particles | Coconut fibre | 2 h | 4 h | 6 h | 8 h | 10 h | 24 h |
|---------------------|------------------------|--------------|-----|-----|-----|-----|------|------|
| 0 10%               | 0                      | 40           | 0.51| 0.90| 1.28| 1.98| 3.23 | 4.08 |
| 10 30%              | 10                     | 30           | 0.40| 0.80| 1.34| 1.86| 2.34 | 3.38 |
| 20 20%              | 20                     | 20           | 0.37| 0.77| 1.10| 1.49| 1.90 | 2.55 |
| 30 10%              | 30                     | 10           | 0.34| 0.75| 1.04| 1.35| 1.49 | 1.95 |
| 40 0%               | 40                     | 0            | 0.30| 0.63| 0.78| 0.93| 1.01 | 1.61 |

The increase of water absorption becomes greater after 2 hours of immersion. In addition to the hygroscopic lignocellulose contained in the fiber, the resin can also absorb water. The ester group can bind water. Coconut fiber which has a lignocellulose content greater than coconut shell particles is able to absorb more water. When using 40% by weight fraction of coconut fiber, the resin does not completely wet or coat the entire surface of the fiber. The contact area between the fibers become smaller and adhesion of the interface between fiber and resin is also small. Increase in volume fraction of coconut shell particle, decrease in adhesion interface shell particles, fiber and resin. The particles and fibers are tightly bound. At 40% weight fraction of coconut shell particles, the resin wets the entire the particles and fibers. In this condition, the surface of bio-composite was coated the resin completely. It is difficult for water to enter the fibers and voids. The water absorption capacity of this bio-composite board is 1.61%. The interfacial adhesion between natural fibres and polymeric matrices is critical to the composite performance [17-18]

With a soaking time of 24 hours, the thickness swelling of the bio-composite board with 10% weight fraction of coconut shell particles and 30% weight fraction of coconut fiber was 2.86%. This value is smaller for bio-composite boards that are only filled with 40% coconut fiber or greater on composite boards filled with only coconut shell particles. The longer the immersion time, the greater the thickness of the bio-composite board for all variations in the volume fraction of fibers.

Table 2. Thickness swelling of the bio-composite board

| Weight fraction (%) | Coconut shell particles | Coconut fibre | 2 h | 4 h | 6 h | 8 h | 10 h | 24 h |
|---------------------|------------------------|--------------|-----|-----|-----|-----|------|------|
| 0 10%               | 0                      | 40           | 0.57| 1.03| 1.57| 1.92| 2.26 | 3.12 |
| 10 30%              | 10                     | 30           | 0.35| 0.52| 0.93| 1.19| 1.59 | 2.86 |
| 20 20%              | 20                     | 20           | 0.18| 0.49| 0.98| 1.13| 1.30 | 2.11 |
| 30 10%              | 30                     | 10           | 0.17| 0.43| 0.88| 1.06| 1.30 | 1.78 |
| 40 0%               | 40                     | 0            | 0.13| 0.27| 0.48| 0.59| 0.76 | 1.18 |
In high-density bio-composite boards, the fibers are subjected to greater stress during the pressing process. The fiber cell cavity is shrinking. The resin cannot enter the very small fiber cavities during the pressing process. Fibers that are not completely bonded to other fibers make it easier for the fibers to break away from the remaining tension. The absorption of water by the fibers causes the restoration of the fiber size to its original dimensions. The cell wall of the fiber or the size of the fiber cavity expands. After 2 hours of immersion, the expansion in cell wall size increased. Bio-composite boards with shell particles weight fraction greater than the weight fraction of fibers, resins perfectly bond particles and fibers. The adhesive force is large. The resin also coats the entire surface of the composite. As a result, it is difficult for water to enter the fiber, the recovery of the fiber size to its original dimension becomes quite small.

4. Conclusion

The density of the bio-composite board reinforced with shell particles and coconut fiber is in the range $0.938 \leq \rho \leq 1.020 \text{ g/cm}^3$. The increase in weight fraction of coconut shell particles ($\leq 74 \mu m$ in size) can reduce the density of the bio-composite board. The increase in the weight fraction of the resin can increase the adhesion of fibers and particles. Its use for furniture requires further testing, namely the screw strength.

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