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The Effect of Sugar Palm Fiber Stitching on the Shear Strength of the Polyurethane Rigid Foam Sandwich Composites

Agus Dwi Catur[1], I Made Suartika[2]
[1,2] Mechanical Engineering Department, Engineering Faculty, University of Mataram
Jln. Majapahit No.62 Mataram, Indonesia, 83125
Corresponding Author: agus.dc@unram.ac.id

ABSTRACT: *The stitching technique for sandwich composites is very suitable to be applied because it can increase the core strength. The stitch pattern and fiber type can be selected according to the desired mechanical properties and application of the sandwich composite structure. In this paper, we study the effect of running stitch spacing on the shear strength of polyurethane rigid foam (PUR)-fiberglass-polyester sandwich composites. The stitch distance varies by 6 mm, 8 mm, and 10 mm. The natural fiber used for stitching is sugar palm fiber connecting the two skins of the sandwich composite. It was found that the sugar palm fiber stitch increased the shear strength of the sandwich composite*

NOMENCLATURE

Symbol	Description	Unit
P	shear force	N
P_{max}	maximum shear force	N
l_s	speciment length	m
w_s	speciment width	m
τ_{xy}	shear strength	Pascal
ΔL	displacement	mm

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I. INTRODUCTION

Aren (sugar palm tree / Arenga pinnata) is a type of palm tree originating from the tropical region of Southeast Asia.[1]. This tree is cultivated mainly for its juice which is used to produce sugar. In addition, fruit, wood, and fiber can also be utilized. Sugar palm fiber is extracted from the outer sheath of the Aren tree trunk. The sheath consists of long parallel fibers bundled together and can be extracted by mechanical or manual processes. The fibers are cleaned, dried, and processed into a form that can be used as rope, mats, brooms, paintbrushes, rugs, and water filters and also has great potential for a variety of applications including composite reinforcement. The use of natural fibers in composite materials has several advantages, including abundance, renewable, low price, and environmentally friendly. Sugar palm fiber composite is considered environmentally friendly due to its renewable source of fiber. The utilization of sugar palm fiber as a reinforcing material in composites can reduce dependence on synthetic fibers derived from non-renewable resources. In addition, post-use sugar palm fiber composites have a lower environmental impact compared to synthetic fiber composites.

Sugar palm fiber has mechanical properties that make it suitable for strengthening composites. They have high tensile strength, stiffness, and toughness, enabling them to increase the strength and durability of composite materials.[2]. Sugar palm fiber can be incorporated into various matrix composites such as polymers, concrete and bio-based materials. Fiber as a reinforcement is added to the matrix material to improve its mechanical properties. The addition of sugar palm fiber to the composite offers several advantages. This increases the strength, stiffness, and impact resistance of the resulting material, making it suitable for structural applications.[3]. Sugar palm fiber also helps reduce the weight of the composite, making it lighter than traditional materials.

Sandwich composites are widely used in various industries because of their high strength-to-weight ratio and excellent load-bearing ability. However, under certain loads, the core material of the sandwich structure may exhibit weaknesses, such as low shear strength or susceptibility to delamination.[4]. To overcome this problem, a technique called stitching is used to strengthen the core and improve its mechanical properties. The stitch involves inserting fibers through the thickness of the core in a regular pattern.[5]. These fibers act as reinforcing elements, providing additional strength and preventing the spread of cracks or delaminations within the core. The stitching process is carried out by hand, simple sewing machines, and even automatic equipment to ensure proper fiber placement.[6].

The stitching technique has several advantages in sandwich composite reinforcement. The seams increase the impact resistance of sandwich composites by providing additional energy absorption and damage tolerance. The fibers absorb energy during impact events, minimizing the risk of core damage and maintaining the structural integrity of the composite. The compressive strength after the low impact of multi-stitched composites is higher than that of unstitched composites. Multi-stitched composites reduce delamination to prevent more catastrophic composite failures.[7]. Stitched sandwich composites drastically improve flexural properties compared to unstitched composites. As the stitch density increases, localized fiber failure can be seen in crack propagation and this seam failure results in relatively high flexural strength. Composites with a stitched sandwich structure improve mechanical properties by increasing the number of thread stitches.[8]. With the fibers being sewn together, the core material becomes more resistant to crack initiation and propagation. The stitch fibers act as a barrier, preventing cracks from spreading and increasing the overall structural cohesiveness of the sandwich composite. The stitched sandwich composite increases the interfacial toughness, the energy required to initiate a crack at the foam/core interface is ten times higher whereas the failure of a seam requires a hundred times higher energy than that of an unstitched interface.[9].

The reinforcement of sandwich composites with stitching at the core is a very important technique for improving the mechanical properties and performance of sandwich structures, namely: increasing crack resistance, interlaminar shear strength, impact resistance, fatigue resistance, and structural integrity of the sandwich. It is a valuable solution for a wide range of industries: aerospace, automotive, marine, and construction. Even though there is reinforcement in the sandwich composite, stitches can increase the weight of the sandwich composite. The high-strength fibers such as fiberglass, carbon fiber, or specially made fibers used in this process can impact the overall weight of the sandwich structure and are not friendly to the environment.

Meanwhile, with proper processing sugar palm fiber can achieve optimal mechanical properties and is friendly to the environment. The use of sugar palm fiber as a composite reinforcement material offers a sustainable and cost-effective solution, one of which is to strengthen the sandwich composite in the form of stitching. This paper is the result of research with a sandwich composite object with a polyurethane rigid foam core and a skin in the form of a polyester-fiberglass laminate composite. This research effort aims to increase the shear strength of sandwich composites with sugar palm fiber stitching. This is intended to broaden the scope of application of sugar palm fiber and trigger this composite to be more widely adopted in various industries.

II. RESEARCH METHOD

In this study, the sandwich composite was made of polyurethane rigid foam (PUR) as the core and a polyester-fiberglass laminate composite as the skin. The density of polyurethane rigid foam is 42 kg/m^3 with a thickness of 25 mm. The resin used as the sandwich composite skin matrix is unsaturated polyester with 1% catalyst, while the skin reinforcement is e-fiberglass woven 200 gr/m^2. The sandwich composite was reinforced with sugar palm fiber stitches on the core with variations in stitch spacing of 6 mm, 8 mm, and 10 mm.

Procurement of sugar palm fiber is done by cutting the base of the palm fronds, then removing the fiber from the fronds. Sugar palm fiber was selected with a diameter of 0.6 to 0.7 mm (figure 1a). To form a core size of 300 mm x 60 mm x 25 mm, PUR was cut with hot wire. Making sandwich composite skin is done by hand layup technique on PUR. Three layers of woven fiberglass measuring 300 mm x 60 mm are laid over and under the PUR which will be stitched with sugar palm fiber. PUR-fiberglass is hand-stitched with a running stitch type (fig. 1b). The fibers that have been connected to the needle are inserted vertically downwards so that they connect the fiberglass-PUR-fiberglass. Then it is stabbed vertically upwards until the distance between the stitches is uniform. The distances forward and to the side between the seams varied for different composites, namely 6 mm, 8 mm, and 10 mm (figure 1. c).

The next step is to make the sandwich composite skin. The fiberglass fibers that have been sewn onto the PUR surface are then coated with hardened polyester resin. A fourth piece of fiberglass was used to seal the stitch and was covered with hardened polyester. Making the sandwich composite skin on the other side is done in the same way so as to obtain a symmetrical structure. The curing process of the sandwich composite until dry occurs for 24 hours then the finishing process is continued by cutting using a cutting grinder into a test object that is ready for testing (figure 1d).

a b

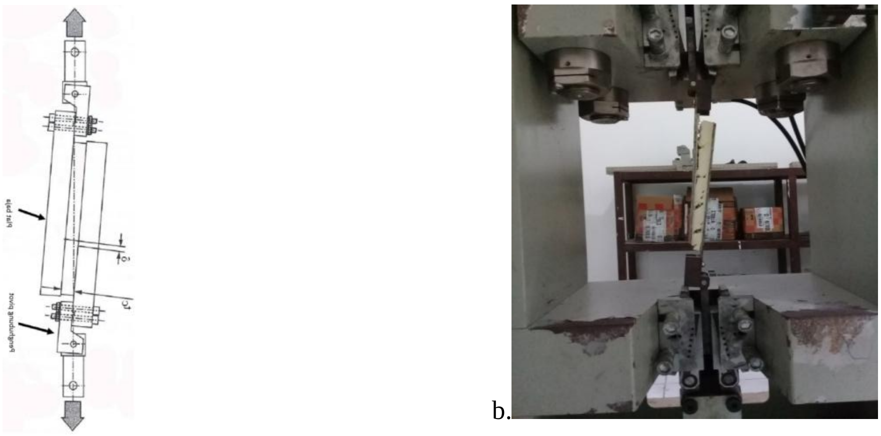
c d

Figure 1 a. sugar palm fiber b. hand running stitch on PUR-fiberglass c. PUR-fiberglass has been sutured d. sandwich composite has been completed

The sandwich composite shear test method is based on ASTM C 273-61 standard.[10]. The test is to determine the shear strength of the sandwich composite parallel to the surface of the composite skin. Shear tests are carried out according to standards to minimize the effect of other stresses on the specimen. The composite skin is firmly bonded to the steel plate supports with epoxy resin, shear failure should not occur at this joint but at the core. The shear strength is calculated by dividing the maximum shear force (P max) by the shear area, namely the length (ls) multiplied by the width of the shear test object (ws), as follows:

$$\tau_{xy} = \frac{P_{max}}{l_s.w_s} \qquad (1)$$

The shear test was carried out using a universal testing machine model C08207C. Testing for each variant was carried out three repetitions for the sandwich composite without and with seams at each distance variation. The test results are then averaged.



b.

a.

Gambar 2 a. Schematic shear test **b. Sample were tested under tension shear load**

III. RESULTS AND DISCUSSION

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 against the shear displacement is automatically recorded by the computer during the test. The shear behavior of stitched foam sandwich panels differs from that of non-stitched sandwich panels due to their plasticity and brittleness. As can be seen in Figure 3, the force-to-displacement graph of the sandwich composite without stitching looks curved, which means it is more plastic. The unstitched specimen load increases to maximum failure force and then the specimen suddenly fails at the sandwich structure interface. In all stitched specimens, graphical non-linearity was also observed up to the maximum load, after which the load drop was significant and the specimen failed. The addition of stitching reduces the relative displacement of the two skins under shear conditions with increasing shear forces, in other words, the tensile shear modulus of sandwich composites is higher than without stitching.[11].

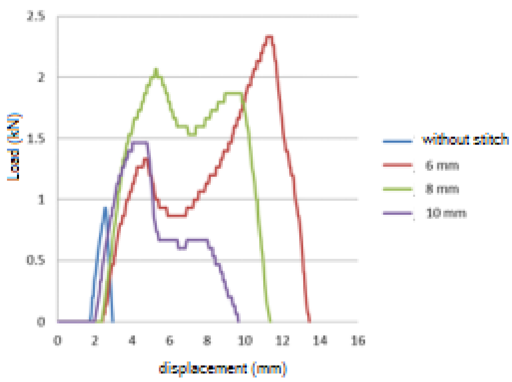


Figure 3 Sandwich composite shear force versus stitch spacing

The average maximum shear force of the sandwich composite is very small, 866 N, because only the weak polyurethane foam resists the shear force. With the stitches on the core, the average maximum force is greater, namely 1244 N, 1710 N, 2244 N for each stitch spacing of 10 mm, 8 mm and 6 mm. This is due to the contribution of the sugar palm fiber stitch in reacting to the shear load of the sandwich composite. The number of sugar palm fiber stitches contained in the sandwich composite causes different shear forces. The more palm fiber stitches used, the greater the shear force. Shear test specimens with 6 mm stitches have the most palm fiber stitches compared to 8 mm and 10 mm stitch spacing causing the maximum shear force to be the greatest.

Figure 3 shows that the maximum shear force only occurs once in the sandwich composite without stitching, whereas in the sandwich composite with stitching it occurs twice, with very lengthy break displacement even up to 12 mm. When PUR fails, the sugar palm stitch that resists the shear force. The running stitch type makes the displacement lengther.

Each variant of the sandwich composite was carried out 3 repetitions of the shear test with different specimens, the maximum shear force was recorded, the shear area was measured and the shear strength was calculated by equation (1) and then averaged. The shear strength of the stitched and unstitched sandwich composites is shown in figure 4.

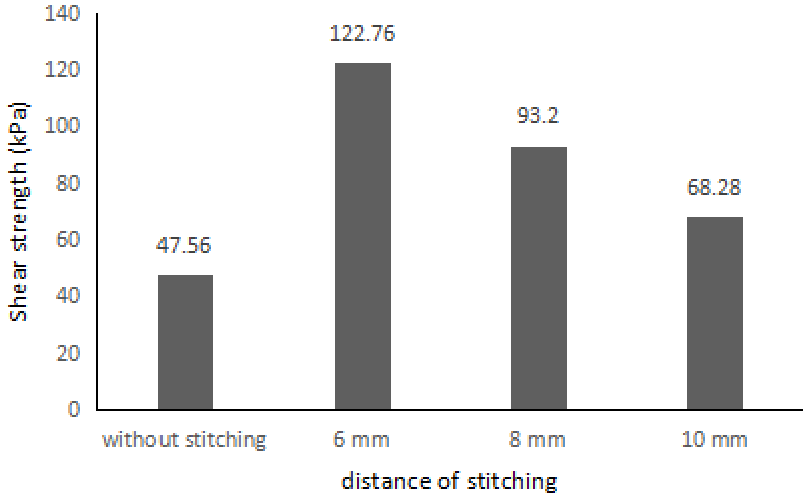


Figure 4 Shear strength of sandwich composites vs stitch spacing

It can be seen in Figure 4 that the shear strength of the sandwich composite without stitch is the lowest at 47.6 kPa. Then it becomes 68.28 kPa due to the stitch spacing of 10 mm, followed by 93.2 kPa at the stitch spacing of 8 mm and the highest is 122.76 kPa at the stitch spacing of 6 mm. The increase in the shear strength of the sandwich composite was due to the small PUR shear strength, so almost all the shear loads were borne by the sugar palm fiber.

The 6 mm stitch spacing has the most stable shear mode of all other stitch spacings. Because the smaller stitch spacing affects a more even distribution of shear stress in the composite core, this can be seen from the failure mode of the sandwich composite which is stitched with a spacing of 6 mm more evenly not centered (Fig. 5). Post-test shear specimen photos show the main and special failure modes under shear stress, it is shown that the failure mode of a stitched composite sandwich structure is different from that of a non-stitched sandwich structure.[12]. For unstitching sandwich composites, the behavior is mainly determined by the interfacial bonding force between the skin sheet and the PUR core. Thus the main failure modes are interface bond breakdown resulting in loss of load bearing capacity of the sandwich composite.

For stitched sandwich composites, the shear behavior is affected by that of the stitching. Scin-core interface debonding events are delayed due to the composite stitch-bonding effect. The primary failure mode of this structure is that failure occurs first at the foam core at an angle of approximately 45°. Then the stitch begin to break at the point of fiber bonding, all the fiber break very quickly one after another, which results in rapid degradation of the composite and finally followed by debonding of the skin and core of the composite by maximum stress.[12].

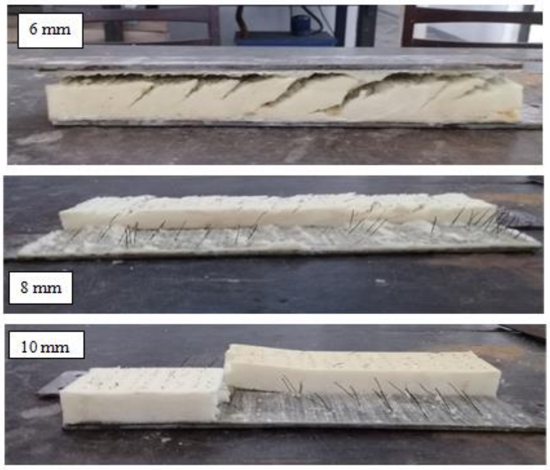


Figure 5 photos of specimen failure after shear test

IV. CONCLUSION

Sugar palm fiber stitch on sandwich composites with PUR core increases their shear strength, so stitching PUR on sandwich composite cores is highly recommended. The smaller distance between the stitching makes the greater sandwich shear strength. The average shear strength of sandwich composites with PUR cores is 47.6 kPa. With a stitch spacing of 10 mm the average shear strength becomes 68.28 kPa, a stitch spacing of 8 mm gives a shear strength of 93.2 kPa and the highest shear strength for a seam spacing of 6 mm is 122.76 kPa.

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