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Shear Strength Analysis of Sandwich Composite Cores Stitched with Natural Fibers

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Abstract—A sandwich panel with a polyurethane rigid foam core is a composite structure consisting of a core layer sandwiched by fiber-reinforced layers, which are generally made of glass fiber. Natural fibers are attracting interest as an environmentally friendly alternative to foam reinforcement. In this research, an analysis was carried out on the shear strength of sandwich composite cores stitched with natural fibers. The specimen is a sandwich composite with polyurethane foam as the composite core and a fiberglass-reinforced polyester laminate as the composite skin. Natural fibers are stitched into polyurethane foam to strengthen it. Experimental methods are used to evaluate the shear strength of sandwich panels with various types of natural fibers. Shear tests were carried out in accordance with ASTM C 273-61 standards, to determine the shear strength between polyurethane and composite skin. The results show that stitching the composite core with natural fibers significantly increases the shear strength compared to unstitched panels. Varying types of natural fibers affect the mechanical performance of panels differently. The use of natural fibers improves the mechanical performance of the panels. This research shows the potential of using natural fibers as an alternative reinforcement with promising experimental results.

Keywords—Natural Fiber, Stitch, Sandwich Core.

I. INTRODUCTION

Research on shear strength analysis of sandwich panel cores stitching with natural fibers has two main points, namely the increasing need for environmentally friendly construction materials and the development of composite technology to improve structural performance. Environmental sustainability is one of the main benchmarks in materials technology. Environmentally friendly material technology aims to reduce negative impacts on the environment, including the use of sustainable materials. Natural fibers, such as sisal fiber, banana tree fiber, and sugar palm fiber, have emerged as an attractive alternative because of their renewable nature and good biodegradability.

Even though natural fiber is not good for use with moisture and its strength is still below that of glass fiber, it has several other advantages. Natural fibers are widely used for composite applications because they are more available and varied, more environmentally friendly because they are able to degrade naturally, better aesthetics, lower energy consumption during processing, and the price is cheaper than glass fiber [1,2]. Therefore, the integration of natural fibers into construction materials, such as in polyurethane rigid foam sandwich panels, is an important research subject to support sustainability in the construction materials industry. Integrating natural fibers into composite structures provides an opportunity to develop environmentally friendly construction materials without compromising performance.

Palm fiber is a natural fiber that comes from sugar palm trees. Palm fiber has elastic, hard, water-resistant properties, and is difficult for destructive organisms such as termites to digest [3]. Sisal leaf fiber is a plant fiber obtained from the leaves of the sisal plant, has a smooth surface [4] (Fahmi and Hermansyah, 2011). The sisal plant is very widely distributed, so it can be found in tropical and subtropical areas as well as areas that have wet and dry climates [5]. Banana tree fiber is a type of fiber of good quality, and is an alternative material that can be used as reinforcement in making composites [6]. Various types of bananas with good quality grow abundantly in various regions in Indonesia.

The development of composite technology continues to improve the structural and functional performance of materials. A sandwich composite structure consists of two thin, stiff, and strong skins, separated by a lightweight core usually made of polymer foam, honeycomb, or a corrugated core structure. The core material maintains the position of the skin sheet in its position with a slight increase in weight, to increase bending strength, buckling, shear, and impact energy absorption capabilities [7].

Polyurethane rigid foam sandwich panels are an example of a composite product that is widely used in various construction applications, such as walls, roofs and floors. This is due to its thermal insulation properties, hight strength-to-weight ratio and excellent load-bearing ability. However, in accepting loads, the core material of the sandwich structure shows weaknesses such as low shear strength or susceptibility to delamination between the skin and core of the sandwich composite [8]. To overcome this problem, a technique called stitching is used to strengthen the core and improve its mechanical properties[9]. Stitching involves the insertion of fibers through the thickness of the core in a regular pattern. Reinforcement of sandwich composites with stitching of the core is a very important technique. It improves crack resistance, interlaminar shear strength, impact resistance, fatigue resistance, and structural integrity. These fibers act as reinforcing elements, providing additional strength and preventing the spread of cracks or delamination within the core. The stitching process is carried out by hand, simple sewing machines and even automatic equipment to ensure proper fiber placement [10].

Although sandwich composites are strong, stitching can make them heavier. This is because high-strength fibers such as fiberglass, fibercarbon, or specially made threads used in this process can impact the overall weight of the sandwich, which is detrimental to the environment. By using natural fibers as an alternative reinforcement, the composite remains light and the potential to increase the strength and durability of sandwich panels is significant. Therefore, research on the shear strength analysis of sandwich panel cores with polyurethane foam cores stitched with natural fibers is important to evaluate the technical potential of this new construction material. By understanding the mechanical behavior of sandwich panel cores under shear loading conditions, this research can provide insight into the ability of natural fiber reinforcement to increase the structural strength of panels, while maintaining or even improving environmental sustainability.

II. MATERIAL AND EXPERIMENTAL PROCEDURES

The sandwich composite in this study consists of two polyester-fiberglass laminates sandwiching a composite core made from polyurethane rigid foam (PUR). The first material prepared to make a sandwich composite is PUR as the core of the sandwich composite. The PUR used is a hard foam sheet measuring 300 mm x 60 mm with a thickness of 25 mm and a density of 42 kg/m^3. This size is obtained by cutting with a hot wire. Sandwich composite skin is a polyester-fiberglass laminate made from unsaturated polyester with 1% catalyst and 200 gr/m^2 e-fiberglass woven reinforcement.

Sugar palm fiber is taken by removing it from the midrib of the palm tree (figure 1a). Sugar palm fiber in one palm tree frond has different diameters. In this study, the sugar palm fiber used had an average diameter of 0.11 mm with a length of 60 cm. Sisal leaf fiber is taken from old leaves (figure 1b) or that are located at the bottom compared to the other leaves. The length of sisal leaves can reach 150 cm and the smaller the diameter of the sisal leaf, the smaller the diameter. Sisal leaves are picked from the base of the tree and the thorns are cleaned. Then dry it first for 3 hours so that the sisal leaves wilt and make the process of separating the fibers easier. Cutting and peeling is done on the top leaves carefully, the fibers can be pulled from the sisal leaves if the top surface of the leaves has been cut off. Pull the fiber slowly so it doesn't break.

Banana stem fiber (figure 1c) is taken from old or harvested banana stems. The banana stem sheets are soaked for 1 hour and dried in the sun for 3 hours so that the membrane of the banana stem dries and can be cut using a tool in the form of a spatula. A plastic spatula is used to separate the membrane from the fiber.

a. b. c.

Fig. 1. a. palm fiber b. sisal leaf fiber c. banana tree fiber

Palm fiber, sisal leaf fiber, and banana tree fiber are dried in the sun to reduce their water content. Fiber diameter measurements were carried out with a micrometer to obtain fibers that were close to uniform. The average diameter of palm fiber from measurements was 0.11 mm, sisal leaf fiber 0.2 mm, and banana tree fiber 0.3 mm. Sandwich composite skin is made by hand lay up technique on both sides of the PUR. Three layers of woven fiberglass measuring 300 mm x 60 mm are spread over and under the PUR and then stitched with natural fiber. PUR-fiberglass is stitched with running stitch type hand stitching. The natural fiber that has been attached to the needle is inserted at an angle of 45^0 vertically downwards (figure 2a) so that it connects the fiberglass-PUR-fiberglass. Then it is inserted at an angle of 45 degree to the vertical upwards with a uniform distance between the stitches, namely 15 mm x 15 mm.

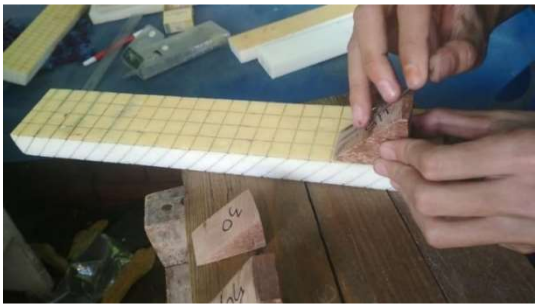
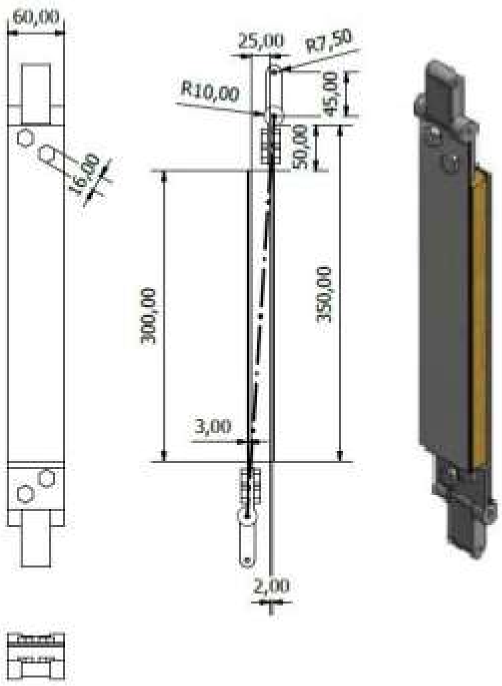
a.  b. 

Fig. 2. direction of hand sewing running stitch on PUR-fiberglass b. hand lay-up tecknic on both sides of the PUR.

The fiberglass cloth that has been stitched onto the PUR surface is then coated with polyester resin. A fourth fiberglass cloth was used to cover the stitch and smeared with polyester (figure 2b). Making sandwich composite skin on the opposite side is done in the same way to produce a symmetrical arrangement. The sandwich composite curing process takes 24 hours until it is strong. Next, the finishing process continues using a cutting and grinding machine to form the sandwich composite into a test object and prepare it for testing.



a.

b.

Fig. 3. Specimen with shear test holder plate. b. Set up of shear test

The sandwich composite core shear test is based on ASTM C 273, to determine the shear strength parallel to the surface of the sandwich composite skin [11]. The composite skin is firmly bonded to the steel plate mounts with epoxy resin to prevent shear failure at this joint. The plate is made with the same width as the sandwich composite, namely 60 mm, plate length of 350 mm and with plate thickness of 3 mm. The plate functions as a link between the composite and the shear testing machine which will later be tested (figure 3a). The plate attachment will be carried out after the cleaning process on the surface of the skins using sandpaper so that the adhesive can stick firmly to the two composite skins. Shear strength is calculated by dividing the maximum shear force (P max) by the shear area, namely shear length (ls = 300 mm) times shear width (ws = 60 mm), as follows

$$:\tau = \frac{P_{max}}{l_s . w_s} \qquad (1)$$

The shear test was carried out using a universal testing machine Tensilon RTG-1310 (figure 3b). Testing for each variant was carried out three times for sandwich composites without and with stitches for each variation of natural fiber type. The shear test was carried out on the specimen with a shear displacement speed of 0.5 mm/minute. The magnitude of the shear force is automatically recorded by the computer during testing. To obtain the shear strength, calculations are carried out using equation (1), and the results of these calculations are then averaged.

III. Result And Discussion

Shear tests were carried out on samples to determine the shear strength of the sandwich panel core. Shear displacement was carried out at a speed of 0.5 mm/min. The shear force versus shear displacement graph is recorded automatically by the computer as long as the displacement is carried out on the specimen. It can be seen in Figure 4 that the shear behavior of the stitched foam sandwich panel is different from that of the unstitched sandwich panel. The force-displacement diagram of the unstitched sandwich composite shows a more downward curve, meaning more plastic. There is a maximum shear force that occurs twice, the decrease in force occurs suddenly although it then increases again. Then the load on the specimen increases until breaking at the maximum force, the specimen suddenly collapses at the interface of the sandwich structure. Break displacement of specimens can be very long, even up to 3 mm. When polyurethane foam fails, the fiber stitching resists the shear force, and it makes the displacement longer.

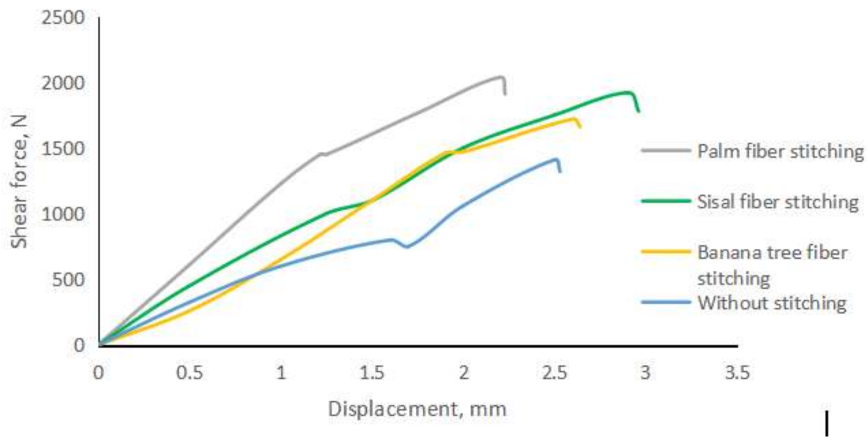


Fig. 4. Force on the shear displacement of unstitched and stitched sandwich composites with natural fibers

Nonlinearity in the graphs is also observed for all samples stitched up to the maximum load, after which the load drops significantly and the samples fail. The addition of sutures reduces the relative displacement of the two skins under shear conditions where the shear force increases. The increase in shear force with increasing displacement of the test results of the stitched sandwich composite in Figure 4 shows that its stiffness is greater than that which is not stitched. According to H. Santhanakrishnana R. et al., the tensile shear modulus of sandwich composites with stitches is higher than without stitches [10].

The sandwich composite without stitch is only able to withstand a maximum average shear force of 1471 N, polyurethane foam with small strength causes the sandwich composite shear force to be small as well. The stitching on the core that connects the upper and lower skins of the sandwich composite causes the average maximum shear force to increase to 2030 N, 1971 N, and 1726 N for each type of palm fiber, sisal and banana stitching. This is due to the role of fiber stitching in increasing the reaction force due to the shear load of the sandwich composite. Sandwich panels stitching with palm fiber show a more significant increase in shear force and increase in shear stiffness compared to panels reinforced with sisal fiber or banana tree fiber, this is due to the mechanical properties of palm fiber which are better than sisal fiber and banana tree fiber.

The maximum shear force divided by the length times the width of the composite specimen is the shear strength of the sandwich panel core, as formulated in Equation 1. Each sandwich composite with different types of natural fiber stitching was subjected to 3 repeated shear tests with 3 specimens. The shear area on the specimen is measured, the maximum shear force is obtained from the machine and the shear strength is calculated using Equation 1 and then averaged. The core shear strength of sandwich composite panels stitched with various types of natural and unstitched fibers is shown in Figure 5.

The shear strength of the sandwich composite core before the stitch is 81.7 kPa. With the presence of natural fiber, the shear strength of the sandwich composite core increases to 95.9 kPa due to the presence of banana tree fiber sutures, and to 109.5 kPa in the presence of sisal fiber, and to a maximum of 112.8 kPa with palm fiber. The shear strength of the with out stitch sandwich composite core is small, all the shear load is borne by the polyurethane foam and this is very small. After stitching, the shear load is borne by the stitch, so the shear strength increases.

The magnitude of the shear strength of the sandwich composite core differs depending on the type of stitching fiber. The highest shear strength is possessed by stitched sandwich composites with palm fiber. This is related to the strength of the single palm fiber which is greater than the strength of the other fibers, especially with the cross-sectional diameter of the palm fiber which is greater than the other two fibers. [12,13].

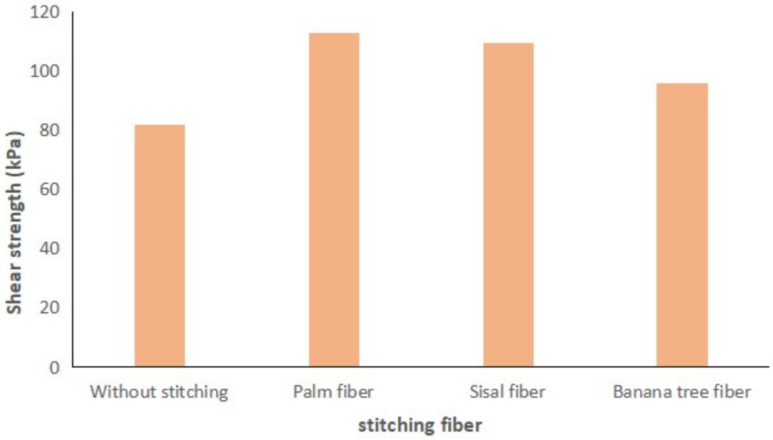


Fig. 5. Shear strength of the sandwich panel core against the type of natural fiber stitch

These findings have important implications in the development of environmentally friendly and economically efficient construction materials. The use of natural fibers as reinforcement for polyurethane foam sandwich panels can help reduce pollution from the construction industry while improving structural performance. Although this research provides valuable insights, there are still some limitations that need to be considered, such as optimizing panel design. Future plans include further research to overcome these limitations and explore the potential use of natural fibers in broader construction applications.

IV. CONCLUSION

This research produces an in-depth understanding of the use of natural fibers as reinforcement for the core of polyurethane rigid foam sandwich panels by stitching them to increase shear strength. Based on the results of the experiments and analyses carried out, the following can be concluded:

1. The use of natural fibers as reinforcement in sandwich panels significantly increases the shear strength of the sandwich panel core. Natural fibers, especially palm fiber, show good potential in improving the shear performance of materials.
2. The type of natural fiber has a significant influence on the shear strength of the panel. Palm fiber tends to provide better results compared to sisal fiber and banana tree fiber.

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