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Tensile Strength and Punch Shear Strength of Bamboo Woven- Reinforced Polyester Composite

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ABSTRACT*: Bamboo woven is one of the natural reinforcements applied to polyester matrix composites. Appropriate bamboo woven patterns can be selected for higher strength. In this study, the addition and influence of bamboo woven on the strengthening of polyester composites is reported. Three woven patterns: plain weave, twill weave, and satin weave are applied to the bamboo strips to strengthen the polyester resin. The results obtained were that bamboo strips woven with a satin weave pattern provided higher strength than the other two woven patterns.*
Keywords: bamboo, woven, composite, tensile, shear

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I. INTRODUCTION

Fiberglass is a fiber that comes from molten glass which is drawn into small fibers. The fibers are then spun into thread and woven into cloth, or arranged randomly into a mat. Glass fiber-reinforced polymer composites are capable of achieving high tensile strength [1]. Glass fiber also bonds easily with polymer adhesive or cement, is corrosion resistant, resistant to chemicals so it is widely used as a composite material in vehicle and panel applications[2]. However, glass fiber also has weaknesses, namely that it has a high specific gravity, is detrimental to health, is not environmentally friendly, and requires high heat to produce it. In the framework of Back to Nature, the fibers used are not only synthetic fibers but also natural fibers with different advantages. Even though natural fiber is not resistant to moisture and its strength is still below that of glass fiber, it is still moderate and has several advantages. Natural fibers are widely used for composite applications because they are more available and varied, are more environmentally friendly because they can be degraded naturally, are better in terms of aesthetics, and are cheaper than glass fiber[3,4].

Bamboo has been widely researched as a composite reinforcing material because the potential of bamboo is very large. Bamboo is a plant that is often found in rural areas, the annual production of bamboo fiber in the world reaches 10 million tons[5]. The tensile strength of bamboo fiber is 290 MPa, with an elastic modulus of 17 GPa[6]. Bamboo fiber as the main reinforcement or a hybrid with synthetic fibers has been widely researched to strengthen thermoplastic and thermoset polymers to form composites. Bamboo is processed into blades, strips or extracted into fibers as a reinforcing material for polymer matrices. Bamboo was chosen as a reinforcement in composites because of its good tensile strength, flexibility, ease of processing, low price, environmental friendliness, aesthetics, and its ability to be used as a product in industry on a par with hardwood [7].

The mechanical properties of polymer composites reinforced with natural fibers are influenced by several factors, namely polymer type, fiber content, fiber distribution, interfacial adhesion, fiber direction and fiber aspect ratio [8]. Apart from that, if the fiber is woven, the woven pattern affects its mechanical properties. The woven model of waru tree bark fibers (Hibiscus Tiliceus) influences the tensile strength of bisphenol composites. The use of waru tree bark fiber for composite reinforcement is more appropriate when using a basket weave pattern (2-2) compared to using unidirectional fiber models [9].

The shape of the bamboo weave has a significant effect on the mechanical characteristics of the composite. Chang C.W. et all discussed the influence of woven structure and impact mode on the low-speed impact properties and fractography of polymer composites reinforced with bamboo textiles. The results show that the woven structure allows energy transmission in all directions during impact so that the absorbed energy increases. The bamboo woven reinforced composite with a twill woven 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[10].

Bamboo has the potential and capability as a reinforcement for natural fiber composites, but more specific research is needed to examine the effect of bamboo strip woven patterns on the tensile characteristics and shear strength of polyester composites reinforced with bamboo woven. This research aims to determine a woven pattern that is able to provide better tensile strength and shear strength. This research is intended to trigger bamboo reinforced polyester composites to be more widely adopted in various industries.

II. RESEARCH METHOD

The object of this paper is to determine the relationship between the woven pattern and the tensile characteristics and shear strength of polyester composite reinforced with bamboo and fiberglass woven. Composites were fabricated from bamboo preforms cured in a polyester matrix. The woven material is made from apus bamboo stems (Gigantochloa Apus) that are more than 3 years old and grow on Lombok Island. Bamboo stems are cut and dried in the sun to reduce the water content. Bamboo is split and whittled to obtain thin strips with a thickness of 0.7 mm, then the strips are woven with 3 different basic weave patterns, namely plain weave, twill weave, and satin weave (figure 1). The woven bamboo is soaked in a 5% NaOH solution for 2 hours and it must be ensured that all parts are submerged so that they are evenly exposed to alkaline treatment. The bamboo woven is washed in running water to remove NaOH, then dried in the hot sun for 1 day.

The polyester composite in this study was varied based on its reinforcement, the FFF code is a composite reinforced with 3 layers of woven fiberglass reinforcement. A composite with the code FPF is a composite reinforced with bamboo woven with a plain weave pattern sandwiched between two woven fiberglass. A composite with the code FTF is a composite reinforced with bamboo woven with a twill weave pattern sandwiched between two woven fiberglass. Meanwhile, composites with the FSF code are composites reinforced with bamboo woven with a satin weave pattern sandwiched between two woven fiberglass.

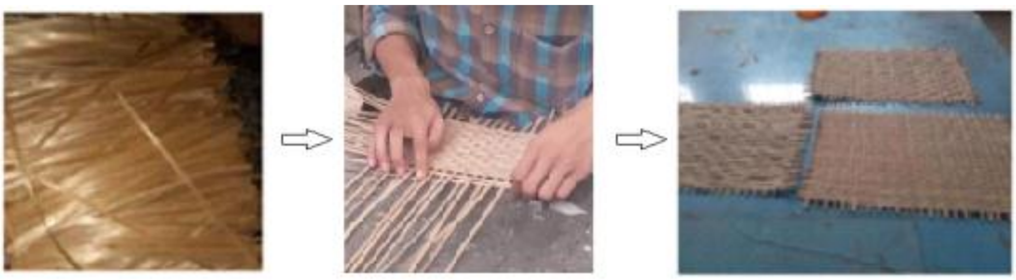

Figure 1 Processing bamboo into woven material

The hand lay-up method is used to make laminate composites. The composite mold is made of glass with a cavity size of 260 x 210 x 5 mm^3, the mold base is also made of glass. To make it easier to disassemble the composite, the mold is coated with mirror glaze. Composite reinforcement is arranged in the mold cavity in the order of fiberglass woven - bamboo woven - fiberglass woven. The composite matrix consists of a mixture of unsaturated polyester resin produced by Yukalaq, methyl ethyl ketone as a catalyst, and thinner A as a diluent. The matrix composition consists of 300 grams of resin, 3 grams of catalyst, and 60 grams of thinner A (or a weight ratio of 100:1:20). The polyester resin and thinner A are stirred until well mixed, and the vacuum equipment is applied to remove trapped air. The catalyst is then added to the polyester-thinner mixture and stirred until smooth and then poured into the mold. The weight per area of woven fiberglass is 200 gr/m^2, while the weight per area of woven bamboo is 215 gr/m^2. If the mold is filled with glass fiber reinforcement - bamboo woven- fiberglass covering the mold area and then a fully filled matrix is inserted with a mold thickness of 5 mm, then from the calculations a reinforcement volume fraction of 9.12% will be obtained. Meanwhile, for composites reinforced with 3 sheets of fiberglass (FFF), to obtain the same volume fraction, the mold thickness is made 2.5 mm, ignoring the presence of voids.

Curing occurs perfectly for 24 hours before finally being removed from the mold. Composites with other variations of woven bamboo were produced in the same way to obtain 4 composite variants. The produced laminate composite was cut with a high speed cutter into specimens for tensile tests and punch shear tests (figure 2).

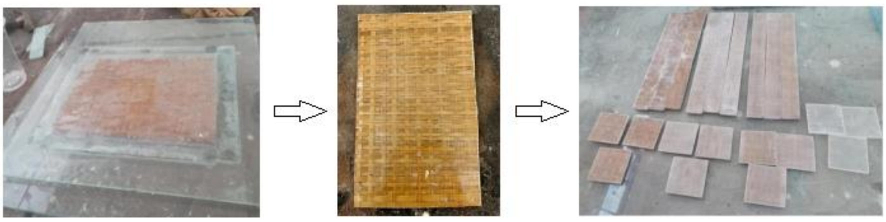

Figure 2 Composite molding process and specimen cutting

Tensile tests were carried out to determine the tensile strength, fracture strain, and elastic modulus of the composite. Specimen dimensions and testing are based on ASTM D039 standards. The thickness of the tensile specimen is 5 mm with a width of 25 mm, the measuring length of the test specimen is 150 mm, and the length of the tensile holder is 50 mm so the total length of the specimen is 250 mm. Displacement was administered at a speed of 5 mm/minute. The tensile testing equipment used is a universal testing machine of the Tensilon RTG 1310 with a capacity of 10 kN as shown in Figure 3a.

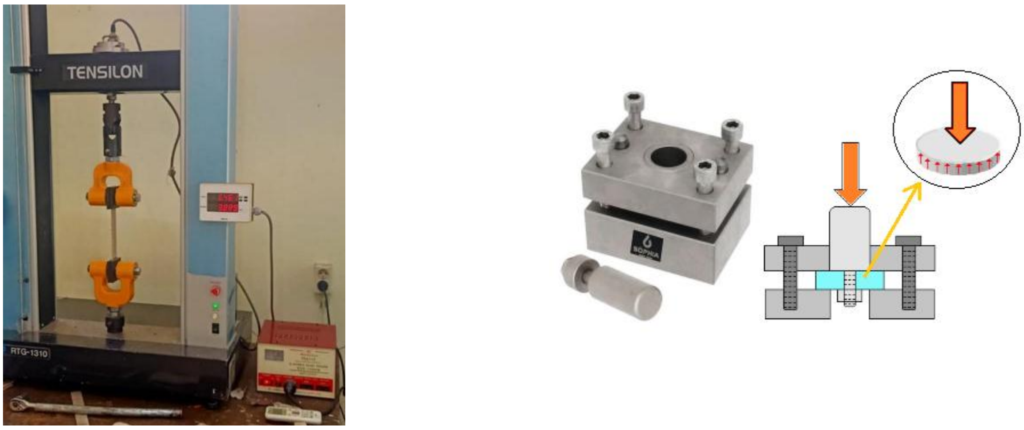

Figure 3 a. UTM Tensilon RTG 1310 b. punch shear test equipment

The shear test carried out was a punch-type of shear stress based on ASTM D732 standards. Shear testing is carried out with a compression testing machine on a universal testing machine using special additional equipment (figure 3b). The test specimen is placed in the clamp in such a way that its top and bottom surfaces are supported. The test specimen is a composite square plate with a side length of 50 mm and a thickness corresponding to the thickness of the laminate with a drilled hole in the middle. A punch-type shear tool with a punch diameter of 25.4 mm (1 in) is bolted to the specimen and a load is applied to the punch. The shear strength is calculated as the maximum force obtained during the test divided by the area of the incised edge (the circumference of the perforated circle multiplied by the thickness of the specimen).

III. RESULTS AND DISCUSSION

Tensile test results data in the form of graphs of stress - strain for the four variations of reinforcement are shown in Figure 4. It can be seen that the graph is a linear line at the beginning of the strain, then curves with increasing strain until the peak of the load, and finally, the load drops suddenly when the specimen breaks. The graph in Figure 4 is a stress-strain graph of the tensile specimen of FFF, FPF, FTF and FSF laminate composite.

From all the tensile test stress-strain graphs, the tensile strength, modulus of elasticity, and strain at fracture are then calculated in Table 1. The highest tensile strength presented in Table 1 and Figure 4 is the composite specimen with woven glass fiber reinforcement (FFF), namely 121 MPa, this is due to the contribution of the tensile strength of glass fiber which is higher than bamboo fiber. From the Figure 4 and Table 1 it can also be seen that variations in the bamboo woven pattern used as reinforcement affect the tensile strength and fracture strain of the composite. The next order of tensile strength with a value of 81.7 MPa belongs to the polyester composite reinforced with bamboo satin weave - fiberglass woven (FSF). Followed by the polyester composite reinforced with bamboo plain weave - fiberglass woven (FPF), and the composite reinforced with bamboo twill weave - fiberglass woven (FSF) which has almost the same tensile strength, namely 65.5 MPa and 64.5 MPa.

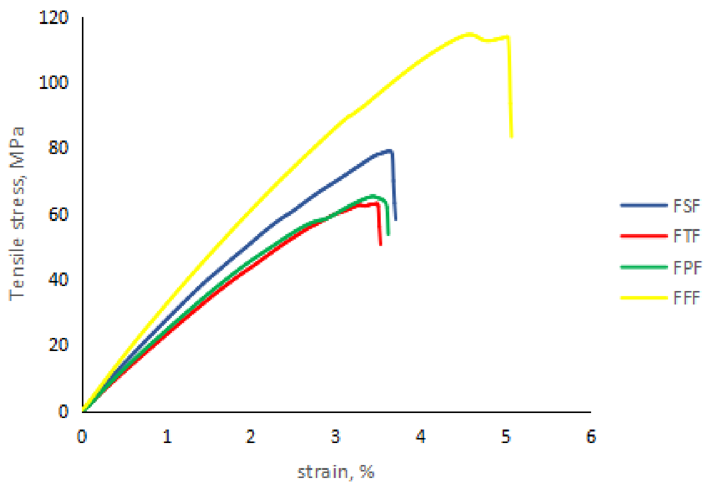

Figure 4. Tensile stress versus strain of laminate composite

Table 1 Tensile test results of laminate composites

Composite variants	Repetition	Tensile strength (MPa)	Fracture strain (%)	Elastic modulus (MPa)
FFF	1	96,3	4,38	2314
	2	130,3	3,16	2688
	3	136,3	5,00	2937
	Rata-rata	121,0	4,18	2646
FPF	1	53,2	2,66	2470
	2	73,0	3,50	2557
	3	70,4	3,42	2564
	Rata-rata	65,5	3,19	2530
FTF	1	67,8	3,67	2321
	2	63,3	3,40	2278
	3	62,5	3,28	2357
	Rata-rata	64,5	3,45	2319
FSF	1	78,2	3,63	2746
	2	84,1	3,90	2688
	3	82,7	3,57	2889
	Rata-rata	81,7	3,70	2774

The strength of composites reinforced by woven is influenced by several things, namely: woven geometry, size of fibers or reinforcing strips, distance between fibers, crimp, lamination parameters (reinforcement orientation and volume fraction), and properties of the matrix and reinforcement materials [11]. The three woven patterns applied in this study provide different geometries and distances thereby providing different composite strengths. The webbing consists of the warp, the fill, and the gaps between them. Fill is fiber which has a horizontal direction and has the function of binding between woven fibers. While warp is fiber that has a vertical direction and also has the function of binding between woven fibers, between the warp and fill in the woven pattern there is a small gap [12]. From the tensile test data above, the bamboo-reinforced composite with a satin weave pattern is able to withstand tensile stress better than the bamboo-reinforced composite with a plain weave or twill weave pattern. This trend is different from composites reinforced with woven threads. Composites reinforced with woven threads with plain patterns actually have better tensile strength than those reinforced with satin and twill woven patterns [9].

The thread is easy to bend without defects and tension, the force that the thread can withstand is only in the direction parallel to the thread. Woven threads when subjected to a tensile load produce interlocking between the weft and warp threads [12]. The plain weave pattern has more intersections between the warp and fill threads than the twill weave or satin weave patterns. A greater number of crosses causes more interlocking, resulting in a more even distribution of the load received by the plain thread so that the tensile strength is greater. Composites that are reinforced with woven threads with a woven pattern that has more crosses, such as plain patterns, have higher strength than those reinforced with twill or satin patterns.

Bamboo strips are flexible, but cannot be bent like thread. If it is bent, stress will arise during the bend, if the bend is sharpened then deformation will occur and it can fail. When bamboo strips are woven into woven material, the bamboo strips experience cross-linking. The crossing makes the strip bend to form the contour of the webbing. In these bends, stress occurs even before the tensile load is applied. When the webbing is subjected to a tensile force, its tensile strength decreases. The webbing causes interlocking when it is pulled (shown by arrows in Figure 5), but the bamboo strip woven also causes bending with initial stress in it and this results in a decrease in its tensile strength.

The amount of bending reduces the tensile strength, the more bending causes the tensile strength to decrease. As can be seen in Figure 5, different weaving patterns have different amounts of bending. The satin weave pattern only has 2 bends for a total of 8 bamboo strip warps, while the twill weave has 2.5 bends and the plain weave pattern has 8 bends. The tensile strength of the composite reinforced with satin pattern is higher with the least amount of bending than the other two patterns. The strengthening effect of interlocking is not as great as the reduction in strength of bending at the intersection

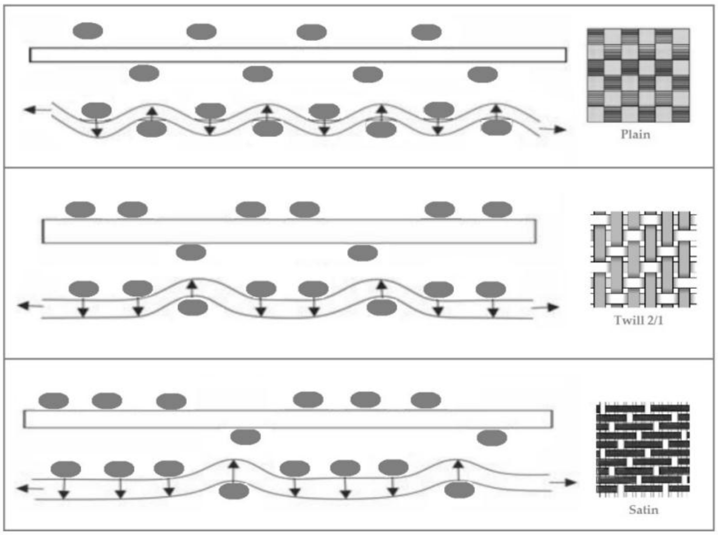

Figure 5 Illustration of bending and interlocking in a woven pattern

The fracture strain in the tensile test of composites reinforced with fiberglass (FFF) was 4.18%. By adding bamboo woven, the tensile fracture strain decreased to 3.19%; 3.45%; and 3.7% respectively for composites that added bamboo woven reinforcement with plain weave, twill weave, and satin weave. The modulus of elasticity of the composite increased after adding reinforcement of a satin weave bamboo but decreased with the addition reinforcement of bamboo woven with plain weave and twill weave patterns, as shown in Table 1.

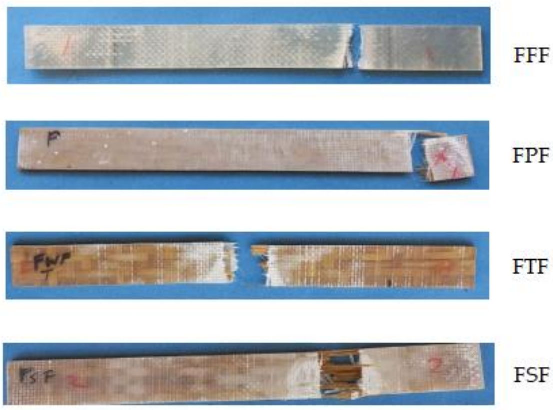

Figure 6 Composite tensile fracture

Figure 6 shows the fracture of the composite specimen after the tensile test. As seen in the image of the FFF composite fracture, the fracture area looks white even though the area is not large, this indicates that there was a separation of the fiber bond with the matrix only in a very small area before it finally broke. The fiberglass has been pulled out, although in small amounts, this indicates that the bond between the resin and the fiberglass is very tight. In the FPF, FTF and FSF composite fracture, it can be seen that the area near the fracture that turns white is wider. It can also be seen that the bamboo strips and fiberglass have been pulled out of the resin, this indicates that before breaking, the bond between the matrix and the bamboo was already separated. This could be because the matrix bond with the bamboo is smaller than the strength of the bamboo, so the bamboo is pulled out of the resin first and then breaks. Of the three composite variations, the plain weave bamboo as reinforcement provides less fiber pull out. The satin weave pattern provides more fiber pull out, the satin weave pattern is no more stable than the other two patterns.

The results of the punch shear strength test are shown in Figure 7. The shear strength of the composite reinforced with three fiberglass woven has the highest value, namely 40.8 MPa. When bamboo woven partially replaces fiberglass woven, so the strength of the composite decreases, although the decrease is small. Figure 7 shows that the punch shear strength of the composite reinforced with bamboo woven for the three woven patterns is not much different, namely between 30.6 MPa and 33.1 MPa. In the three woven patterns the weft and warp are perpendicular to each other (bidirectional) so that this composite supports the load in four mutually perpendicular directions [13].

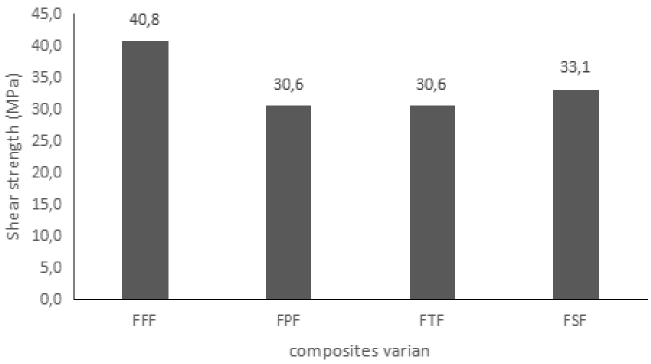

Figure 7 Composite shear strength

Composites reinforced with satin weave bamboo have higher shear strength than those reinforced with plain weave and twill weave patterns, although the difference is small. Satin weave patterns have smaller gaps between strips, while plain weave patterns have the largest gaps between strips. The gaps between the strips will be filled with resin and can even cause porosity when molding the composite. The plain weave pattern provides acceptable porosity, while the satin weave provides an excellent ranking for the porosity of the composite [14]. Fewer gaps in the satin weave pattern cause the resistance of the bamboo strip to a greater shear test load. This is what causes the satin weave pattern to have a better contribution to providing composite shear strength than the other two weave patterns.

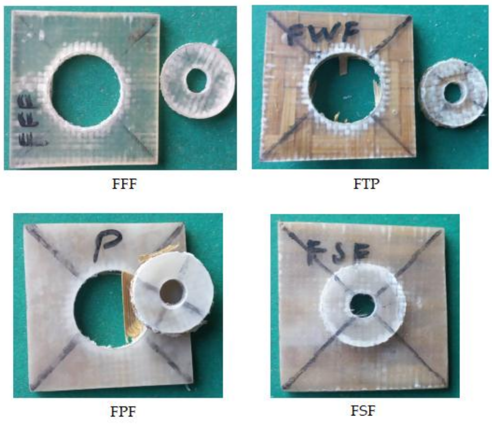

Figure 8 Composite specimen after punch shear test

The role of the satin weave pattern on bamboo in increasing the shear strength was also confirmed by photos of the failure mode of the specimen after the punch shear test. It can be seen in Figure 8 that around the shear hole of the FTP and FTF composite appear white due to failure in the form of separation between the reinforcement and the matrix indicating a weak bond. Meanwhile, in the FSF composite, the composite does not change to white, meaning that the satin weave bamboo has a better bond with the resin in resisting the punch shear load than the plain weave and twill weave patterns.

IV. CONCLUSION

The bamboo woven pattern influences the tensile and punch shear characteristics of the polyester composite reinforced with the bamboo woven-fiberglass woven hybrid. Bamboo strips woven with a satin weave pattern provide better strength than plain and twill woven patterns. The tensile strength of the polyester composite reinforced satin weave bamboo - fiberglass woven is 81.7 MPa, while the shear strength is 33.1 MPa.

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