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Potensi Bambu sebagai Material Atap Mobil

Potential of Bamboo as Car Roof Material

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Abstract

An effort to achieve SDGs 12# responsible for consumption and production is by optimizing the application of natural recycled materials, such as bamboo, in the automotive industry. Bamboo is a potential insulating material because it has low thermal conductivity. This study used Gigantochloa Atroviolacea as a thermal insulator projected as a car roof. Experiments were performed to identify the effective thermal conductivity. There were two shapes tested: slab and box. The first specimen is a laminated bamboo slab, and the second is a combined slab of laminated bamboo, glass wool, and aluminum foil. Based on the heat transfer calculation, the effective thermal conductivity is 0.21 W/mK and 0.14 W/mK for the laminated bamboo slab and combined slab, respectively. The thermal flow characteristic was analyzed in two box models with different material arrangements. The first box is laminated bamboo and fiber, and the second is laminated bamboo and glass wool. The results show that the first box can insulate heat better than the second. It was concluded that laminated bamboo and bamboo fiber can be used as a substitute for glass wool material. The bending test of laminated bamboo with three different layers was performed according to ASTM D 790. The maximum load was 616 kg for five layers. The bending test showed that laminated bamboo is insufficient as a car roof. Steel plates are still necessary to comply with the requirements of the FMVSS 216 standard.

Keywords: *laminated bamboo, Gigantochloa Atroviolacea, glass wool, effective thermal conductivity.*

Abstrak

Salah satu upaya pencapaian SDGs 12# konsumsi dan produksi yang bertanggung jawab adalah dengan mengoptimalkan penerapan bahan daur ulang alami, seperti bambu, dalam industri otomotif. Bambu merupakan bahan isolasi yang potensial karena memiliki konduktivitas termal yang rendah. Penelitian ini menggunakan Gigantochloa Atroviolacea sebagai isolator termal yang diproyeksikan sebagai atap mobil. Uji eksperimen dilakukan untuk mengidentifikasi konduktivitas termal efektif. Ada dua bentuk yang diuji: pelat dan kotak. Spesimen pertama adalah pelat bambu laminasi, dan yang kedua adalah pelat gabungan bambu laminasi, *glass wool*, dan aluminium *foil*. Berdasarkan perhitungan perpindahan panas, konduktivitas termal efektif masing-masing adalah 0,21 W/mK dan 0,14 W/mK untuk pelat bambu laminasi dan pelat kombinasi. Karakteristik aliran termal dianalisis menggunakan dua model kotak dengan susunan material yang berbeda. Kotak pertama adalah bambu laminasi dan serat, dan yang kedua adalah bambu laminasi dan *glass wool*. Hasilnya menunjukkan bahwa kotak pertama dapat mengisolasi panas lebih baik daripada yang kedua. Disimpulkan bahwa bambu laminasi dan serat bambu dapat digunakan sebagai pengganti bahan *glass wool*. Pengujian lentur bambu laminasi dengan tiga lapisan berbeda dilakukan sesuai dengan ASTM D790. Beban maksimum adalah 616 kg untuk lima lapisan. Hasil pengujian lentur menunjukkan bahwa kekuatan bambu laminasi tidak mencukupi sebagai atap mobil. Pelat baja masih diperlukan untuk memenuhi persyaratan standar FMVSS 216.

Kata Kunci: laminasi bambu, Gigantochloa Atroviolacea, *glass wool*, konduktivitas termal efektif.

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1. INTRODUCTION

The automotive industry is a highly developed, with motor vehicle sales growing year after year. Various innovations have been developed to improve the quality and sustainability of motor vehicle components. One example is the use of glass wool as a heat absorber in the car cabin. Glass wool is a recyclable material made of glass waste, sand, limestone, and other minerals that is melted at temperatures ranging from 1400 to 1500°C, twisted into fiber, and mixed with organic resin (Gellert, 2010). During switching, aqueous binders are injected into the fiber. The fiber will quickly cool and stiffen, like glass. Although glass wool is a recycled material, its waste can damage the environment and affect the sustainability of ecosystems since it is difficult to compose by soil.

Various studies have been conducted to identify alternate materials for replacing glass wool in car interiors. Getu *et al.* developed car interior materials from bamboo and sisal fiber with a ratio of 3:1 using hand-lay-up techniques (Getu *et al.*, 2021). Komariyah created a composite matrix of bamboo strawberries (Dendrocalamus Asper) with a 5 percent, 10%, and 15% composite mass fraction variation in bamboo powder composition (Komariyah, Farid and Rasyida, 2016). Polyurethane is composed of polyphenyl isocyanate and polypropylene glycol with a 70:30 mass fraction ratios. Composites are made using the blending method. According to the test results, adding 15% bamboo powder to a composite mass fraction increases flexibility. Meanwhile, Adriant *et al.* identified bamboo composite as a cool box (Adriant *et al.*, 2019). From the test results, it is known that a composite matrix with a mesh size of 20 may keep cold better than a mesh of 30 and 40, but not as good as styrofoam. As a result, the bamboo composite matrix is more suited for use as a thermal insulator than for cold storage.

In the study of Abedom *et al.*, bamboo strains were ground into coal powder and combined with cider fiber and resin binders (Abedom *et al.*, 2021). Five specimens with the ratio of bamboo coal powder and cider fiber were tested and analyzed. The results concluded that the specimen with a 30/70 bamboo coal powder ratio provided low thermal conductivity, so it is suitable for use as a heat insulator in automotive interiors. In addition to the powder and coal form, another method for using bamboo is with a type of lamination. One of the lamination products is that developed by Supomo *et al.* (Supomo *et al.*, 2022) and Arifin *et al.* (Arifin, Manik and Jokosiworo, 2017), for shipbuilding. According to the findings of the tests performed on the lamination materials, bamboo lamination may be used in shipbuilding. In this study, the thermal and mechanical characteristics of the bamboo lamination material were tested for use as an insulating material in the car cabin. Black bamboo (Gigantochloa Atroviolacea) was selected for this study because it is more accessible and stronger than other varieties of bamboo, such as Apus/Tali and Andong bamboo (Bahtiar *et al.*, 2019).

2. METHODOLOGY

The research process is shown in Figure 1, there are generally three forms of prepared specimens, including plaque-shaped specimens, box-shaped specimens, and specimens according to ASTM D790 standard for curved testing. Each specimen is made of different materials. There are two research methods used experimental testing and numerical analysis using ANSYS Fluent software. The experimental test method carried out is to measure the thermal conductivity and strength of the bamboo laminate against bending loads. ANSYS Fluent is used to analyze the heat flow in the model created.

To determine the heat absorption that occurs, the test was carried out using two plate-shaped specimens with dimensions 230x230 mm and thickness 10 mm. The one specimen is a bamboo lamination, as in Figure 2, whereas the two specimen is a combination between bamboo lamination, KIMMCO glass wool and stainless steel 304 DOP aluminum foil as shown in Figure 3. Epoxy resin adhesives and hardener/amplifiers from the World of Chemistry are used as lamination adhesives. The IR thermometer GM320 is used to measure the temperature on the specimens.

Two samples were placed on a 240-watt heat source with a heat transfer rate (H) of 240 watts.

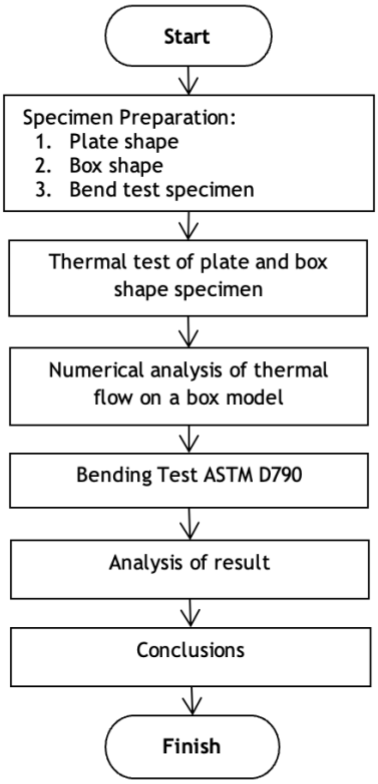

Figure 1. Research flow chart

After 60 minutes, the temperature of the heat source and the specimen was measured at eight separate places to satisfy equation (1), where T is the source temperature difference. measurement of temperature and specimen Where l is the specimen's thickness, which is 10 mm, and A is the specimen's cross-sectional area, which is 0.0529 m2, the thermal conductivity of the specimen under test conditions may be calculated.

$$k = \frac{H \cdot l}{A \cdot \Delta T} \quad \text{W/m.K} \qquad (1)$$

To determine the thermal flow that occurs, two box sample models (sample 3 and sample 4) are made of the same shape and size, as seen in Figure 4 and Figure 5. The box contains four baffles and a top and bottom four-fold hole measuring 80 x 80 mm. The distinction between specimens 3 and 4 is the material that makes up the walls and the baffle. The 3 specimens have walls composed of bamboo fibers (see Figure 6) placed between bamboo laminations. Both used epoxy resin adhesives and hardens. Temperature measurements are carried out at 8 points on the upper surface and the inside side of the box.

Figure 2. Specimen 1 (bamboo lamination)

Figure 3. Specimen 2 (bamboo lamination, glass wool, dan aluminum)

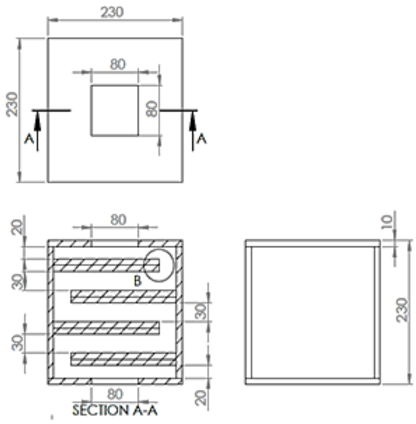

Figure 4. 2D Model of Specimen 3 and 4

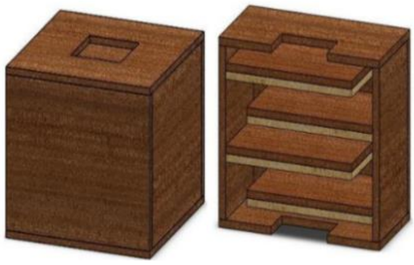

Figure 5. 3D Model of specimen 3 and 4

Figure 6. Combination of lamination and bamboo fibers

To find out if the bamboo laminate has sufficient strength as a car cabin roof, a bend test was performed referring to ASTM D790 as illustrated in Figure 7 using the three points bending method (Beigpour, Shokrollahi and Khalili, 2021). Testing was performed using the Universal Testing Machine Gotech AI-7000 LA 10 as shown in Figure 8. It has a test capacity of up to 100 kN with an accuracy of ±0.5%.

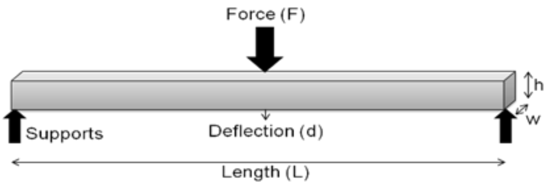

Figure 7. Three points bending ASTMD790

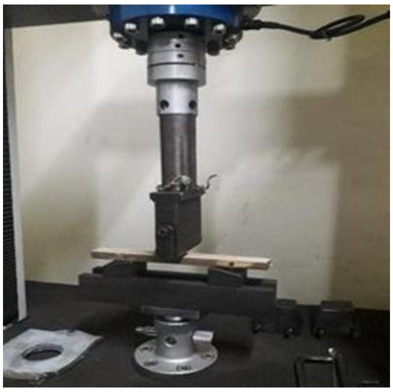

Figure 8. Gotech AI-7000 LA 10

As shown in Figure 9, there are three different test specimen variations: 3, 4, and 5 layer lamination. Each lamination is the same length (96 mm) and total thickness (12,02 mm), however each lamination has a different width (26,22 mm for a 3-layer lamination, 34,06 mm for a 4-layer lamination, and 42 mm for a 5-layer lamination).

Figure 9. Bending test specimen; (a) 3 layers; (b) 4 layers; (c) 5 layers

3. RESULTS AND DISCUSSION

3.1. Heat Absorption

Figure 10 shows the temperature measurement process on specimen 1 using an infrared thermal gun. Eight different points on sample 1 which is bamboo lamination are shown in Figure 11, while Figure 12 shows points on sample 2 which is a combination of bamboo lamination, glass wool and aluminum foil.

Figure 10. Temperature measurement process on specimen 1

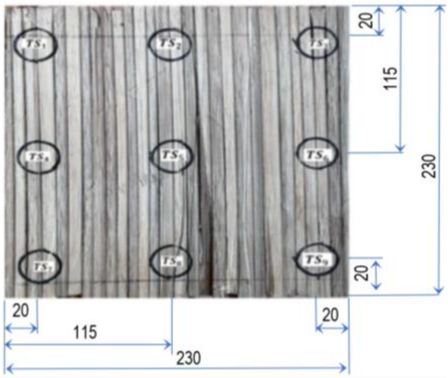

Figure 11. Position of eight measurement points on specimen 1 (unit of measure in mm)

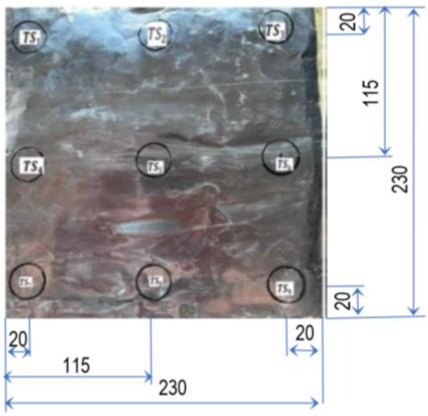

Figure 12. Position of eight measurement points on specimen 2 (unit of measure in mm)

Tabel 1 shows the temperature of the measurement results of each point in specimens 1 and 2 after 60 minutes of being placed over a heat source. The temperature recorded in the heat source is 75 °C, while the ambient temperature is 28 °C. Thus, it is known that the heat absorption in specimen 1 is 28%, while in specimen 2 is 44%.

Tabel 1. Specimen temperature 1 and 2

Points	Specimen 1 (°C)	Specimen 2 (°C)
T1	54,3	44,4
T2	55,8	41,6
T3	55,6	42,6
T4	53,1	42,5
T5	52,6	44,1
T6	54,3	41,6
T7	53,8	43,6
T8	51,4	39,9
T9	52,6	38,3
Average	53,72	42,067

Equation (1) is used to calculate the effective thermal conductivity (k, W/m.K) with known parameter values: H=24 W, l=10 mm, and A=0.0529 m2. Based on the calculation of all these parameters, the effective thermal conductivity value for specimen 1 is 2.1 W/mK, while specimen 2 has an effective thermal conductivity of 0.14 W/mK.

Compared to existing research results, The effective thermal conductivity of specimen 1 (bamboo laminate) is 0.21 W/mK, which differs by 82% from the effective thermal conductivity of glass wool, which is 0.0391 W/mK (Marhoon and Rasheed, 2015). Like example 2, which is a lamination of bamboo, glass wool, and aluminum foil valued at 0.14 W/mK, it nevertheless differs by 72%. Glass wool outperforms bamboo lamination when the value of tin's heat conductivity is the sole factor properly considered. However, bamboo lamination can be an option to eco-friendly material as a thermal insulator for the car cabin roof if elements of strength and influence on the environment are accounted.

3.2. Thermal Flow Analysis

Figure 13 illustrates a contact-shaped specimen 3 whose walls are composed of bamboo laminations on the outside and bamboo fibers on the inside with thicknesses of 10 mm each. Figure 14 shows specimen 4 with walls composed of bamboo lamination on the outside and glass wool on the inside, each with a thickness of 10 mm. Temperature measurements were made at 8 (eight) points on the upper surface of the specimen, as indicated in Figure 15.

Figure 13. Specimen 3 with bamboo lamination wall

Figure 14. Specimen 4 with bamboo lamination wall

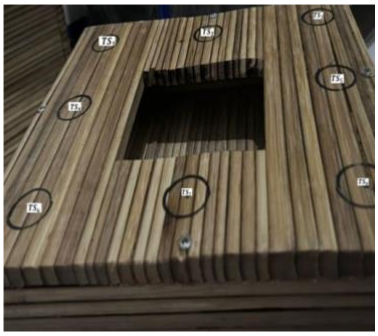

Figure 15. Position of temperature measurement point

Tabel 2 shows the results of temperature measurements taken after 60 minutes on the upper side of the box. The temperature of the heat source is 75 °C and the ambient temperature is 28 °C. These temperature data lead to the conclusion that specimen 3 absorbs heat at a rate of 60% and specimen 4 absorbs heat at a rate of 57%. Lamination and bamboo fibers combined for heat absorption are preferable.

With the boundary conditions shown in Figure 16 and the transient flow type (unsteady state), thermal flow analysis is carried out using ANSYS Fluent. The value of effective thermal conductivity obtained from the experimental test results is used as an input parameter in the created model. Figure 17 shows the simulation results in which heat is distributed conductively and convectively over time.

Tabel 2. Specimen temperature 3 and 4

Points	Specimen 3 (˚C)	Specimen 4 (˚C)
T1	30.6	32,6
T2	30.3	32,9
T3	30.6	33
T4	30.1	31,7
T5	30.5	32,1
T6	30.4	31,6
T7	30.8	31,5
T8	29.7	31,3
T9	30.6	32,6
Average	42,1	32,1

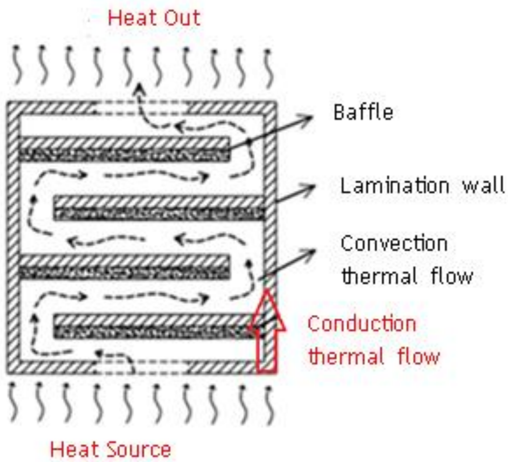

Figure 16. Boundary condition

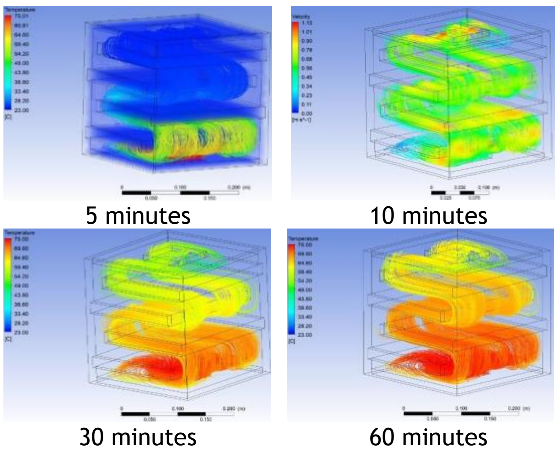

Figure 17. Result of analysis of temperature distribution for 60 minutes

In ANSYS simulations, residual data are used to assess the convergence condition. The difference between the actual value and the value predicted by the simulation is known as the residual value. As the value decreases, accuracy increases, and the simulation approaches closer to reality. If the residual value exceeds the convergence limit the simulation can be said to satisfy convergent conditions. The residual value set for convergent conditions in this simulation is 0.001. If convergence conditions have not been satisfied, the parameter is reset on ANSYS Fluent until convergence is achieved.

3.3. Bending Test ASTM D790 Result

Figure 18 illustrates the actual bending test, and Figure 19 represents the test subject after being subjected to a load. The information from the Gotech AI-7000 LA 10 Universal Testing Machine is displayed in Tabel 3.

Figure 18. Bending test on 5-layer bamboo lamination specimen

Figure 19. Condition of specimen after test; (a) 3 layer; (b) 4 layer; (c) 5 layer

Based on the Federation of Motor Vehicle Safety Standards No.216 (FMVSS 216) (NHTSA, 2006), the roof of the car must be able to withstand 1.5x the weight of the vehicle. The SUV's clean weight is in the range of 1,100 kg; thus the roof material must be able to support a load of at least 1,650 kg. Only 37% of the needed requirement is met by the results of the 5-layer bamboo lamination test when compared. The steel plate on the outside of the car roof must be strengthened for bamboo lamination to be utilized as a car cabin roof.

Tabel 3. Bending test result and calculations

Specimen	3 layer	4 layer	5 layer
Thick (t, mm)	12,02	12,02	12,02
Wide (w, mm)	26,22	34,06	42
Area (A, mm^2)	315,16	409,4	504,84
Maximum bending load (kg)	289	422	616
Maximum bending force (kN)	2,8	4,1	6,0
Bending strength (MPa)	8,99	10,11	11,97

4. CONCLUSIONS

The findings of the experiments and the numerical analysis carried out with ANSYS Fluent serve as the foundation for the conclusions. A laminate made of bamboo can absorb up to 28% of the heat that is applied to it, while a laminate that combines bamboo, glass wool, and aluminium foil can absorb up to 44% of the heat. Based on these findings, one can draw the conclusion that the most effective method of insulating the roofs of automobile cabins is to use a composite material consisting of bamboo, glass wool, and aluminium foil.

Glass wool has a thermal conductivity of 0.039 W/mK, whereas bamboo laminate has an effective thermal conductivity of 0.21 W/mK, which is still 82% lower than glass wool's thermal conductivity. Laminate can strengthen the roof of the car cabin more so than glass wool does. Because of this, it will be an efficient material for retaining heat and will lend the roof of the automobile the structural strength it needs.

Glass wool, bamboo lamination, and aluminium all have an effective thermal conductivity of 0.14 W/mK, which is better than the thermal conductivity of bamboo lamination, which is only 65 percent. Even though this combination laminate does not have the same level of thermal conductivity as glass wool, it would be preferable to use it as an addition to the bamboo laminate to improve the overall performance. The bamboo fibre and laminate combination absorbed 60 percent more heat than the bamboo fibre and glass wool laminate combination, which only absorbed 57 percent of the heat during the heat transfer test on box-shaped pieces with baffles. According to the findings of the thermal flow study performed on the model in the shape of a box with baffles, heat will disperse over time via conduction and convection.

The maximum bending load for bamboo lamination is determined to be 616 kg for five-layer lamination when tested in accordance with ASTM D790 and the findings of the three-point bending strength tests. This number is still lower than the required total of 1,650 kg that must be achieved by automobiles with a weight of 1,100 kg. For a car to have a roof made of bamboo, the bamboo would need to be quite long. The roof of the automobile was clad in steel plates on the outside, and bamboo insulation was installed on the inside.

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