

Tensile Strength of Natural Fiber in Different Types of Matrix

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Received : June 3, 2022

Received in revised from September 1, 2022

Accepted : September 2, 2022

Online : September 3, 2022

Abstract: In recent years, product-based products with low environmental impact have become one of the considerations in the construction structure. The attention of researchers toward the development of natural materials has been increasing. The use of natural fibers as composite materials for the strengthened structure has been studied. However, natural fibers are influenced by their hydrophilic nature and specific morphology. Thus, research on natural fiber composite materials still needs to be explored. This study evaluates the tensile strength of natural fiber composite materials based on the type of fiber, fiber layer used, and resin type according to ASTM D3039. The highest tensile strength was found in the epoxy resin-based matrix composite with three layers of abaca^a fiber (SAAE-LP3) by 111.45 MPa. The results show that the type of fiber, fiber layer used, and resin in the composite matrix considerably affect its tensile strength performance.

Keywords: natural fiber, tensile strength, matrix, resin

Introduction

Natural fibers are increasingly used in various industrial fields to create an environmentally friendly industry. Using natural fiber as a composite material becomes an alternative due to its good tensile strength. Some fibers commonly used in various industries are flax, kenaf, linen, sisal, and bamboo. In (Tong *et al.*, 2017) mentions that natural fiber's advantages are abundant in nature and renewable, low specific gravity, lightweight, and non-toxicity. One fiber with a high tensile strength type is hemp, which ranges from 99.97 MPa to 189.479 MPa (Sen and Jagannatha Reddy, 2013; Alam *et al.*, 2015).

Various natural fibers have been explored and researched to produce composite materials. (Jeyanthi and Janci Rani, 2012) developed the use of natural fibers as composite materials in the automotive industry. In addition, the use of natural fibers has also been developed in the construction industry to repair and strengthen structures against shear and bending (Sen and Jagannatha Reddy, 2013; Alam and Al Riyami, 2018; Salvana *et al.*, 2022). The maximum capacity of strengthened reinforced concrete beams by using natural fiber as composite material depends on the type and configuration of fiber (Hasan, Saidi, and Amalia, 2021; Taufiq as a reference Saidi *et al.*, 2021). However, the tensile strength of natural fibers as a composite material is not only influenced by the type of fiber. Although the type of fiber is the same, its composition can be different because the soil and the planting treatment influence it. In addition, the treatment process during the production of natural fiber composite materials also greatly affects its strength (Sen and Paul, 2015). Moisture absorption rates and behavior after moisture absorption differ in different kinds of natural fiber (Bachchan, Das and Chaudhar, 2022). Thus, research on the tensile strength of natural fiber composite materials still needs to be done to develop science and industry for further research. Therefore, this study aims to evaluate the tensile strength of natural fiber composite materials based on the type of fiber, fiber layer used, and type of resin.

Materials and Methods

Fabrics

The most used fabric to produce composite materials is the 2D fabric. It is classified into four typologies: nonwoven, woven, braided, and knitted. In this study, woven fabrics have been used with a simple cross pattern, as seen in Figure 1. Four fabrics were investigated: jute, silk made from caterpillars that eat cassava leaves, pineapple fiber, and abaca fiber. Abaca is a leaf fiber from Abaca plants (*Musa Textilis*). The abaca plant is native to the Philippines and similar to banana trees. Two types of abaca fiber have been investigated based on the distance between the yarn. Abaca^b was tighter than abaca^a. Each fabric was prepared in the warp direction (90°) and subjected to direct tensile tests. A total of 39 specimens have been examined for all study parameters, as seen in Table 1.

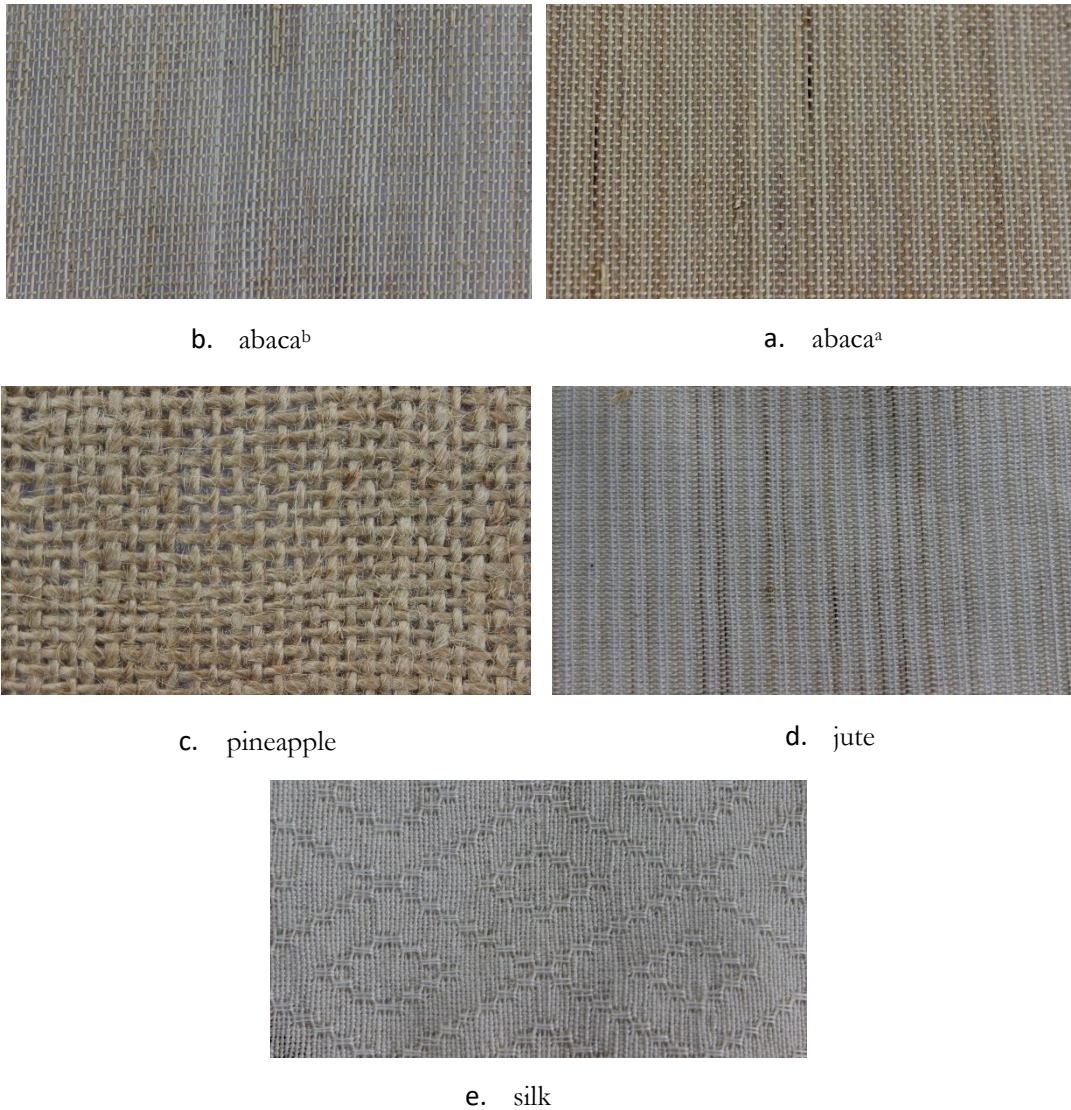


Figure 1. Cross pattern of investigated fiber: a. abaca^a, b. abaca^b, c. jute, d. pineapple, e. silk

Matrices

In producing Natural Fiber Reinforced Polymer (NFRP) composite material, fiber was impregnated using thermosetting resin as its matrix. The fiber must adhere to the matrix used and be compatible with achieving

load distribution properly (Purboputro and Hariyanto, 2017). The most commonly used matrices were epoxy resin and polyester resin.

In this study, three types of resin were used to evaluate the effect of resin on the tensile strength of NFRP composite material: standard epoxy resin, thixotropic epoxy adhesive, and polyester resin. The composition of the standard epoxy resin as the matrix in the production of NFRP composite material was made of two components: resin and hardener by 1:1 ratio.

The second type of epoxy used in this study was thixotropic epoxy adhesive. It was a kind of epoxy resin with a thick texture and gray color. This type of epoxy has not been widely used as a matrix of NFRP composite materials. This type of epoxy was used only for the adhesive between concrete and FRP, especially Carbon Fiber Reinforced Polymer (CFRP). In this study, the thixotropic epoxy adhesive used was Sikadur 31 CF Normal. It has two components, A and B liquid, with a 2:1 ratio in the production of NFRP composite material. This study used the latter type of resin, unsaturated polyester resin Yukalac 157 BTQN-EX. In order to produce the matrix, the polyester resin was mixed with catalyst by a ratio of 10 cc catalyst per 1 kg of polyester resin.

Parameter study

Table 1 shows the parameter of this study. For the aim of this study, 13 series of specimens were conducted, each with 3 specimens.

Table 1. Parameter of the study

Series	Fiber	Number of the fiber layer	Type of matrices	Number of specimens
SAAE-LP1	Abaca ^a	1	standard epoxy	3
SAAE-LP2		2	standard epoxy	3
SAAE-LP3		3	standard epoxy	3
SABE-LP1	Abaca ^b	1	standard epoxy	3
SABS-LP1		1	thixotropic epoxy	3
SABP-LP1		1	polyester	3
SABE-LP2		2	standard epoxy	3
SABS-LP2		2	thixotropic epoxy	3
SABP-LP2		2	polyester	3
SABE-LP3	Pineapple	3	standard epoxy	3
SNE-LP2		2	standard epoxy	3
SSE-LP2		2	standard epoxy	3
SRE-LP2	Jute	2	standard epoxy	3

Fabricated tensile test specimen and test procedure

The composite laminate for the specimen was made using the hand lay-up method manually using the wood mold as formwork. The fabrics were pressed gently in the formwork during the fabrication process to ensure no air void inside the laminate. The specimen has been removed from the formwork after 24 hours. Figure 2 shows the fabricated process of NFRP composite material. All composite specimens have been cut with a size equal to 25x250 mm in accordance with the standard (ASTM D3039, 2014), which can be seen in Figure 3. The resin and fiber composition of each specimen are mentioned in Table 2. The tensile test was conducted using Universal Testing Machine with displacement control at a rate of 2mm/minute, as seen in Figure 3.

Results

Mechanical Properties of NFRP

The mechanical properties of natural fiber composite material from the tests were tensile strength, f_t , young's modulus, E , and the maximum strain. Tensile stress was calculated based on the composite material specimen's maximum load and cross-section area. Young's modulus was calculated within the stress range between 20% and 50% of the tensile strength (Codispoti *et al.*, 2015). Table 3 summarizes the experimental results.



Figure 2. Process of fabricated NFRP composite materials

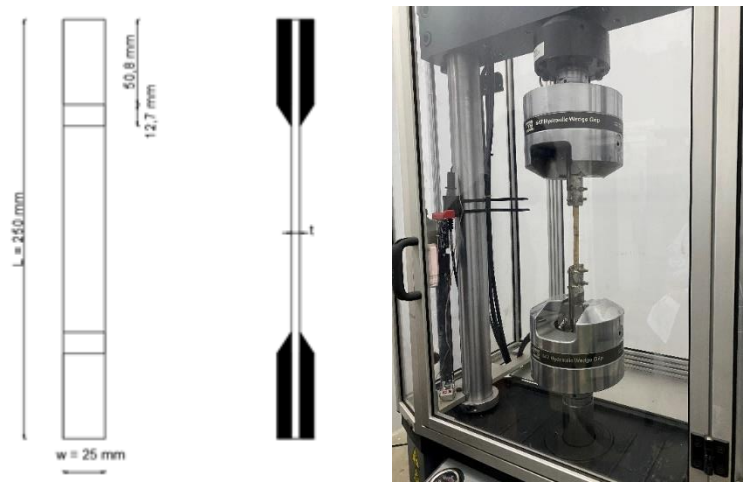


Figure 3. Composite material specimen and set up of the test

Table 2. Composition of NFRP composite materials

Series	Fiber (gram)	Resin (gram)
SAAE-LP1	1.40	7.10
SAAE-LP2	2.80	10.90
SAAE-LP3	4.20	12.50
SABE-LP1	2.00	7.80
SABS-LP1	2.00	19.60
SABP-LP1	2.00	6.80
SABE-LP2	4.00	13.50
SABS-LP2	4.00	30.40
SABP-LP2	4.00	14.40
SABE-LP3	6.00	10.60
SNE-LP2	3.33	17.67
SSE-LP2	3.47	16.13
SRE-LP2	6.00	26.00

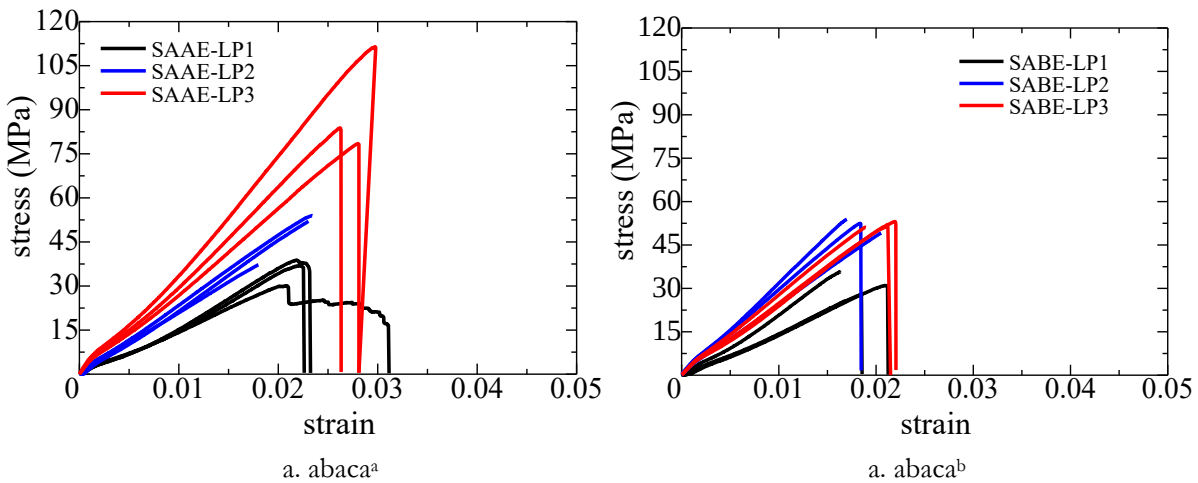
Table 3. Tensile test results of NFRP composite materials

Series	f_t (MPa)	E (MPa)	Maximum ϵ
SAAE-LP1	38.83	1468.23	0.0218
SAAE-LP2	53.99	2228.16	0.0234
SAAE-LP3	111.45	2859.70	0.0297
SABE-LP1	35.69	1365.15	0.0163
SABS-LP1	33.82	5960.86	0.0206
SABP-LP1	32.18	3588.82	0.0169
SABE-LP2	53.86	2578.04	0.0170
SABS-LP2	59.14	6542.12	0.0276
SABP-LP2	78.63	5960.86	0.0280
SABE-LP3	53.13	2474.35	0.0219
SNE-LP2	39.05	2657.65	0.0063
SSE-LP2	38.03	4184.09	0.0021
SRE-LP2	28.83	1524.58	0.0262

Stress-strain relationship of different specimen thickness

The test results showed a clear difference between all series. The fiber with the highest tensile strength was epoxy resin-based matrix composite with three layers of abaca^a fiber (SAAE-LP3) by 111.45 MPa. The lowest tensile strength was epoxy resin-based matrix composite with two layers of jute fiber (SRE-LP2) by 28.83 MPa.

Figure 4 shows the mechanical behavior of abaca^a fiber with epoxy resin-based specimen with differences in the number of the fiber layer. It can be seen that a higher number of fiber layers gives higher tensile stress. The maximum tensile stress achieved was 111.45 MPa obtained in SAAE-LP3. In terms of material stiffness, the higher number of fiber layers has more stiffness. A higher number of fiber layers denotes more fiber in its composition, as seen in Table 2, thus affecting its strength. However, abaca^b shows that SABE-LP2 and SABE-LP3 have similar results, as seen in Figure 4b. The tensile stress of SABE-LP2 and SABE-LP3 were 53.86 MPa and 53.13 MPa, respectively.

**Figure 4.** Mechanical behavior of abaca fiber: a. abaca^a, b. abaca^b

Stress-strain relationship of different fiber types

From the experimental test, abaca fiber has the highest stiffness, followed by jute fiber. On the other hand, both pineapple and silk fiber have similar stiffness. The stress-strain relationship of these natural fiber composites with epoxy resin-based is shown in Figure 5.

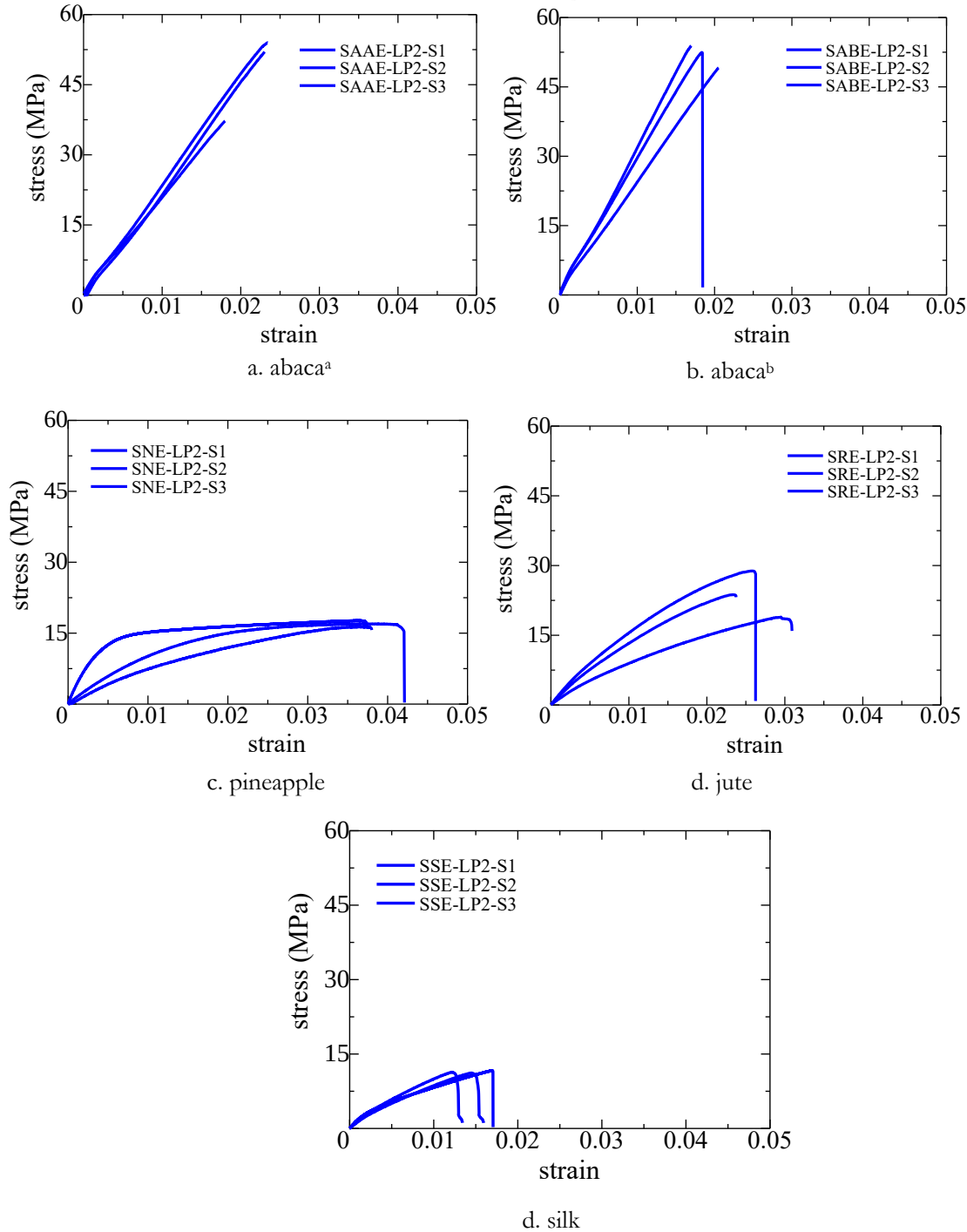


Figure 5. The stress-strain relationship of natural fiber composite with epoxy resin-based

Stress-strain relationship of different resin type

Figures 6-7 performed the stress-strain relationship of resin used in this study. It can be seen that thixotropic epoxy has the highest stiffness, but the tensile strength did not ensure a considerable level of strength. Epoxy resin presents lower tensile strength than polyester resin.

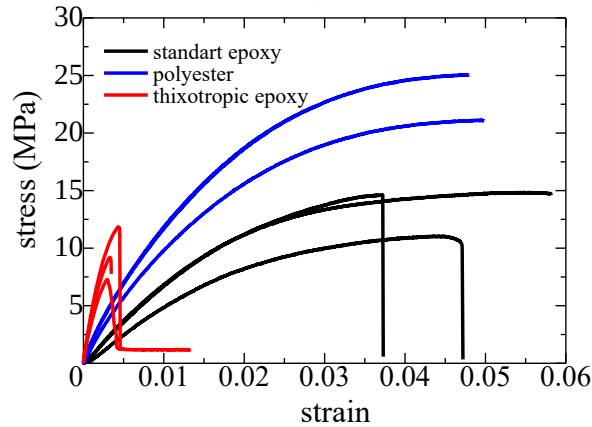


Figure 6. Stress-strain relationship of resin used

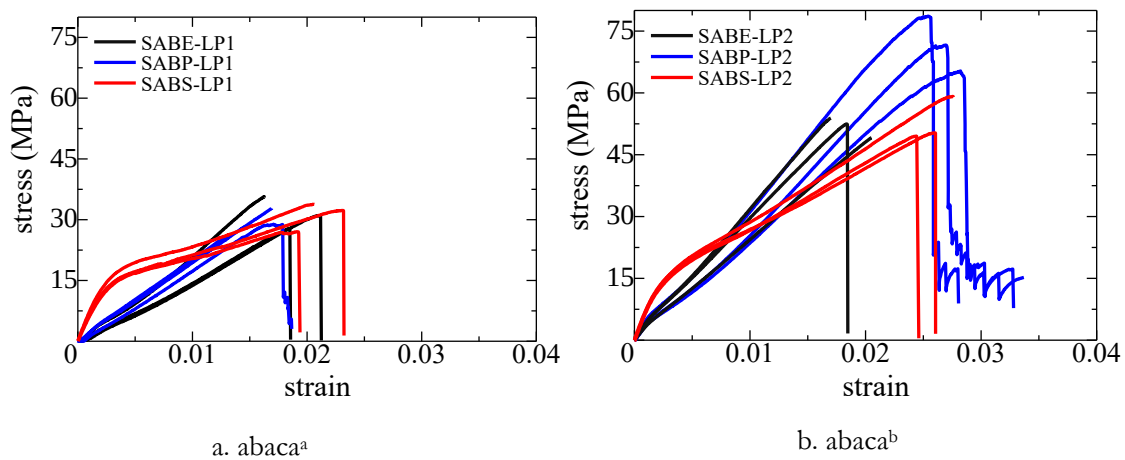


Figure 7. Mechanical behavior of abaca fiber composite material with different resin type

Discussion

Specimen thickness effect

Figure 4 shows that a higher number of fiber layers gives higher tensile stress. However, specimens SABLE-LP2 and SABLE-LP3 have similar results. This figure might be happened due to imperfect adherence of the fibers to the matrix. A large number of fibers makes the resin imperfectly cover all parts of the fiber; thus, it affects its tensile strength. This can be seen by the results obtained in abaca^a and abaca^b. Abaca^b with tighter braid distance shows less tensile stress compare to abaca^a. In addition, (Venkateshwaran, Elaya Perumal and Arunsundaranayagam, 2013) mention that interface between natural fiber and matrix was weak because natural fibers are hydrophilic. It could be affected by tensile strength. Fiber and matrix could be incompatible, and the strength came from the resin only. Moreover, less precision in the manufacturing process of NFRP could be because the manual wet lay-up method is more challenging to obtain a uniform configuration of the composite (Codispoti *et al.*, 2015).

Type of fabric effect

All fiber composites with epoxy resin-based materials show brittle behavior where no post-peak behavior could be captured, as seen in Figure 5. Abaca fiber has the highest stiffness, followed by jute fiber. On the other hand, both pineapple and silk fiber have similar stiffness. This behavior has the same trend according to (Codispoti *et al.*, 2015). According to the experimental results, it was confirmed that abaca fiber could be used as a natural composite material in building materials. However, (Jariwala and Jain, 2019) mentioned that to enhance the fiber matrix interfacial strength and to minimize the moisture absorption by these fibers, some chemical treatments are required, which would ultimately improve the physic mechanical properties of these fiber-

reinforced composites. The impurities, lignin, and hemicellulose could be removed by doing chemical treatment of the fiber surface and improve the tensile strength significantly (Kumar *et al.*, 2022)

Type of resin effect

Based on Figure 6, thixotropic epoxy has the highest stiffness. However, its tensile strength did not ensure a considerable level of strength. Epoxy resin presents lower tensile strength than polyester resin. This founding is contrary to previous studies (Codispoti *et al.*, 2015), where polyester had lower tensile strength than epoxy resin. It could happen because the polyester used in this study has been oxidized, thus may affect the results. It was also found in the study of (Tauiq Saidi *et al.*, 2021) that oxidized polyester resin used in the composite matrix affected the maximum capacity of the strengthened reinforced concrete beam. This result corresponds to the mechanical behavior of abaca^b fiber composite material shown in Figure 7. The graph in Figures 7a and 7b corresponds to the abaca^b fiber composite material with one layer of abaca^b fiber and two layers of abaca^b fiber in composite material thickness, respectively. The same behavior with the stress-strain relationship of resin was observed. Thixotropic epoxy adhesive resin-based matrix composite has the lowest tensile strength followed by epoxy resin-based and polyester resin-based matrix composite. The stress-strain curve of epoxy resin-based and polyester resin-based matrix composite has linier behavior while thixotropic epoxy adhesive resin-based matrix composite has bilinear behavior. Initial stiffness of thixotropic epoxy adhesive resin-based matrix composite is higher than those epoxy resin-based and polyester resin-based matrix composite, however approximately at 15 ton of loading, the curve was changing.

Conclusion

Based on the study results, it can be concluded that natural fiber has potential tensile strength to be used as a building material. The highest tensile strength was found in the epoxy resin-based matrix composite with three layers of abaca^a fiber (SAAE-LP3) by 111.45 MPa. The type of fabric used affected the tensile strength. Silk fiber has the lowest tensile strength compared to the others. The higher number of fiber layers used in the composite matrix influenced its tensile strength performance. The higher number of fiber layers gives higher tensile stress. However, it was found that three layers of abaca^b fiber with epoxy resin-based specimen have a contrary result. It might be happened due to the imperfect adherence of the fibers to the matrix if more fiber is used in its composition. In addition, the type of resin used in the composite matrix should be concerned in the design. In this study, thixotropic epoxy adhesive resin-based matrix composite has the lowest tensile strength, followed by epoxy resin-based and polyester resin-based matrix composite.

Acknowledgment

PNBP Innovation Funding Universitas Syiah Kuala supported this work. The authors also acknowledge the support of Nazira Suha Al-Bakri, Sarah Nadia, Shafira Salsabila, and Rahmi Rabaiyani Joda.

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