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BENDING STRENGTH OF CELLULAR LIGHTWEIGHT CONCRETE SANDWICH COMPOSITES WITH BAMBOO PIN REINFORCEMENT

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ABSTRACT

Concrete has high compressive strength but the presence of bubbles added to the concrete mix makes cellular lightweight concrete very brittle and has low strength. Using cellular concrete as a sandwich composite core is risky with its strength, it is necessary to connect the two composite skins to strengthen the core. Bamboo is a type of grass, part of a potential non-timber forest product commodity. Using bamboo pins to connect the two sandwich composite skins is a strengthening method in this study. The purpose of this study was to determine the effect of the insertion of bamboo pins on the bending strength of sandwich composites with variations of tilt angles of 90^0, 75^0 and 60^0.

INTRODUCTION

In general, the basic constituents of a composite material is not single, but there are at least two elements that work together to produce material properties that are different from the properties of the constituent material elements. Composite materials consist of more than one type of material and are designed to obtain the best combination of characteristics of each constituent component. Processing of the material into composites is necessary to obtain other materials with high strength and low to medium density, sandwich composites are made to obtain a lightweight structure but have high strength. Structural composites create a material called a sandwich composite which usually consists of two skins encasing a composite core and is used when sufficient flexural stiffness and relatively light weight are desired (deshmukh et al, 2015). The strength of this composite comes from the strong composite skins, while the lightness of this composite comes from the composite core. These two properties combine to create a light yet strong structure, namely a sandwich composite structure. The sandwich composite core can consist of lightweight materials such as polystyrene foam, rigid polyurethane foam, aluminum foam, aluminum cells, paper cells, lightweight wood, lightweight stone or other manufactured lightweight materials such as lightweight concrete (Chakravarti U.K., 2010; Davies, 2001).

Concrete is generally a mixture of sand, gravel, crushed stone or other aggregates mixed together with a cement paste and water to form a compacted mass similar to rock. Sometimes one or more additives are added to produce concrete with certain characteristics, such as workability and hardening time (Cormac, 2004). Lightweight cellular concrete meets expectations as the core of sandwich composite panels in terms of specific gravity, but the consequence of having air inside cellular lightweight concrete makes its strength is small. The problem that will occur when using cellular lightweight concrete as the core material for sandwich composite panels is that this material has a low capacity to withstand pressure and bending.

The strengthening of the sandwich composite panel core has been widely studied but on plastic sandwich composites. As was done by Xie, H. et al 2022, on GFRP-PET foam sandwich panels. The use of beveled reinforcement can further improve the structural efficiency of the sandwich. This is due to the higher stiffness of pin-reinforced structures compared to foam core-only structures. The small range of pin angles to the horizontal does not significantly change pin penetration, compared to all pins being perfectly aligned in orthogonal directions. Collapse of the foam core was caused by pin buckling, and pin buckling significantly occurred at the indenter location. Pins with a greater horizontal angle are required for resistance to the shear forces normally supported by the sandwich core.

Reinforcement of lightweight concrete at the core of sandwich composite panels using natural material pins connecting the two skins is still limited. A solution that can be developed to overcome this problem is to add reinforcement to the sandwich composite core with natural, inexpensive and easy-to-process materials, namely bamboo pins (Catur A.D, 2023). Bamboo is a type of grass that belongs to the Gramineae family and is part of the non-timber forest product commodity. Bamboo has great potential as a substitute for wood because a bamboo clump can continue to produce as long as harvesting is controlled and planned. Bamboo has several advantages over wood, namely having a small shrinkage ratio, being able to bend or having high elasticity (Arsad, 2014). Therefore the need for a research that utilizes natural resources such as bamboo can be used optimally. So a research was conducted on the addition of bamboo pins to cellular lightweight concrete sandwich composites which function as reinforcement with the aim of producing better compressive and bending strength.

This study aims to determine the material characteristics of sandwich composite panels with a lightweight concrete core reinforced with bamboo pins. Which later can be useful to provide additional knowledge for the development of science in the field of non-metallic material technology, especially sandwich composites for building materials. The sandwich composite results from this study answer the human need for materials that are environmentally friendly, cheap, and easy to make and are able to replace other materials made of wood or metal materials. With the results of this study wider utilization in the field of materials engineering on the abundant resource in the form of bamboo which can be found in many rural areas.

Materials And Methods

The cellular lightweight concrete sandwich composite reinforced with bamboo pins consists of two composite skins made from glass fiber reinforced concrete board (GRC board), a core of lightweight concrete, and a bamboo pin reinforcement that connects the two sandwich composite skins. In the manufacturing process, the two GRC boards as sandwich composite skins are first connected with bamboo pins (figure 1). Bamboo pins 3 mm in diameter were attached to the two skins with glue. The distance between the pins is 10 mm. To make the structure more sturdy, bamboo pins were embedded into the skin as deep as 1 mm. Holes were made 1 mm deep in GRC board with a 3 mm diameter drill. The slope of the bamboo pin to the GRC board is varied, namely forming an angle of 60^0, 75^0 and 90^0.

Making the core of a sandwich composite panel in the form of cellular lightweight concrete begins with weighing the aggregate and water. The materials prepared are 4 kg of portland cement, 4 kg of fine sand and 2 liters of water or with a ratio of 2:2:1. The ingredients are mixed and stirred in the container until they are mixed perfectly using a mixer into wet concrete. Foam is made by mixing 100 ml of foam agent with 1500 ml of water or with a ratio of 1:15, then put into the foam reactor. Concrete panels can be light because they contain cellular cement filled with air. In cellular formed concrete, it is obtained by mixing the foam into the concrete while it is still wet.

The foam formed from the reactor foam gun is directly sprayed into the wet concrete and stirred using a mixer to form wet cellular concrete. Mixing is done evenly so that the foam can be mixed evenly throughout the wet concrete. Spraying and mixing the foam into the wet concrete until a wet cellular concrete density of 1 kg/lt is obtained. This specific gravity check must always be carried out to maintain the uniformity of the cellular concrete specific gravity in each specimen manufacture.

Figure 1a The two sandwich composite skins are connected with bamboo pins, b. The angle of the bamboo pin to the sandwich composite skin: 60^0, 75^0 dan 90^0

The mold is prepared so that the liquid cellular concrete that is poured between the two sandwich composite skins does not flow out of the mold. The bending test specimen has a length of 400 mm, a width of 100 mm and a thickness of 55 mm. The bottom and side molds are lightly greased so that they can be easily disassembled later. Wet cellular concrete is then poured into moulds, leveled and allowed to harden. The specimen drying process lasted for 20 hours, to reach the perfect strong level it took 28 days. And disassembly of the sandwich composite from the mold was carried out after the cellular lightweight concrete panels had completely hardened after 28 days. Then the specimen is finished and ready for the bending test (figure 2b).

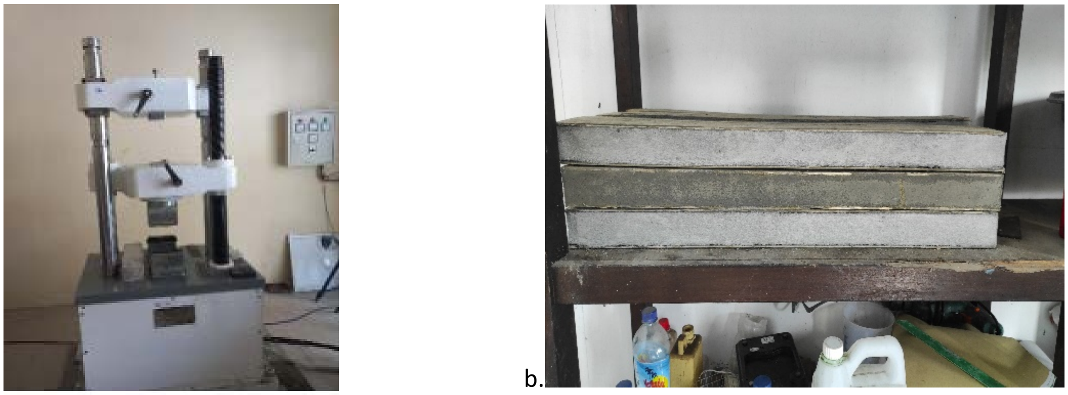
a.  b.

Figure 2. a. Universal testing machine and b.bending testing

To determine the bending strength can be done by three-point bending test to the sandwich composite material. Bending test refers to the standard with static test conditions. Bending force was tested in a direction perpendicular to the composite surface (flat direction). The applied bending test standard is C393-00. Loading was carried out with a displacement speed of 0.5 mm/minute with the Universal Testing Machine type testometric M500 25CT (figure 2a). The bending strength of the material is calculated by the following formula (ASTM, 2017):

$$\sigma = \frac{P.L}{2t(d+c)b} \tag{1}$$

Where:

σ = sandwich composite bending strength (MPa); P = maximum bending load (kN)
L = span length (mm); t = skin thickness (mm)
d = sandwich composite thickness (mm); c = core thickness (mm)
b = sandwich composite width (mm).

Results And Discussion

Building construction is expected to have a small weight so that in the event of an earthquake it is safer, for this reason building materials with a small density are also needed. In addition, the small specific gravity of the material makes it easier for the material to be transported so that fuel for transportation is more efficient. From the results of previous tests, it was found that the average density of cellular lightweight concrete sandwich composite panels with bamboo pin reinforcement was 1031 kg/m^3. When compared to other insulating materials made of red brick, insulating concrete or concrete brick, the specific gravity of this lightweight concrete sandwich composite panel is smaller (Catur, A.D., 2023).

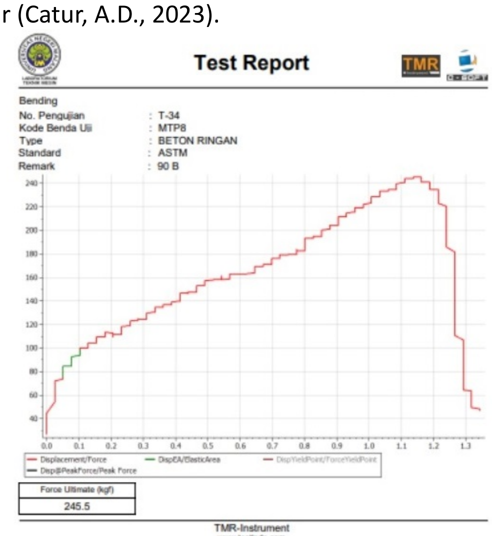


Figure 3. Bending force to deflection of sandwich composite specimens reinforced with bamboo pins with an insertion angle of 90^0.

The bending test produces data in the form of a graph of bending force to deflection as shown in Figure 3. It can be seen from the graph that there is a constant graphical gradient at the beginning of loading but very little. This shows that this sandwich composite is elastic at the beginning of loading but is more dominated by inelastic deformation. The skin and core components contribute less elasticity to the initial loading area. The increase in force occurs with the addition of the sandwich composite deflection. After the peak point of loading, the bending force continues to decrease even though it is continued by increasing the deflection. And in certain parts of the composite sandwich fracture with a sudden decrease in bending force. This indicates that the sandwich composite with skin made from GRC board and the core of lightweight concrete reinforced with bamboo pins is a brittle. The crosshead of the bending test is above the composite sandwich pressing down on the specimen, and the pressing is stopped when the force drops drastically indicating that the specimen is no longer able to withstand the force.

The failure mode of the lightweight concrete sandwich composite specimen is shown in Figure 4. During the bending test, the lower side of the composite experienced the greatest tensile stress, this resulted in the first crack occurring at the bottom of the composite skin and spreading upwards (Figure 4a). Another failure mode is the occurrence of separation between the lower skin and the composite core (Fig. 4b). In this failure mode, the crack starts from the lower composite skin slightly to the left of loading, then a shift of the skin and core occurs, followed by a core crack under loading from the bottom to the top. It is assumed that the angle of the bamboo pin does not affect the failure mode. The flexural failure mode is affected by the pin spacing and pin diameter in a carbon fiber/epoxy sandwich composite with a polymethacrylimide foam core (Yan C. et al, 2022).

a. b.

Figure 4. Failure modes in the bending test of lightweight concrete sandwich composites

The bending test was carried out with the aim of knowing the effect of adding bamboo pins with variations of inclination angles of 60^0, 75^0, and 90^0 on the bending strength of lightweight concrete sandwich composites. When the sandwich composite is subjected to a three-point bending load, the crosshead force is transmitted to all its parts and stresses occur in the constituent materials. It is this internal force due to tension that opposes the crosshead bending force. At a certain deflection the bending load reaches a maximum value and the bending stress that occurs in the sandwich composite is also maximum. If the applied load causes the stress to exceed the strength of the constituent material, the bending force decreases and eventually failure occurs in the material. In the data from the bending test results, the magnitude of the maximum load force is recorded when bending. The data from measuring the dimensions of the specimen and the maximum force of the three point bending test are used to calculate the bending strength of the sandwich composite with equation 1, the results of which are graphed in Figure 5.

Figure 5 shows that the bending strength of cellular lightweight concrete sandwich composites is increased by inserting bamboo pins in the core. The bending strength of the lightweight concrete sandwich composite without being reinforced with bamboo pins was 9.46 MPa, the highest increase being 17.33 MPa on insertion of bamboo pins with an angle of 60^0. The bamboo pin insertion angle of 75^0 gives the sandwich composite a bending strength of 13.12 MPa, and the bending strength of the bamboo pin reinforced sandwich composite with an insertion angle of 90^0 is 11.85 MPa. A study was also conducted by Selver E. et al (2019) to improve the flexural properties of glass or carbon fiber sandwich composites by inserting Z-pins into extruded-polystyrene (XPS) foam cores. The carbon and glass pins were placed through XPS foam with two different column and row densities (15 and 30 mm). The results showed that the flexural load, strength and modulus of the glass/XPS and carbon/XPS sandwich composites increased significantly after inserting glass and carbon rods.

In the pinless sandwich composite subjected to a bending test, debonding occurs between the face sheet and the core causing a decrease in maximum deflection before failure and maximum bending load. This deficiency was overcome by strengthening the sandwich composite panels with bamboo pins in the thickness direction. Based on the test results obtained with the presence of bamboo pins on the sandwich composite panel the maximum deflection before failure and the maximum bending load increases. The highest increase in bending strength of sandwich composites in the presence of bamboo pins was 83%, namely when the pin angle was 60^0, this increase was higher than the increase in strength of fiber glass / epoxy sandwich panels with a PVC core reinforced by resin pins carried out by Eyfazian A. et al (2020) which is 68%.

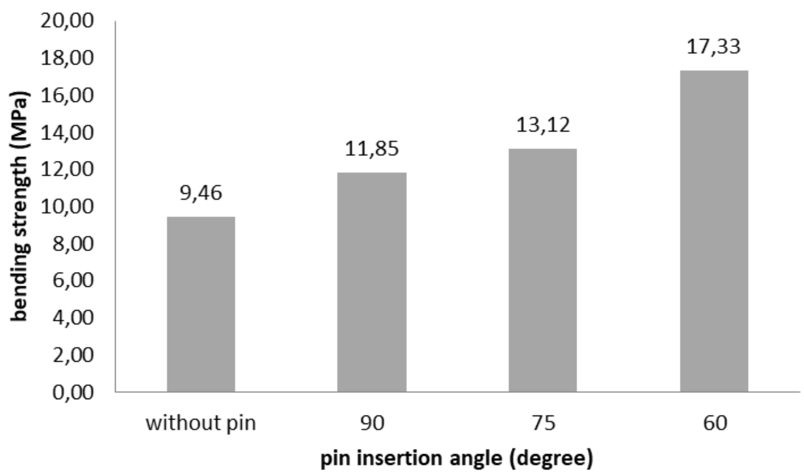


Figure 5 Bending strength of the sandwich composite without and with reinforced bamboo pins with variations in the insertion angle of the bamboo pins

The angle of insertion of bamboo pins in lightweight concrete sandwich composites affects their bending strength. The smaller the angle of insertion of the bamboo pin, the greater the value of the bending strength, this applies at least to angles of 90^0,75^0 and 60^0. The smaller the angle of insertion of the pin to the horizontal, the greater the role of the bamboo pin in holding the tensile stress at the bottom of the sandwich composite. Optimization of the slope angle of the Z-pin was carried out to increase the stiffness and flexural strength of the sandwich panel, by Kerche E.F et al on a GFRP-PET foam sandwich panel. Optimization of the pin angle increases the flexural modulus ≈ 63.0% compared to if the pin is installed at an angle of 90^0 to the horizontal (Kerche E.F. et al, 2023).

Conclusion

It is highly recommended to connect two lightweight concrete sandwich composite skins with bamboo pins. The bending strength of the cellular lightweight concrete sandwich composite increases with the presence of bamboo pins in the cellular concrete that connects the two sandwich composite skins. The smaller the insertion angle of the bamboo pin to the composite skin, the greater the bending strength. The presence of bamboo pins in lightweight concrete can solve the problem of its strength, the bending strength of sandwich composites increases from 9.46 MPa without pins to 17.33 MPa with the addition of pins with an tilt angle of 60^0.

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