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FLEXURAL STRENGTH OF BAMBOO WOVEN REINFORCED POLYESTER COMPOSITE AFTER IMPACTED

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ABSTRACT

Bamboo is used as reinforcement in composites because it is strong, light and biodegradable. Composite design is carried out to obtain a strong composite. The selection of bamboo woven patterns can be used to increase resistance to impact loads so that the flexural strength of the composite is still maintained even though it is deformed due to impact. The results of this research can be a basis for the development of superior composite materials in various applications. In this research, composite specimens were reinforced with 3 bamboo woven patterns: plain, twill, and satin. Low impact loads are applied to the specimen using a drop weight. After that, the flexural strength of the specimens was tested using a three-point bending test to evaluate the effect of the bamboo woven pattern on the mechanical properties after drop weight loading. The results of this research show that the bamboo woven pattern has a different contribution to reducing the flexural strength of the composite after drop weight loading.

INTRODUCTION

Composites are one type of material that is increasingly popular in various applications of construction, automotive, and manufacturingbecause it has high strength and lightweight.In the context of developing composite materials with natural fiber reinforcements such as bamboo, this is an interesting research topic. Bamboo is an abundant natural resource and has good mechanical properties.The tensile strength of bamboo fiber is 290 MPa, with a stiffness of 17 GPa [1]. Bamboo has been widely researched as a composite reinforcement material because of this and has great potential. Bamboo is a plant that is often found in rural areas. The annual production of bamboo fiber in the world reaches 10 million tons [2].Bamboo fiber as the main reinforcement and as a hybrid with synthetic fibers has been widely researched to strengthen polymers into composites. Bamboo is processed into blades, strips, or extracted into fibers as a reinforcing material for polymer matrices. The choice of bamboo as reinforcement in composites is also due to its ease of processing, low price, environmental friendliness, aesthetics, and its ability to be used as a product in industry on a par with hardwood. [3].

Post-impact bending strength testing must be carried out to determine the residual strength of the composite after impact. Composite oftenexperiences light impact loads during applicationsuch as impact with gravel, blows from a screwdriver or falling keys and vibrations. When a composite is hit, it becomes deformed. How deformed the material is after the impact depends on the amount of impact energy. The greater the impact energy, the larger the defects it creates. Post-impact flexural strength is reported to generally decrease with increasing impact energy. Bending strength higher in the case of bending outward than in the case of bending inward, becausereduces the compressive properties of skin affected by impact [4]. Post-impact compressive strength also decreases in glass fiber-epoxy composites, a decrease in compressive strength occurs with increasing impact energy [5]. Defects due to impact reduce the strength of the composite, but the composite still has the strength to remain in use at a certain residual strength [6].

In the development of composites reinforced with bamboo, it is important to understand how variables in bamboo can influence the behavior of the composite, one of which is the pattern of bamboo weaving. The shape of the bamboo arrangement has a significant effect on the mechanical characteristics of the composite. The bamboo woven pattern influences the tensile and shear characteristics of polyester composites reinforced with hybrid of bamboo woven-fiberglass woven. Strip bamboo woven with a satin pattern provides better tensile strength than plain and twill patterns. The tensile strength of the polyester composite reinforced with satin bamboo woven - fiberglass woven is 81.7 MPa, while the shear strength is 33.1 MPa. [7]. The woven structure and impact mode influence the low-speed impact properties and fractography of polymer composites reinforced with bamboo woven. The woven structure allows energy transmission in all directions during impact so that the energy absorbed increases. The bamboo woven reinforced composite with a twill pattern provides the highest impact strength namely 95.95 kJ/m ^{2}, while the plain woven pattern provides the highest impact strength namely 94.11 kJ/m ^{2} [8].

A deeper understanding of the influence of bamboo weaving patterns is important to ensure desired performance. Woven bamboo pattern refers to the layout and orientation of bamboo strips in a polyester matrix. This woven pattern can varyplain , twill , and satin. Each pattern can provide different mechanical characteristics.However, to date, little research has been conducted to examine the real impact of variations in bamboo woven patterns on the flexural strength of composites after low-impact loads. This study aims to fill the knowledge gap and investigate the effect of bamboo woven patterns on the flexural strength of polyester composites reinforced with bamboo woven after experiencing low impact loads.The results of this research are expected to provide valuable guidance in the selection of optimal weaving patterns for specific composite applications and enable the development of superior and durable materials. Also to support sustainable development by utilizing natural resources, such as bamboo, and increasing the efficiency of using composite materials in various industries.

RESEARCH METHODS

This paper discusses the effect of bamboo woven patterns on the flexural strength of polyester composites reinforced with bamboo woven after experiencing low-impact loads. Composite specimens are made from woven bamboo fabricated into laminates with a solid polyester matrix. The woven material is made from old Apus bamboo (Gigantochloa Apus) more than 3 years old. Bamboo is split and trimmed into thin strips 0.7 mm thick and 10 mm wide. The bamboo strip are dried in the sunlight for 1 day to reduce the water content. Then the strip are woven with 3 basic types of weave: plain, twill, and satin. The basic woven pattern is shown in Figure 1. The bamboo woven is soaked in 5% NaOH solution for 2 hours and care must be taken to ensure that all parts are submerged so that they receive a uniform alkali treatment. The woven bamboo is washed with running water to remove NaOH and then dried in the sunlight for 1 day.

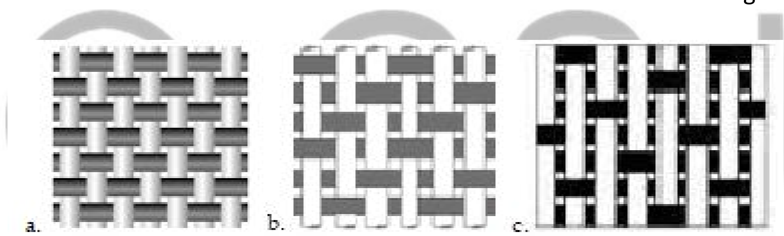


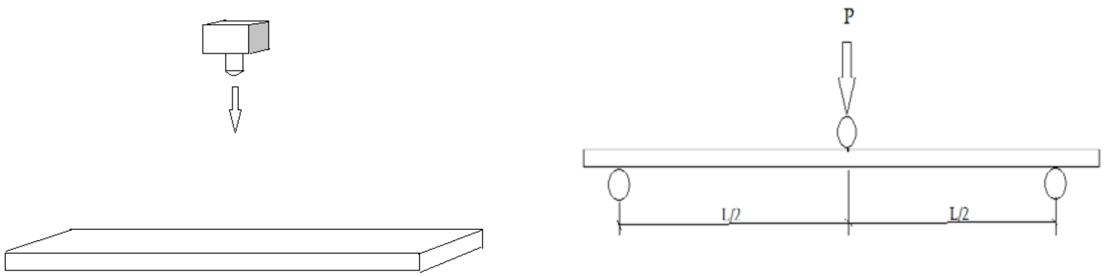
Figure 1 Basic weaving pattern: a. plain , b. twill , and c. satin

The coding of polyester composite samples in this study was carried out based on the type of woven reinforcement pattern. The FFF-code is a composite reinforced with 3 layers of woven fiberglass. The FPF-coded composite is a composite reinforced with bamboo woven with a plain pattern sandwiched between two fiberglass woven. The FTF-coded composite is a composite reinforced with bamboo woven with a twill pattern sandwiched between two fiberglass woven. Meanwhile, the FSF-coded composite is a composite reinforced with bamboo woven with a satin pattern sandwiched between two fiberglass woven.

Laminate composites are made using the hand lay-up molding method. The mold is made of glass without glue between the sides to make disassembly easier. Mold cavity size: length 260 mm x width 210 mm x thickness 5 mm. The specific gravity of fiberglass is 2.63 gr/cm ^{3} , the weight per area of fiberglass woven is 200 gr/m ^{2}, while the specific gravity of bamboo strip is 0.7052 gr/cm ^{3}, the average weight per area of bamboo woven is 215 gr/m ^{2}. For FPF, FTF and FSF composites with a mold thickness of 5 mm which is completely filled when the matrix solidifies, a reinforcement volume fraction of 9.12% is obtained. Meanwhile for composites reinforced with 3 sheets of fiberglass woven (FFF), the mold thickness is made 2.5 mm to obtain the same volume fraction ignoring the presence of voids.

After the mold is assembled, it is smeared with mirror glaze so that the composite is easily removed from the mold. If the composite is to be made with the FPF code, the composite reinforcement is arranged in the mold cavity in the order of fiberglass woven - plain pattern bamboo woven - fiberglass woven. The matrix material prepared consists of 300 grams of Yukalaq brand of unsaturated polyester resin, 3 grams of methyl ethyl ketone as a catalyst, and 60 grams of A thinner as a diluent (or a weight ratio of 100:1:20). The resin and A thinner are stirred until they are mixed homogeneously, then the resulting mixture is given a vacuum treatment to remove trapped air. Then a catalyst is added to the mixture and stirred until smooth and then poured into the mold cavity. Curing occurs perfectly for 24 hours before finally being removed from the mold. The composites with other variations of bamboo woven were made in the same way to obtain 4 composite variants. The composite that has been made is then cut with a high speed grinder with a high speed cutter grinder into an after impact bending test specimen. The specimen dimensions are 200 mm long x 65 mm wide x 5 mm thick. The width is 65 mm because the reinforcement is made from woven bamboo strips, each strip is 10 mm wide so there are at least 6 strands so that it can represent even strength in the composite. Specifically for composites reinforced with 3 sheets of fiberglass woven (FFF), the thickness is made to 2.5 mm so that the volume fraction of fiberglass is the same as the volume fraction if the composite is reinforced with bamboo woven.

Impact treatment on composites in this research is intended to provide defects on the composite surface. The occurrence of defects in composites due to impact is analogous to when a vehicle made of composite material receives an unexpected impact during use and must remain in use with the remaining strength until it is time to be repaired. Impact on composite specimens using the drop-weight method. The impactor is dropped from a certain height onto the surface of the composite specimen which is supported by clamps at both ends (figure 2a). The impactor is a steel cylinder with a hemispherical tip with a diameter of 1 inch. Dropweight impact provides a shock force on the composite surface with energy equal to the potential energy of the bat before it is dropped, namely the mass of the bat times the gravitational acceleration times the height of the bat against the composite surface. In this study, the impact energy was varied by 5 J, 10 J, and 15 joules. The impactor mass was 2.6 kg, so to produce this energy the height of the impactor on the specimen was 19.6 cm, 39.2 cm, and 58.7 cm respectively. Defects due to impact on the specimen are observed and their diameters measured.



a. b.

Figure 2 Schematic a. dropweight impact b. three point bending test.

After the impact is carried out, the specimen is bending tested to determine the residual bending strength. The type of bending test carried out is three-point bending. The bending force is applied slowly in the middle of the specimen which is supported by two supports (Figure 2b). The laminate composite bending test standard is ASTM D7264. From this bending test, it is known that the bending force of the composite can withstand the load until the composite breaks or the bending load decreases drastically [9]. Measurement of specimen dimensions is carried out before bending testing. The bending specimen supports are shifted so that the distance between the supports is 160 mm and the penetrator is in the middle between the supports. The bending specimen was placed on the bending support of the universal testing machine (Tensilon RTG 1310) and tested with a displacement speed of 5 mm/minute. The amount of bending load applied and the bending deflection that occurs in the specimen are automaticly recorded and its visible on the computer. Bending strength is calculated by the following formula 1:

$$\sigma_b = \frac{3FL}{2bd^2} \quad \ldots\ldots (1)$$

With σ_b = composite bending strength (MPa), F = maximum bending force (N), L = distance between supports (m), b = composite width (m), d = composite thickness (m).

RESULTS AND DISCUSSION

Impact to the composite has been carried out, the penetration of the composite surface by the impactor indicates that the surface is not strong enough to withstand the penetration force of the impactor during a dropweight impact with greater energy. Damage occurs on the composite surface and for greater energy holes occur in the composite. Although the damage to the composite surface is not necessarily the same as the surface inside the composite, at least the damage can be described by surface damage. Fiber damage and matrix damage were visible in the impact area between the specimen and the impactor, but no delamination was observed. Damage without delamination indicates greater interlaminar strength provided by the interlaminar reinforcing woven structure. There was also no cracking of the composite, this indicates that all composite variants reinforced with fiberglass woven and bamboo woven hybrids are resilient enough to withstand drop-weight impacts.

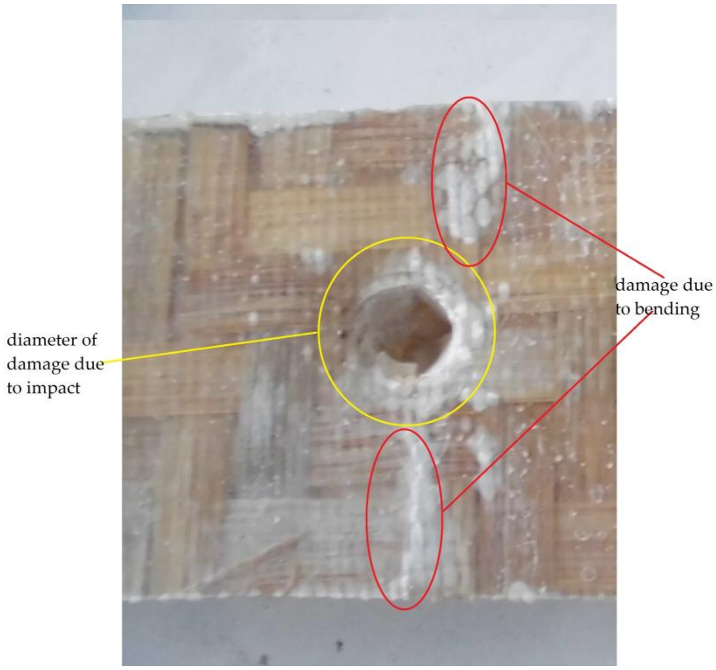


Figure 3 Impact damage and post-impact bending

There are various variables that influence damage during an impact test. One of them is how impact energy affects the type and level of damage in the composite. The lowest impact energy in a dropweight impact is 5 joules, damage only occurs on the middle surface of the contact area. In this condition, the composite is still able to absorb impact energy. When the impact energy is increased to 10 and 15 joules, the impactor energy is absorbed by the composite to damage the fibers, matrix and bonds between them. When the impactor's energy is still excessive, it is able to perforate the composite and finally, the energy runs out when the impactor is stopped by friction with the hole walls. Composite damage due to impact with greater energy in the form of holes and bond damage that spreads in the radial direction at a certain diameter is shown in Figure 3.

Data on the diameter of damage to the composite surface due to impact is shown in Figure 4. The damage that occurs is in the form of loose bonds between the matrix and the fiber, and between the matrix, which is indicated by the color changing of the composite surface to white. Another damage that occurred was a hole penetrating into the composite. It appears that the greater the impact energy applied to the composite, the greater the diameter of the damage. The largest damage diameter occurred in the polyester composite reinforced with three fiberglass woven. The thickness of this composite is only 2.5 mm which allows the available impact energy to easily cause damage compared to a polyester composite reinforced with fiberglass woven - bamboo woven which has a thickness of 5 mm at the same impact energy.

The diameter of the damage increases if the impact energy is increased, this also happens to all composite variants reinforced with fiberglass woven - bamboo woven. But if you look closely, the damage to the composite with woven bamboo reinforcement becomes 10 joules, which increases more low compared to the composite reinforced with three layers of fiberglass. Of the three composite variants reinforced with bamboo woven, the composite reinforced with bamboo woven with a plain pattern (FPF) experienced less damage compared to the damage to the composite reinforced with bamboo twill wave (FTF) and stin wave (FSF), especially in terms of low energy impact, namely 5 joules and 10 joules. The low impact energy mainly causes cracking and damage to the matrix, but the failure of the reinforcing fibers is not obvious. Damaged layers due to impact were more frequently detected in cross-woven composites (twill and satin pattern) compared to plain weave composites after low-energy impacts. This shows that the plain weave structure has the ability to protect the composite from damage better at low impact energy. These differences in damage protection are closely related to the weave structure. The plain weave structure can withstand impacts in the x and y directions in each layer, while only impacts along the fiber orientation can be resisted in the cross-woven layers [10]. Meanwhile, at high impact energy (15 joules), it can be seen in Figure 2 that the damage diameter does not differ sharply between FPF and FTF or FSF. This indicates that the bamboo woven pattern has a big influence on the composite damage diameter at low impact energy, whereas this is not the case at high impact energy.

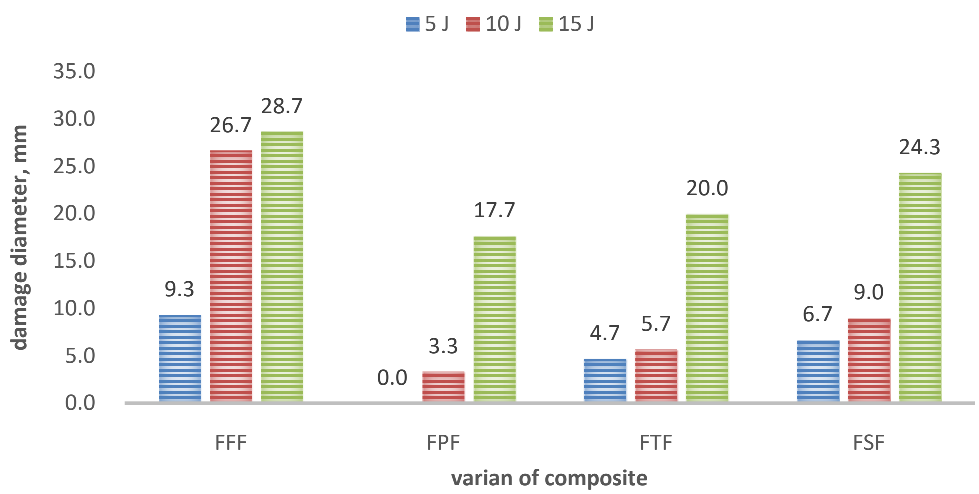


Figure 4 Diameter of impact damage on composites

Bending tests are carried out on specimens that have not been subjected to impact loads or those that have been subjected to impact loads. Bending failure that occurs in composites occurs under the bending press rod. It can be seen in Figure 1 that the failure that occurred shows that the polyester composite material reinforced with fiberglass woven - bamboo woven is ductile, the composite did not break apart after experiencing bending loads even though it had previously been perforated due to impact. The bending defect formed in Figure 1 is not straight across the width of the composite, the defect bends in the weaker part, this is because the impact defect is not symmetrical and the strength of the material is not the same in all directions with the presence of woven bamboo as reinforcement.

In general, polymer matrix composites have three causes of bending failure, namely plastic deformation of the matrix, loss of fiber-matrix bonds, and fiber breakage. The failure morphology of the composite showed no shear damage within the layer due to the strong interaction between the woven strips. Generally, fiber failure occurs when high local stress exceeds the strength of the fiber in place, in this case high bending stress. The local stress at the damage area is much lower than the fiber strength. Therefore, matrix cracking is the main form of damage that occurs at this location.

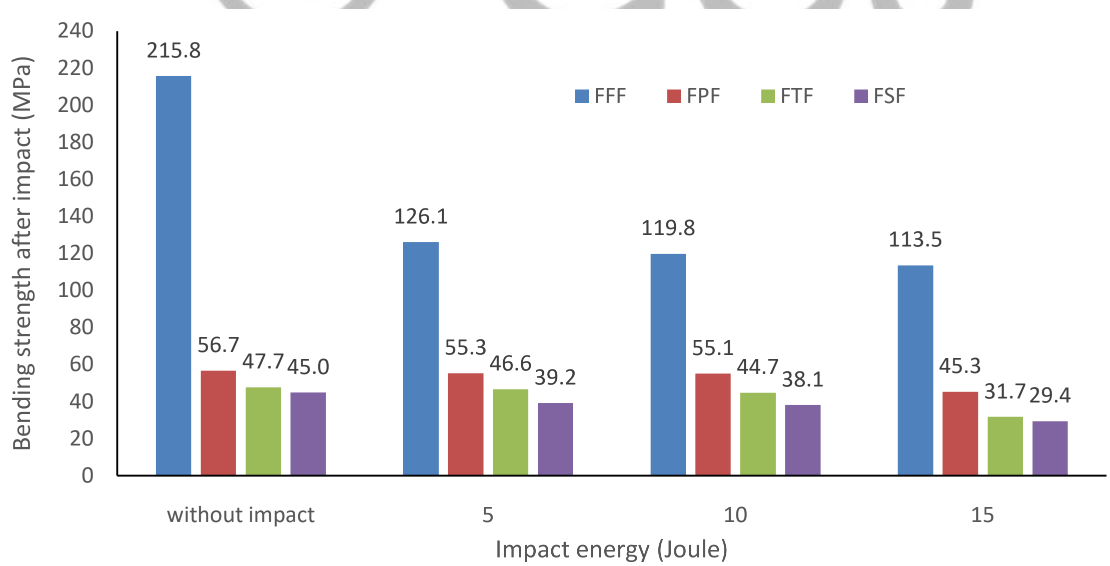


Figure 5 Composite bending strength after impact

The bending strength of the composite before and after experiencing impact is shown in Figure 5. It can be seen that the bending strength of the composite reinforced with 3-layer fiberglass woven (FFF) before impact is 215.8 MPa. That is much higher than that reinforced with a hybrid of fiberglass woven - bamboo woven whose value is 45 MPa for FSF, 47.7 MPa for FTF and 56.7 MPa for FPF. The bending strength of the composite after impact decreases due to defects in the composite. Greater impact energy causes a larger diameter of impact defects. The larger defects cause a greater reduction in the bending strength of the composite so the greater the impact energy imposed on the composite causes the bending strength of the composite to decrease after impact. The decrease in bending strength after impact in the FFF composite was steeper, namely 41.5% to 47.4%, while the decrease in the hybrid of fiberglass woven - bamboo woven reinforced composite was smaller, between 2.3% to 34.6%. Bamboo woven is more able to maintain bending strength than fiberglass woven when the composite has been deformed by impact.

The bending strength of the composite reinforced with a hybrid of fiberglass woven - bamboo woven with a plain pattern (FPF) only decreased by 2.3% to 55.3 MPa after experiencing a 5 Joule impact. The bending strength of the FPF composite decreased by 2.9% after experiencing an impact of 10 joules and decreased by 20.1% after experiencing an impact of 15 joules. The decrease in bending strength after impact of the FPF composite is much smaller than the decrease experienced by the FTF and FSF composites, namely up to 34.6%. Plain patterncomposites FPF have more cross-sections between warp and weft strips than twill and satin woven patterns . Composites that are reinforced with woven patterns that have more crosses, such as plain patterns, have higher strength than those reinforced with twill or satin woven patterns [11]. A greater number of crosses causes a lot of interlocking , thus causing a distribution of the load received by the woven threadplain is more evenly distributed so the bending strength is greater.

Conclusion

The pattern of woven bamboo as reinforcement has a big influence on the damage dimensions of composites that applied drop-weight impacts at low energy, while at high impact energy, the damage to the composite is almost the same. The bamboo woven pattern influences the difference in the reduction in the flexural strength of the composite after the drop-weight impact. The decrease in bending strength after the impact of composites reinforced with the hybrid of fiberglass woven-bamboo woven with plain patterns is smaller than those with twill weave and satin weave patterns.

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