

Study of mechanical properties of fiberglass polymer composite material mixed with west papua-indonesia sago palm fiber

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West Papua has been one of the largest sago-producing regions in Indonesia, with sago trees primarily used for daily needs by the community, including house walls, roofs, and food. Composite materials have taken various forms, including fiber, sheet, and particle reinforced, or self-reinforced polymer matrix, ceramic matrix, or metal matrix composites. This research focuses on polymer composite materials composed of natural and synthetic fibers combined using an epoxy resin. The materials used include sago midrib fiber, fiber glass type Woven Rofin 600 (WR), and a resin-catalyst solution (Epoxy Resin type BQTN-EX 157, Hardener type MEPOXE). An alkaline solution of NaOH and H₂O at 4.5% and the percentage volume of matrix material with sago sheath fiber, each sample being 95%:5%, have been applied. Matrix variation has been explored in this study. Results have shown that the composite material combining natural and synthetic fibers with matrix variation has exhibited a low tensile strength of 36,560 J and a high tensile strength of 66,440 J. The impact strength for the composite material combining natural and synthetic fibers with matrix variation has been found to be low at 10.87 J and high at 15.3 J.

Keywords: Hybrid composites, Fiber-reinforced composites, Fiberglass, Sago sheath fiber, Mechanical properties

1 Introduction

Sago (Metroxylon sago Rottb) is a native plant from Southeast Asia. Indonesia has the largest sago plantation area in the world, around 1,128 million hectares or 51.3 percent of the 2,291 million hectares of the world's sago area. The distribution of sago palms in Indonesia is found in several areas, namely Papua, Maluku, Riau, Central Sulawesi and Kalimantan. Around 90 percent of this crop area is found in Papua and Maluku¹. In most parts of Papua, especially West Papua, the application of sago palm midrib has existed in traditional buildings. This is because most areas of Papua are scattered with abundant sago trees and have various types². The midrib chosen by the community aims not only to preserve the culture, but also to shelter from the heat. This is supported by the design of the building that has many air cavities, resulting in air being able to enter and leave. The traditional building design of the Papuan people, most of which are made from parts of the sago tree, is presented in Fig. 1.

Rumbia or also called (tree) sago is the name of a type of palm that produces sago flour. The sago palm

tree (sago) or sago palm (MetroxylonsaguRottb) is one of the most potential sources of food and energy³. Sago fronds as waste from harvesting sago in abundant quantities are less than optimal in their utilization. Utilization of sago fronds, especially sago leaves and fronds only as walls and roofs in traditional houses which are applied with a simple arrangement. In addition, the use of sago palm midrib has also been investigated as an alternative acoustic material⁴. Inside the bones of sago leaves there are strong fibers resembling hair feathers. It can be used as a reinforcing material in natural fiber composite materials⁵⁻⁷. Several studies have shown the use of sago sheath fiber as a natural composite material, making bio-composites⁸ and Alternatives to Fiberglass Synthetic Fibers⁹.

There are parts of the sago tree that can be used as reinforcing materials for natural fiber composite materials, some of which have even been researched. Some parts of the sago tree that have been researched include sago midrib⁴, leaf part¹⁰, sago starch¹¹⁻¹³, and sago midrib fiber⁵⁻⁹. Of these parts, there is a part that is the focus of research, which is the fiber part of the sago midrib. This is because sago fiber is a potential that exists in nature as an alternative to synthetic fibers.

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Fig. 1 — Tradisional building of Papuan People

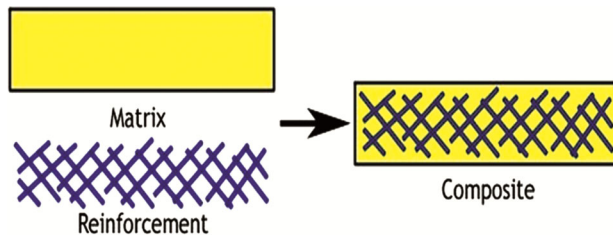


Fig. 2 — Characteristics of composite material

Composite materials are multi-phase combination materials of two or more material components with different properties and different shapes through a blending process, not only retaining the main characteristics of the original components, but also exhibiting new characteristics that are not owned by the original components¹⁴. One constituent is called the reinforcing phase and the embedded constituent is called the matrix. The reinforcing phase material can be fibers, particles, or flakes. The matrix phase materials are generally continuous¹⁵. The characteristics of the composite material are presented in Figure 2.

Then according to the type of matrix used in the composite material, the matrix consists of a metal matrix composite, aluminum matrix and polymer matrix. Many studies have been carried out using polymer matrix composite materials in various applications, such as in the structure of the fuselage¹⁶, military as ballistic resistance¹⁷, and fire retardant material¹⁸. There is also a blend of natural and synthetic reinforced polymer composite materials¹⁹.

Furthermore, in addition to composite materials there are types of matrix materials, in composite materials there are also reinforcing materials from both synthetic and natural materials. There are studies on polymer composite materials using natural reinforcing materials, such as the use of bagasse (Bagasse) fibers^{20,21}, oil palm midrib fibers²²,

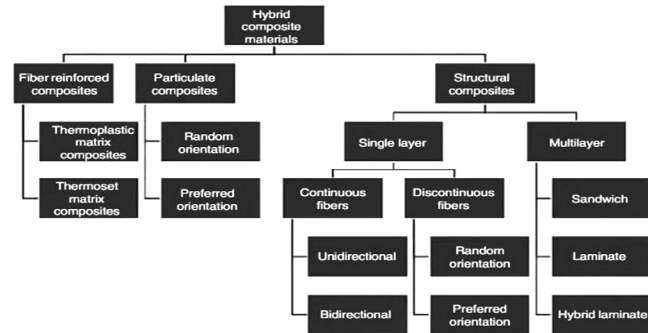


Fig. 3 — The composition of the mixture on composite materials that can be viewed from several aspects

kecombrang stem fibers²³, oil palm midrib fibers^{24,25}, oil palm fiber and banana midrib²⁶, sago stalk fiber⁵, sago midrib fiber^{4,8-9}, sago pith pulp fiber^{6,7}, and palm fiber²⁷, and recently there are Olive pomace flour (OPF/ LLDPE)²⁸. In addition, there are synthetic reinforcing materials used for reinforcement in composite materials. Some of these reinforcing materials include HDPE monofilament²⁹, carbon nano fillers (carbon nanotubes, carbon black) and micron-sized fillers (graphite, schungite)³⁰, milled glass fiber (GGF) embedded in a high density polyethylene membrane (HDPE)³¹, nanoscale MWCNTs and microscale glass fibers³², and fluorinated silica nanoparticles(SiO_2NP_s)³³.

There is not much research on composite materials that combine synthetic fiber reinforcement and natural fibers. Several studies include the combination of kenaf fiber with fiberglass³⁴, hemp fiber combined with carbon fiber³⁵⁻³⁷, E-glass combined with Nacha fiber (*Hibiscus macranthus*Hochst. Ex-A. Rich.) and Sisal fiber (*Agave sisalana*), and hemp fiber combined with fiberglass³⁸. Recently, only a few researchers have conducted research using polymer composite materials with a combination of synthetic fibers and natural fibers, this is because theoretically, the properties of hybrid composites must comply with the hybrid mixture rules so that chemical or physical interactions between reinforcing fibers do not occur³⁹. The mixture compositions of composite materials, which can be viewed from several aspects, are presented in Figure 3.

Fiber-reinforced hybrid polymer composites are widely used as a substitute for metal materials for automotive, building, and aerospace applications⁴⁰⁻⁴². In shipbuilding applications, there is very little literature on natural fiber-reinforced composite materials, especially hybrid polymer composite materials. The application of natural fiber-reinforced

composite materials is widely applied in other fields, such as palm midrib fiber as a material for making car bumpers²², kecombrang trunk fiber as an alternative to fiber²³, oil palm midrib fiber as an alternative to fiber²⁴, coir oil palm and banana midrib as an alternative to fiber²⁶, waste oil palm and sago midrib as acoustic material^{4,25}, sago stalk as an alternative to fiber⁵, sago pith pulp as a natural composite material^{6,7}, sago tree fiber for the manufacture of bio-composites⁸, sago midrib fiber as a substitute for fiberglass fiber⁹, and palm fiber waste as an innovation for bathroom door panels²⁷.

Fiberglass composite material is a material that is well-known for being difficult to decompose in nature when damaged, therefore several studies are needed to find alternatives to replace these materials. In this study, fiberglass composite material combined with sago sheath fiber was used. In its application, the material is used for shipbuilding. The material will be known mechanical properties in the form of tensile strength and impact strength. It is hoped that in this study, these materials can be an alternative to fiberglass composite materials. So that it can reduce the use of fiberglass in full for reinforcing composite materials on ships.

2 Materials and Methods

2.1 Material

In this study, the main material used was sago sheath fiber. The sago midrib fiber used has random diameters and lengths. The amount of sago fiber used is adjusted to the needs of the test spacing. The sago midrib fiber is obtained through several stages. first, the old sago leaf was taken and then separated the sago leaf from the midrib. Old sago midrib, has a characteristic that is located at the bottom of the sago tree. Then, the sago sheath was cut for easy portability and storage. Next, store the sago fronds indoors for three days until the fronds look dry. After it looks dry, cut the sago midrib as needed and peel the outer skin of the midrib. The peeled sago midrib was then grounded or shaved using a knife or separated the pith from the sago midrib fiber so that the sago midrib fiber was obtained. This sago midrib fiber was used as a reinforcing material in this study. The process of obtaining sago midrib fiber as a reinforcing material in natural composite materials is presented in Figure 4.

The use of resin-catalyst is very important in this research. There are many types of resins including Polyethylene (PE) grade⁴³ Homopolymer, LLDPE (SABIC® LLDPEM500026)²⁸, Polypropylene granules



Fig. 4 — The process of obtaining sago midrib fiber material; a) Separation of the leaf from the midrib; b) Cutting the sago midrib; c) Separation of pith with fiber; and d) sago midrib fiber

(Grade: H200MA)³², Isotactic polypropylene³³ and unsaturated polyester resins⁴⁴. As for the catalyst or hardener, there are also many types that have recently been developed, namely ethylene polymerization catalysts including the development of methylaluminoxane (MAO)^{45,46}, and vanadium-magnesium (VMC) catalyst⁴³. Furthermore, for the resins and catalysts used in this study, respectively, Epoxy Resin type BQTN-EX 157 and Hardener type MEPOXE (Methyl Ethyl Ketone Peroxide). These types of resins and catalysts are the most familiar types of resins and catalysts in the city of Sorong. Because it is often used by local people to make or repair fiberglass boats (Fiber Reinforced Plastic). The material properties of Epoxy Resin type BQTN-EX 157 are presented in Table 1, while the material properties of MEPOXE (Methyl Ethyl Ketone Peroxide) are presented in Table 2.

2.2 Specimen preparation

The initial stage of this research is to soak the sago midrib fiber using an alkaline solution ($NaOH$ and H_2O) with a level of 4.5%. The benefit of this treatment is to obtain a clean sago midrib fiber material from the remaining pith, so that it can increase the mechanical value of the composite

material^{26,47}. Furthermore, after soaking, the sago midrib fibers are dried in the sun to dry. After drying, the sago midrib fiber was weighed and combined the reinforcing material in the form of sago midrib fiber with Fiberglass type Woven Rofin 600 (WR) and the matrix material in the form of a resin-catalyst solution (Epoxy Resin type BQTN-EX 157, Hardener type MEPOXE (Methyl Ethyl Ketone Peroxide) In combining the matrix material with reinforcing sago-fiberglass midrib fibers, the respective compositions are determined at 95%:5%. Furthermore, to determine the composition of the weight fraction between the reinforcing material in the form of sago midrib fiber with Fiberglass and the matrix material in the form of a resin-catalyst solution follows equation as follows:

a. Calculating the volume of the composite mold;
Mold volume (cm^3) Rectangular;

$$V_{mold} = P \times L \times T \quad \dots(1)$$

Table 1 — Experimental design for polymer composite materials with variations of reinforcement with variation of sample matrix B1.

Item	Score	Unit	Note
Specific Gravity	1.21±0.02	g/cm^2	25 ⁰ C
Viscosity	4.5±5.0		Poise, at 25 ⁰ C
Hardness	40	-	Barcol/GYZJ 934-1
Water Absorption (25 ⁰ C)	0.188	%	24 Hours
	0.466	%	7 Days
Flexural Strength	9.4	Kg/mm^2	
Flexural Modulus	300	Kg/mm^2	
Range Power	5.5	Kg/mm^2	
Modulus Young	1.18	GPa	
Store Life At 25 ⁰ C	Less than 6	Months	

Table 2 — Material properties of MEPOXE (Methyl Ethyl Ketone Peroxide)

Item	Score	Unit
Appearance	Clear, Colorless liquid	g/cm^2
Phthalate Plasticizer	55 ± 5	%
Active Oxygen	9.5 – 10.0	%
Specific Gravity	1.13 (at 20 ⁰ C)	
Solubility Insoluble Soluble	Water, Glycerine, Petroleum Esters, Alcohols Ketones, Ethers	
Thermal Stability SADT	65	⁰ C

Table 3 — Experimental design for matrix variation polymer composite materials Weight Percentage (%)

Description	Sample A ₂	Sample B ₂	Sample C ₂	Sample D ₂	Sampel E ₂
(1)	(2)	(3)	(4)	(5)	(6)
Laminate Order:					
Epoxy Resins	99.5	99	98.5	98	97.5
Hardener	0.5	1	1.5	2	2.5

Where: P = length (cm)

L = wide (cm)

T = height (cm)

b. Calculating the weight fraction of a composite without fibers;

Fiberless composite weight;

$$B_{matrix} = V_{mold} \times \rho_{matrix} \quad \dots(2)$$

Where: B_{matrix} = Fraction Fiberless composite weight (g)

V_{mold} = Mold Volume (cm^3)

ρ_{matrix} = Matrix Density (g/cm^3)

Composite weight without matrix;

$$B_{fiber} = V_{mold} \times \rho_{fiber} \quad \dots(3)$$

Where: B_{fiber} = Composite Weight Fraction without matrix (g)

V_{mold} = Mold Volume (cm^3)

ρ_{fiber} = Fiber Density (g)

c. Calculating the weight fraction of the overall composite material;

$$B_{total} = (\%_{fiber} \times B_{fiber}) + (\%_{matrix} \times B_{matrix}) \dots(4)$$

Whete: B_{total} = Overall composite material weight fraction (g)

B_{fiber} = Composite Weight Fraction without matrix (g)

B_{matrix} = Fiberless Composite Weight Fraction (g)

The experimental design and arrangement of the laminate in this study are presented in Table 3 and Table 4, respectively.

2.3 Characteristics

2.3.1 Tensile test

In this study, tensile testing was carried out using a tensile testing machine. Tensile testing is a test that is generally used to determine the mechanical properties of materials, both metal, polymer, and composite materials. From the tensile test, data can be obtained in the form of the maximum tensile force of a material and changes in the length of the sample when it is pulled to break. Several studies have used this method to obtain the mechanical properties of the material^{37,48,49}.

Then for the results of the tensile test of fiberglass polymer composite materials combined with various natural fiber matrices, it is expected that material failure will occur in the Gage length section. Each standard has a different Gage length, for example, ASTM D638^{29,32}, while in this study, ASTM D3039/D3039M was used. The geometry of the tensile test specimen and the required specimen geometry are presented in Figure 5 and Table 5, respectively.

2.3.2 Impact test

Impact testing is also one of the common methods used to determine the mechanical properties of materials, both metallic, polymeric, and composite materials. Some researchers, use this method to determine the mechanical properties of the

material^{34,49}. Impact testing is done by pounding the test object using a swayed pendulum. Impact is the kinetic energy required for the material to fracture. In the impact strength test, the value shown on the tool is then entered into a mathematical equation to get the impact value. The mathematical equation is as shown in equation 5.

$$IS = \frac{E_1}{A} = \frac{W\lambda(\cos\beta - \cos\alpha)}{A} \quad \dots(5)$$

Where :

W = The work required to break the test object ($kg\ m$)

λ = Swingarm distance (m)

$\cos\beta$ = The angle of the pendulum's final position

$\cos\alpha$ = Pendulum end position angle

A = cross-sectional area under the notch (m^2)

then the value of impact energy and impact strength is obtained.

Then for the impact test results of fiberglass polymer composite materials combined with various natural fiber matrices, it is expected that material failure will occur in the notch. In this study, the impact test sample was made according to ASTM D6110⁴⁴. The shape of the impact test specimen and

Table 4 — Laminate structure used

No.	Description	Laminate Structure
(1)	(2)	(3)
1.	Laminate order:	
	Layer 1	WR 600
	Layer 2	WR 600
	Layer 3	Sago midrib fiber
	Layer 4	WR 600
	Layer 5	WR 600

Table 5 — Tensiletest geometric specimen

Fiber Orientation	Width, mm [in.]	Overall Length, mm [in.]	Thickness, mm [in.]	Tab Length, mm [in.]	Tab Thickness, mm [in.]	Bevel Tab, Angle, °
(1)	(2)	(3)	(4)	(5)	(6)	(7)
Direction 0°	15 [0,5]	250 [10,0]	1,0 [0,040]	56 [2,25]	1,5 [0,062]	7 atau 90
Direction 90°	25 [1,0]	175 [7,0]	2,0 [0,080]	25 [1,0]	1,5 [0,062]	90
Balance and Symmetry	25 [1,0]	250 [10,0]	2,5 [0,100]	-	-	-
Random - discontinuity	25 [1,0]	250 [10,0]	2,5 [0,100]	-	-	-

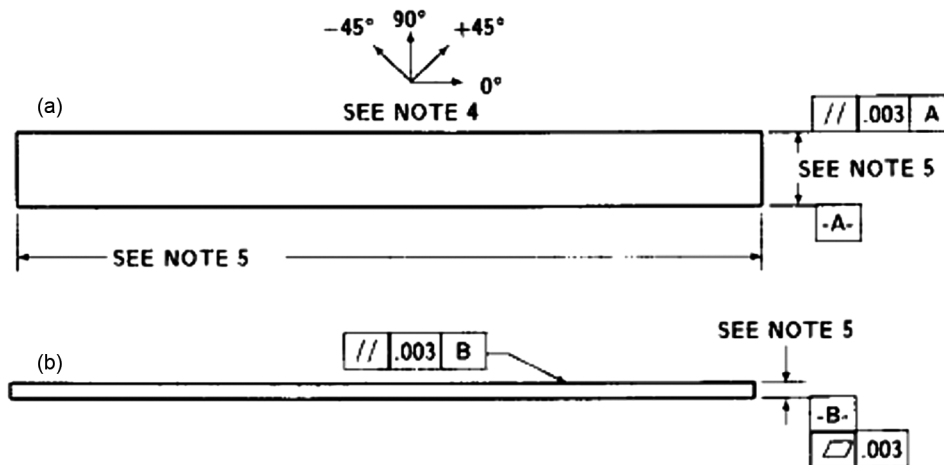


Fig. 5 —Tensile test geometric specimen (ASTM D3039/D3039M a) top view condition of the specimen and b) side view condition of the specimen.

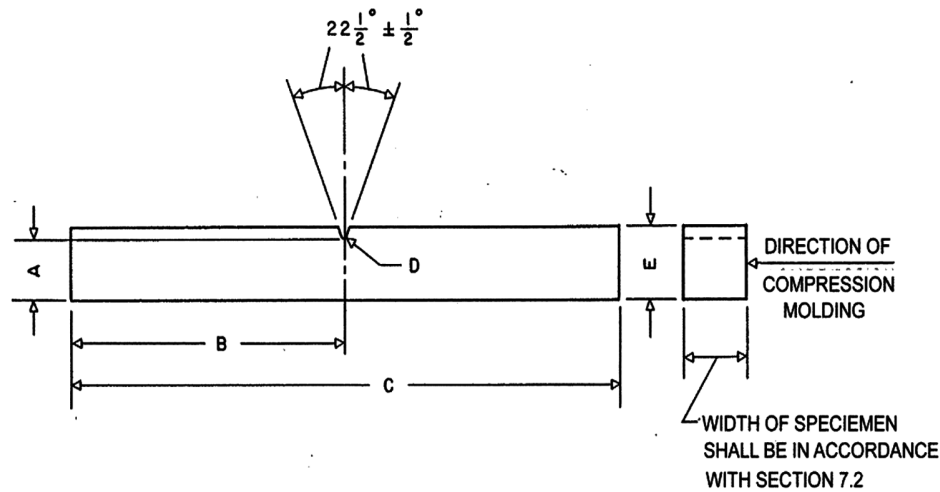


Fig. 6 — Impact Test Specimen (ASTM D6110)

Table 6 — Impact test specimen geometry

Symbol	Size (mm)	Tolerance (mm)
(1)	(2)	(3)
A	10,16 ± 0,05	0,400 ± 0,002
B	63,5	2,5
	61,0	2,40
C	127,0	5,00
	124,5	4,00
D	0,25 ± 0,05	0,010 ± 0,002
E	12,70	0,500 ± 0,006

the required specimen geometry are presented in Figure 6 and Table 6, respectively.

3 Results and Discussion

3.1 Mechanical properties of composite materials

Mechanical properties are one of the properties that state the ability to accept loads/forces/energy. Mechanical properties of materials reflect the relationship between the load / force / energy received by a material with a given reaction or deformation that will occur. Mechanical properties of materials are divided into several properties including; Strength, Hardness, Elasticity, Stiffness, Plasticity, Toughness, Fatigue and creep – crack.

A review of the mechanical properties of polymer composite materials, has been carried out by⁵⁰ on the mechanical behavior of natural fiber composites. Natural fiber has a special attraction for engineers, researchers, professionals and scientists around the world as an alternative reinforcement, because of its superior properties such as having high strength specifications, light weight, low production costs, fairly good mechanical properties, non-abrasive characteristics, environmentally friendly and bio-degradable.

Meanwhile, in this study, to determine the mechanical properties of the fiberglass polymer composite material coupled with sago midrib fiber with various reinforcement and matrix variations on tensile strength and impact strength, characterization was carried out using tensile testing and impact testing.

3.1.1 Tensile test

Tensile strength is one of the important properties to describe the mechanical performance of the material. By using tensile testing, it will be found the magnitude of the stress and strain experienced by a material. Tensile testing of polymer composite materials produces a unique graphic. This is because the composite material has an inhomogeneous and anisotropic structure attached to the composite material, especially polymer composites.

Based on the results of the study, the tensile strength value of the fiberglass polymer composite material combined with natural fibers was 1A = 36560J, 2A = 40890J, 3A = 51040J, 4A = 49720J, and 5A = 66440J. These results indicate that the fiberglass polymer composite material combined with sago sheath fibers in various matrices produces a tensile value that increases with the addition of reinforcement. The results of the tensile test on a fiberglass polymer composite material combined with natural fibers are presented in Figure 7.

Based on the test results, it can be seen that samples 1A to 5A have different fracture characteristics. Even between samples with three repetitions of the test also produced different characteristics. The characteristics of the different faults are located above and some are located below.

In addition, the shape of the fracture is also different. The form of the fracture in question is the remaining fibers and some are neatly shaped. This is because the polymer composite material has a composition reinforced by fiberglass (Fiber-reinforced) combined with sago midrib fibers which have an inherent inhomogeneous structure and anisotropy coupled with the hardening process of the material caused by many factors. In addition, there are impurities that may still be attached to the sago midrib fiber. So that it can affect the test results. An image of a tensile test specimen fracture on a fiberglass polymer composite material combined with various natural fiber matrices is presented in Figure 8.

3.1.2 Impact test

Impact strength is also one of the important properties to describe the mechanical performance of the material. The principle of this test is the absorption of potential energy from a weight pendulum swinging from a certain height and hitting

the test object so that the test object is deformed. Impact testing on polymer composite materials resulted in a unique graphic. This is because the composite material has an inhomogeneous structure and anisotropy inherent in composite materials, especially polymer composites.

Based on the results of the study, the impact strength value of the fiberglass polymer composite material was obtained in combination with natural fibers with various reinforcements 1A = 11.17J, 2A = 11.57J, 3A = 15.3J, 4A = 10.87J, and 5A = 12.27J. These results indicate that the fiberglass polymer composite material combined with sago sheath fibers in various matrices produces an increasing impact value along with the addition of reinforcement to the material. The results of a tensile test on a fiberglass polymer composite material combined with natural fibers and various reinforcements are presented in Figure 9.

Based on the test results, it can be seen that samples 1A to 5A have different fracture

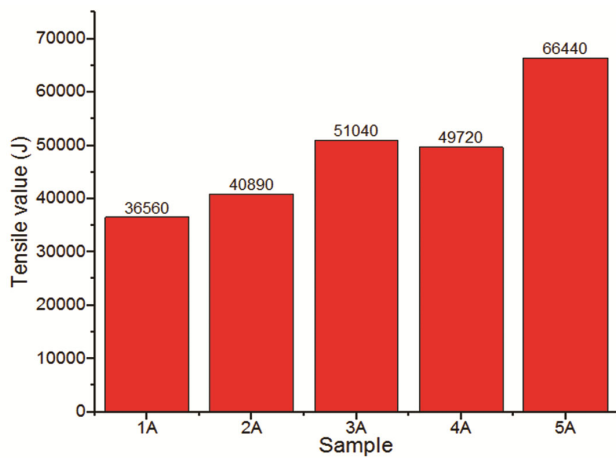


Fig. 7 —Tensile test results on fiberglass polymer composite materials combined with natural fibers.

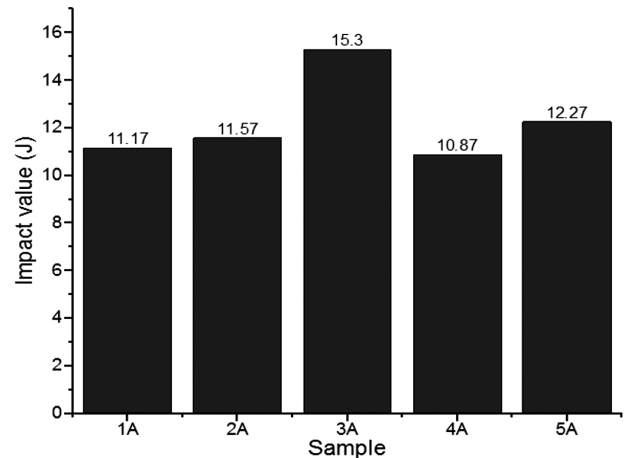


Fig. 9 — Impact test results on variations of fiberglass polymer composite reinforcement material combined with natural fibers

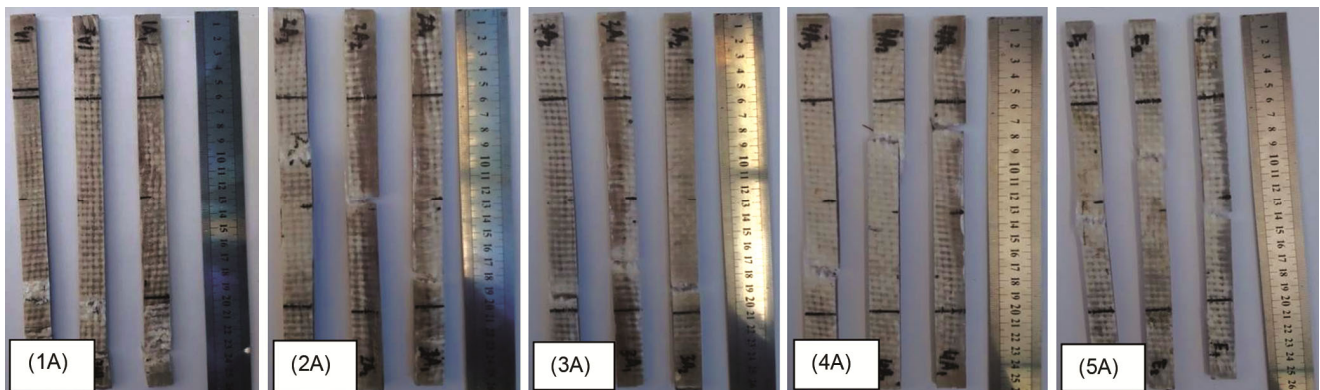


Fig 8 — Fracture of tensile test specimens on fiberglass polymer composite material combined with natural fiber matrix variations

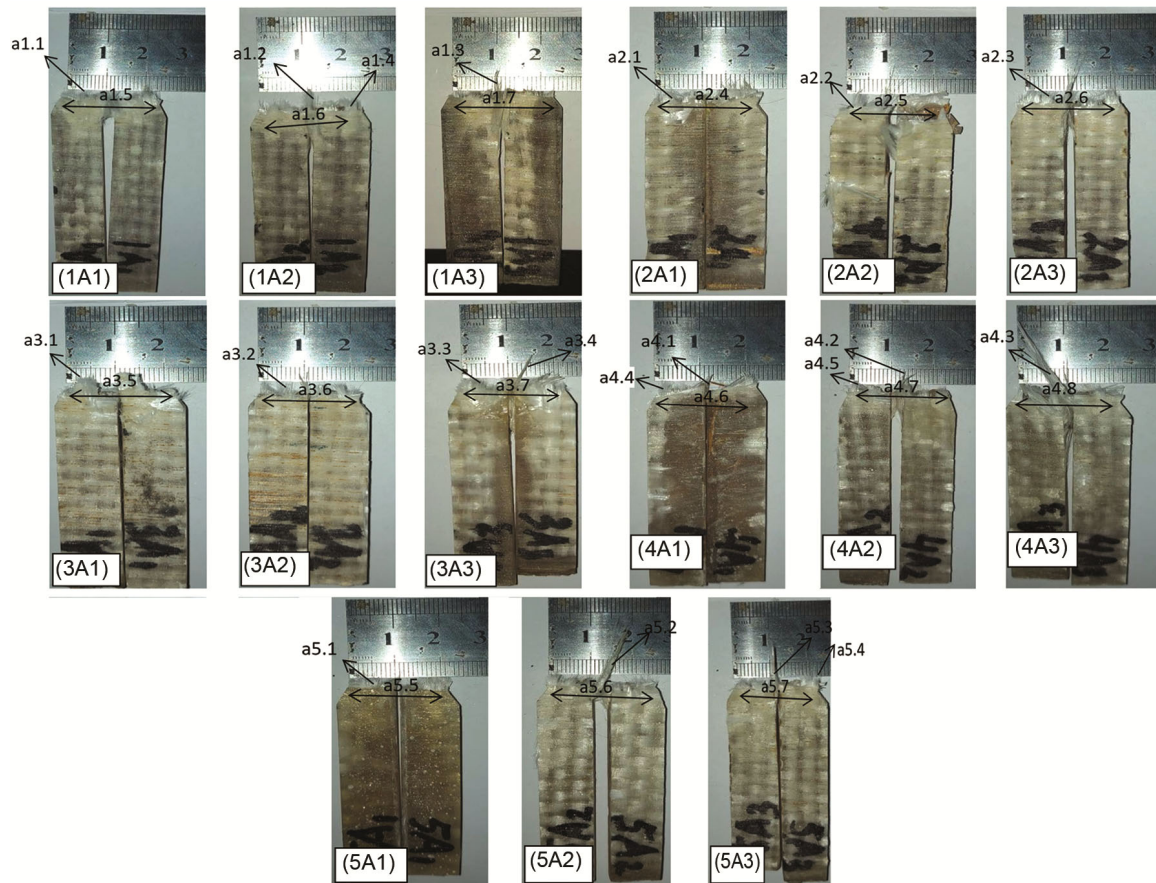


Fig 10.— Fractures of impact testing specimens on fiberglass polymer composite materials combined with matrix variations of natural fibers

characteristics. Even between samples with three repetitions of the test also produced different characteristics. This shows that the combination of synthetic fibers and natural fibers results in an uneven distribution of reinforcing energy for composite materials. Because if we look more closely, there are specimens that do not experience perfect fracture. Furthermore, in the figure, it can be seen that samples A1 to A5 have different fracture characteristics. Even between samples with three repetitions of the test also resulted in different fracture characteristics. The fracture characteristic in question is the presence or absence of residual fibers in the resulting fracture. This is because the polymer composite material, which has a fiber-reinforced composition, has an inherent inhomogeneous and anisotropic structure and the hardening process is uneven. In addition, coupled with the characteristics of sago fiber which is not homogeneous. Some of these things make the fracture characteristics of the specimen different. Meanwhile, from the fracture shape, it shows that the material is

classified as brittle (brittle) and slightly ductile (ductile). Then for the location of the fault in the material, it shows good results because all the faults occur at the corner (notch). An image of the fracture of an impact test specimen on a fiberglass polymer composite material combined with variations in natural fiber reinforcement is presented in Figure 10.

4 Conclusion

From the research that has been done, it was found that there was an increase in the value of the tensile test and impact test on composite materials combined between natural fibers and synthetic fibers for matrix variations. The results show that the composite material combination of natural fiber and synthetic fiber matrix variation has a low tensile strength of 36560J and a highest strength of 66440J. As for the composite material, the combination of natural fibers and synthetic fibers, the matrix variation has a low impact strength of 10.87J and the highest strength of 15.3J.

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References

- 1 Fadila I, Potensi Sagu Dalam Upaya Diversifikasi Pangan. Paper presented at Seminar Nasional, FMIPA-UT, (2011).
- 2 Monim Y, Luhulima F, & Purnomo DW, Jurnal AGROTEK, 5 (2017) 68-80.
- 3 Tulalussy QD, Melanesia, 1 (2016) 85-92.
- 4 Kusno A, & Asriany S, Paper presented at Temu Ilmiah Ikatan Peneliti Lingkungan Binaan Indonesia (IPLBI) 6, Lhokseumawe, Indonesia, (2017).
- 5 Gunawan Y, Aksar P, & Irfan LO, ENTHALPY, 2 (2016) 62-67.
- 6 Leiwakabessy AY, ARIKA, 10 (2016) 147-156.
- 7 Nanulaitta NM, Soeprapto W, & Soenoko R, J. Rekayasa Mesin, 9 (2018) 163-168.
- 8 Syahputra A, & Yulianto D, J. REM (Renewable Energy and Mechanics), 3 (2020) 22-31.
- 9 Sulaeman B, & Natsir R, PENA TEKNIK, 6 (2021) 14-23.
- 10 Umar MZ, & Arsyad M, Prinsip-Prinsip Arsitektur Berkelanjutan Pada Material Atap Daun Sagu. Paper presented at Seminar Nasional Inovasi Dan Aplikasi Teknologi Di Industri 2017 ITN Malang, Malang, Indonesia, (2017).
- 11 Asmuruf F, Wanma JF, & Rumatora A, J. Kehutanan Papuaasia, 4 (2018) 114-127.
- 12 Nappu MB, Wahid A, & Maintang, Morphologi Dan Potensi Beberapa Jenis Tanaman Sagu. Paper presented at Seminar Nasional Mewujudkan Kedaulatan Pangan melalui Penerapan Inovasi Teknologi Pertanian Spesifik Lokasi pada Kawasan Pertanian, Bogor, Indonesia, (2018).
- 13 Irnawati, Nurhidaya, & Histiarini AR, Pelatihan Pengolahan Sagu Di Hutan Alam Secara Tradisional Untuk Meningkatkan Nilai Ekonomi Masyarakat Kampung Puragi Distrik Metemani Kabupaten Sorong Selatan Papua Barat. Paper presented at SNPPM-3 (Seminar Nasional Penelitiandan Pengabdian kepada Masyarakat), Lampung, Indonesia, (2021).
- 14 Wang RM, Zheng SR, & Zheng YP, Polymer Matrix Composites and Technology. 1st published (Woodhead Publishing Limited and Science Press Limited, 3), (2011).
- 15 Kaw AK, Mechanics of Composite Materials, 2nd Ed. (CRC Press is an imprint of Taylor & Francis Group, 33), (2006).
- 16 Naresh K, Shankar K, Rao BS, & Velmurugan R, Compos. Part B, 100 (2016) 125-135.
- 17 Mardiyati, J. Inovasi Pertahanan dan Keamanan, 1 (2018) 20-28.
- 18 Toldy A, Szolnoki B, & Marosi Gy, Polym. Degrad. Stab., 96 (2011) 371-376.
- 19 Kumre A, Rana RS, & Purohit R, A Review on Mechanical Property of Sisal Glass Fiber Reinforced Polymer Composites. Paper presented at 5th International Conference of Materials Processing and Characterization (ICMPC 2016), San Francisco, USA, (2017).
- 20 Clareyna ED, & Mawarani LJ, J. Teknik Pomits, 2 (2013) F-208-F-213.
- 21 Minah FN, Astuti S, & Rastini EK, Karakteristik Mater. Komposit Polimer, 7 (2017) 1-6.
- 22 Hanifi R, Dewangga GB, Kardiman, & Widiyanto E, Gorontalo J. Infrastruct. Sci. Eng., 2 (2019) 15-23.
- 23 Salahudin X, Prabowo TA, Pramono C, & Widodo S, Optimasi Kekuatan Lentur Komposit Serat Batang Kecombrang Dengan Variasi Panjang Serat. Paper presented at Seminar Nasional Riset Teknologi Terapan, Magelang, Jawa Tengah, (2020).
- 24 Mukhtar D, J. Teknik Mesin UBL, 3 (2016) 7-15.
- 25 Yuliza E, & Ekawita R, JoP, 5 (2019) 1-5.
- 26 Setiawan A, Setiani V, Hardiyanti F, & Puspitasari D, J. Res. Technol., 5 (2019) 117-127.
- 27 Wardani DE, & Dwijayanti I, J. Arsitektur Grid – J. Archit. Built Environ., 1 (2019) 10-15.
- 28 Banat R, Aljnaid M, & Al-Rawashdeh M, Polym. J., 9 (2022) 1-14.
- 29 Morshedjan J, Jahani Y, Sharbafian F, & Zarei FS, Polym. J., 2 (2015) 109-119.
- 30 Chmutin I, Novokshonova L, Brevnov P, Yukhayeva G, & Ryvkina N, Polym. J., 4 (2017) 1-12.
- 31 Behboudi A, Jafarzadeh Y, Yegani R, & Akbari A, Polym. J., 4 (2017) 201-212.
- 32 Rasana N, & Jayanarayanan K, Polym. J., 9 (2022) 33-43.
- 33 Raveshiyani S, Amirabedi P, Yegani R, Pourabbas B, & Tavakoli A, Polym. J., 9 (2022) 61-71.
- 34 Supian ABM, Sapuan SM, Zuhri MYM, Zainudin ES, Ya HH, & Hisham HN, J. Mater. Res. Technol., 10 (2021) 1-14.
- 35 Sujon MAS, Habiba MA, & Abedin MZ, J. Mater. Res. Technol., 15 (2020) 1330-1341.
- 36 Bahrami M, Enciso B, Gaifami CM, Abenojar J, & Martinez MA, Compos. Part B, 221 (2021) 109033.
- 37 Hassan SA, Binoj JS, Goh KL, Mansingh BB, Varaprasad KC, Yahya MY, Othman FEC, Ahmed U, Nurhadiyanto D, Mujiyono, & Wulandari AP, Curr. Res. Green Sustain. Chem., 5 (2022) 100284.
- 38 Ashrafa W, Ishak MR, Zuhri MYM, Yidris N, & Ya'acob AM, J. Mater. Res. Technol., 13 (2021) 89-98.
- 39 Castellanos WR, & Rodrigue D, Compos. Renew. Sustain. Mater., Ch. 15 (2016) 273-302.
- 40 Alkbir MF, Sapuan SM, Nuraini AA, & Ishak MR, Compos. Struct., 148 (2016) 59-73.
- 41 Suriani M, Sapuan S, Ruzaidi C, Nair D, & Flammability IR, Textil Res J., (2021) 004051752110086.
- 42 Nurazzi NM, Asyraf MRM, Athiyah SF, Shazleen SS, Rafiqah SA, Harussani MM, Kamarudin SH, Razman MR, Rahmah M, Zainudin ES, Ilyas RA, Aisyah HA, Norrahim MNF, Abdullah N, Sapuan SM, & Khalina A, Polymers, 13 (2021) 2170.
- 43 Zhao Z, Mikenas TB, Zakharov VA, Nikolaeva MI, Matsko MA, Bessudnova EV, & Wu W, Polym. J., 6 (2019) 117-126.
- 44 Bernard MDV, Nicolau VV, & Strumia MC, Polym. J., 9 (2022) 45-60.
- 45 Kaminsky W, & Fernandes M, Polym. J., 2 (2015) 1-16.
- 46 Alt HG, Polym. J., 2 (2015) 17-25.

- 47 Diharjo K, J. TeknikMesin, 8 (2006) 8-13.
- 48 Manikandan A, & Rajkumar R, Polym. Polym. Compos., 24 (2016) 455-462.
- 49 Supian ABM, Jawaid M, Rashid B, Fouad H, Saba N, Dhakal HN, & Khiari R, J. Mater. Res. Technol., 15 (2021) 1330-1341.
- 50 Elanchezhian C, Ramnath BV, Ramakrishnan G, Rajendrakumar D, Naveenkumar V, & Saravanakumar MK, Review On Mechanical Properties Of Natural Fiber Composites. Paper presented at International Conference on Processing of Materials, Minerals and Energy (PMME 2016), Andhra Pradesh, India, (2018).