Investigation of Gnetum Gnemon and Ramie Natural Fiber on the Mechanical Properties of Composites with the Combination of Aramid and Carbon Fiber as Reinforcement for Military Personnel Applications

Annisa Ariesta, Muammar Pierre A. Ferriyanaa, E. I. Bhiftime

Department of Military Mechanical Engineering, Indonesia Defence University,
Indonesia Peace and Security Center (IPSC) Street, Sentul Bogor - West Java 16810, Indonesia
annisaaries@gmail.com

Abstract

Every equipment infrastructure in a TNI unit will be needed to support an operation in the defence system to maintain the integrity of the Unitary State of the Republic of Indonesia. Personal protective equipment is needed for a war operation's safety or continuity. Protective components made from composite fibers have the advantage of being resistant to corrosion caused by the environment. The natural and carbon fibers will be mixed/reinforced with epoxy resin to become composite materials. This study aims to identify Gnetum Gnemon fiber composites with carbon fiber and aramid fiber to determine the mechanical properties of the composite material resulting from a collision. Natural fiber Gnetum gnemon has not been widely studied as a reinforcing material for polymer composites. Gnetum gnemon fiber chemical composition is hemicellulose approx. 25%, 40% alpha cellulose, 10% lignin and 3-5% benzene extractive. Its density is quite light, 1.2087 g/cm³ - 1.8069 g/cm³. Because this fiber has a continuous fiber structure and a strong natural weave, its use is still minimal. Special treatment such as alkali treatment on Gnetum gnemon, can increase the strength of natural fibers. Due to its exceptional mechanical properties, Kevlar or aramid fibre are extensively used in industrial and military applications. The aramid fiber exhibited a transversely anisotropic nature in a small strain range, with its stress-strain behavior as linear and elastic. The anisotropic nature of the aramid fiber was due to its high tensile-to-shear modulus ratio. The high strength and modulus were also found to be scattered due to the larger distribution of defects in the longer fiber. Epoxy resin is a type of polymer characterized often by one or more epoxide functional groups, with at least one of the epoxide functional groups acting as a monomer and terminal unit of the polymer within the structural chain.

Keywords: Aramid, carbon, composite, epoxy, gnetum gnemon, natural fiber

1. Introduction

Composite materials that are reinforced with natural fibers are alternative materials that are very profitable when compared to other materials, which are currently developing rapidly, and are receiving serious attention for scientists. The natural fibers used are coconut frond fiber, palm fiber, banana stem fiber, pineapple leaf fiber, and so on. In addition, natural cellulose fibers can also be used as a mixed material that is able to provide a reinforcing function without the presence of thermo setting plastic polymers and thermo plastics. In order to produce composite materials that can be used as widely as possible. for engineering applications, both structural and non-structural [2]. There are various disadvantages of fiber-reinforced composites, this results in weak interfacial formation, which results in low mechanical properties of the composite. Another drawback of natural fiber reinforced composites is that they have a high sensitivity to water and relatively poor thermal stability. The water absorption capacity of the composite is important because the ability of the fiber to absorb water in the composite can cause swelling and unstable dimensions. Thus reducing the mechanical properties of the fiber and degraded [3-6].

Natural fiber gnetum gnemon has not been widely studied as a reinforcing material for polymer composites. It is known that the gnetum gnemon tree grows spread across the peninsula of Southeast Asia, the Indonesian Archipelago, the Philippines, to Melanesia. The tree reaches a height of 15 m and a trunk diameter of 40 cm. This tree is quite easy to reproduce to a height of more than 20 m. The use of natural fiber gnetum gnemon is utilized by traditional communities, on the island of Papua. These natural fibers are used as the basic material for bags (noken)[1]. Gnetum gnemon fiber chemical composition is hemicellulose approx. 25%, 40% alpha cellulose, 10% lignin and 3-5% benzene extractive. Its density is quite light, namely, 1.2087 g/cm³ - 1.8069 g/cm³. Because this fiber has a continuous fiber structure and a strong natural weave, its use is still very limited. Special treatment such as alkali treatment on Gnetum gnemon can increase the strength of natural fibers.Series of tensile test was carried out on raw Gnetum gnemon fibers to obtain specifically their ultimate tensile properties. From these results, the average tensile strength of the raw Gnetum gnemon fiber is 215 MPa and the fracture strain of 4.3%, with probability analysis using the weibull method it is possible to obtain a tensile strength of 240.5 MPa [7-10].

Ramie is a natural fiber derived from the stem of the Boehmeria nivea plant, which is native to eastern Asia. It is known for its strength, durability, and ability to resist bacterial growth, making it a desirable material for various applications. Ramie fibres have outstanding mechanical properties compared with most of the natural fibres around the world. It is known as eco-friendly fibre resource because ramie fibre has some advantages over synthetic fibres on the environment. Ramie fibres have oddly long fibre cells ranging between 110 mm and 140 mm. The length of ramie is nearly six times higher than cotton and nearly eight times higher than silk [11]. Ramie fi ber has one of the highest values of Young 's modulus and tensile strength among the widevariety of natural fi bers, second only to flax and hemp and a little less stiff than kenaf. The mechanical properties of ramie fibers vary in the literature. The differences could be due to fi ber production methods, fi ber diameters,and/or differences in testing.

The type of carbon fiber generally, high-strength such as T1000 or higher are preferred for storage because they offer superior mechanical properties, such as high tensile strength and stiffness, which are important for withstanding the high pressure and cyclic loading conditions that the vessels may be subjected to during storage and transportation. However, the choice of carbon fiber type also depends on the specific application for example, if the vessel needs to be lightweight, lower-strength carbon fibers such as T300 or T700 may be suitable. In addition, the manufacturing process and cost of the carbon fibers can also be a consideration. Carbon fibers have many benefits, including high stiffness, high tensile strength, low weight, high chemical resistance, high-temperature tolerance, and low thermal expansion. Aramid fiber due to its exceptional mechanical properties, are extensively used in industrial and military applications. Many researchers have studied its mechanical properties.

The aramid fiber exhibited the transversely anisotropic nature in a small strain range, with its stress-strain behavior as linear and elastic. The anisotropic nature of the aramid fiber was due to its high ratio of tensile to shear modulus. The high strength and modulus were also found to be scattered due to the larger distribution of defects in the longer fiber. In a research work, the nature of aramid fiber under different loading condition was investigated. It was found that the effect of axial compression on the recoverable tensile properties was very small. In another study, the dynamic tensile properties of aramid fabric was investigated with different gauge lengths subjected to different range of strain rates. The dynamic properties like young's modulus, tensile strength, maximum strain and toughness were found to be dependent on the strain rate [12]. Under these loading conditions, the fabric has exhibited the non-linear and orthogonal behavior. In a study, the transverse compression response of aramid was analyzed using fiber level finite element. The statistical methods were also used for studying variability of the strength and failure strains of the aramid yarns. It was found that the Gumbel and Weibull distribution were best suited for analyzing failure stress and strain respectively. In a research work, the dependence of mechanical properties of aramid fiber bundles on the strain rate and temperature was investigated and a Weibull distribution model was also developed. At constant temperature, the initial elastic modulus, strength and failure strain was found to be increased with the strain rate. On the other hand, at constant strain rate, the initial elastic modulus decreased and the failure strain increased with the increased in the test temperature [44].

The epoxy resin is a type of polymer characterized often with one or more epoxide functional group with at least one of the epoxide functional group acting as a monomer and terminal unit of the polymer within the structural chain. Epoxy resins are extensively used in the production of lightweight carbon fiber reinforced composites (CRFC) to deliver desired engineering properties such as high modulus and strength, low creep, superb chemical and thermal stability. The epoxy/carbon fiber-reinforced composite design, just like any other composite, is heavily dependent on the mechanical and thermal properties of the resulting composites of the manufactured epoxy/carbon fiber-reinforced composite withstanding the conditions set by its application requirements. Matrix modification is a viable technique for improving mechanical and/or other properties [45-46]. Epoxy has viscosity that is several orders of magnitude greater than water which has a dynamic viscosity of 1 mPa.s at 20◦C. For instance, a typical bisphenol-A based epoxy YD-128 has a dynamic viscosity of 11,500–13,500 MPa.s at 25◦C whereas the lower viscosity epoxy resins available on the market such as example Eposir-7127 which is a variant of DEGBA epoxy has reported dynamic viscosity of 8,000–10,000 MPa.s at 20◦C small amounts is known to improve the mechanical qualities of a composite [13].

This research proposal examines the use of Natural fiber as a Polymer Composite and an additional layer of carbon fiber and aramid fiber as a supporting layer in order so that increase the mechanical properties used as material for applications TNI military personnel The method used in the manufacture of composites is a vacuum and high pressure process.

2. Experimental Method

Observational was evaluated from the mechanical properties, the result of casting using the vacuum prosess. The main materials used were gnetum gnemon natural fiber with the combination of aramid and carbon fiber, with variations in layer thickness for each type of fiber material. Use of epoxy resin with a mixture ratio of 2 : 1. Can be seen Table 1 ingredients composition and Fig 1 materials in use and composite manufacturing results.

Tabel 1. Variations in the Composition of Foundry

Parameters	Materials	Composition Variations (garm)	Volume (gram)
1	Carbon Fiber	5 gram	30 gram
	Gnetum Gnemon Fiber	10 gram	
	Ramie Fiber	10 gram	
	Aramid Fiber	5 gram	
2	Carbon Fiber	5 gram	30 gram
	Gnetum Gnemon Fiber	15 gram	
	Ramie Fiber	5 gram	
	Aramid Fiber	5 gram	
3	Carbon Fiber	5 gram	30 gram
	Gnetum Gnemon Fiber	5 gram	
	Ramie Fiber	15 gram	
	Aramid Fiber	5 gram	
4	Carbon Fiber	1 gram	30 gram
	Gnetum Gnemon Fiber	14 gram	
	Ramie Fiber	14 gram	
	Aramid Fiber	1 gram	

(a) Materials Fiber

(b) Composites

Figure 1. (a) Materials Natural Fiber with Aramid and Carbon Fiber, (b) Composite specimen cast results

The first stage is preparing the materials and tools that will be used. These materials are cut according to the weight ratio of mixing. These materials are done to simplify the process of mixing composition. Each material is weighed to obtain the mass composition according to variations in the composite layer mixture. The result of weighing the material in each variation is shown in Table 1. The next process is the preparation of each layer of fiber material variations. Then mix the epoxy resin with a ratio of 2: 1. Then all the variations of fiber material are put into the camber and mixed with epoxy and vacuumed. Stirring and vacuum process 7 minutes vacuum value -30 psi. After the vacuum process is put into the mold and arranged in various layers. Then the mold is given a pressure of 20 Mpa. Then leave it for 24 hours at room temperature. Then it is removed from the mold and removed from the remaining resin that is attached and then left at room temperature for 12 hours to get optimal dry results. Then the results of making the composite are cut according to the shape of the test specimen. The results of making composites can be seen in Fig 1.

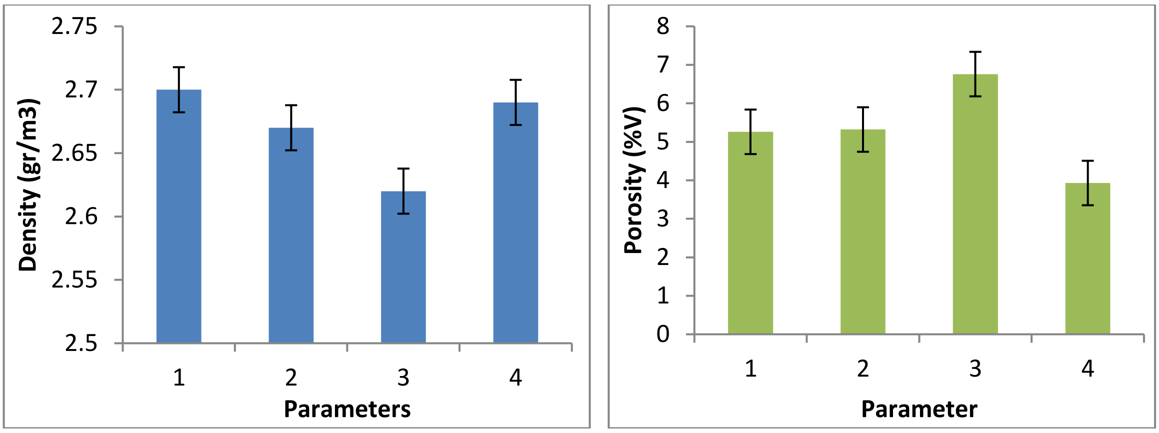
3. Results and Discussions

Density and Porosity

Density testing using VIBRA digital balance. The density test specimen measures 2 cm x 2 cm x 2 cm. Three specimens were made for each composition variation taken from the left, middle and right casting results. This is done to get the average density value, because usually there is a density difference between the left, middle and right. From these weighing values obtained dry period and wet period. The calculation of density can be done by equation (3.1). Theoretical density is calculated by equation (3.2). Porosity is calculated by equation (3.3). The results of density testing and porosity calculations for various fiber composite materials are shown in Table 3 below:

Tabel 1. Variations in the Composition of Foundry

Parameters	Materials	Composition Variations (garm)	ρ_{actual} (g/cm^3)	$\rho_{theoretic}$ (g/cm^3)	Porosity (%V)
1	Carbon Fiber	5 gram	2.70	2.85	5.26
	Gnetum Gnemon Fiber	10 gram	2.67	2.82	5.32
	Ramie Fiber	10 gram	2.62	2.81	6.76
	Aramid Fiber	5 gram	2.69	2.80	3.93
2	Carbon Fiber	5 gram	2.72	2.86	5.27
	Gnetum Gnemon Fiber	15 gram	2.69	2.84	5.35
	Ramie Fiber	5 gram	2.65	2.82	5.76
	Aramid Fiber	5 gram	2.68	2.81	5.93
3	Carbon Fiber	5 gram	2.75	2.88	5.28
	Gnetum Gnemon Fiber	5 gram	2.67	2.85	5.35
	Ramie Fiber	15 gram	2.66	2.83	5.76
	Aramid Fiber	5 gram	2.67	2.82	5.93
4	Carbon Fiber	1 gram	2.75	2.88	6.28
	Gnetum Gnemon Fiber	14 gram	2.67	2.85	6.38
	Ramie Fiber	14 gram	2.66	2.83	6.70
	Aramid Fiber	1 gram	2.67	2.82	6.87



(a) (b)

FIGURE 3. Graph (a) density, (b) the level of porosity composit natural fiber

The data above shows that the density of the composite decreases in parameter variation 4. Then it increases in variation 5, while the porosity increases by 4% according to the ratio of density and porosity values. In composites, the density decreases and increases with variation (5). While the porosity of 2.67% tends to remain constant, then the porosity increases to 6.76% in the variation (4 wt%). There may be a risk of porosity caused by sub-optimal casting results. This test is like the research results of Hashim et al. (1999) which states that the potential for porosity in the casting process is caused by a chemical reaction between the reinforcing particles and the alloy and the presence of trapped gas in the stirring process is caused by the absence of a vacuum process [4]. No gas was used in the casting process in this experiment, so no degassing process was required. The density distribution of the casting results shows the degree of dispersion or dispersion of Mg particles into the Al10Si alloy, which is then analyzed at the top, middle and bottom of the casting. Table 4 below shows the data density for each casting section.

2Tensile Test

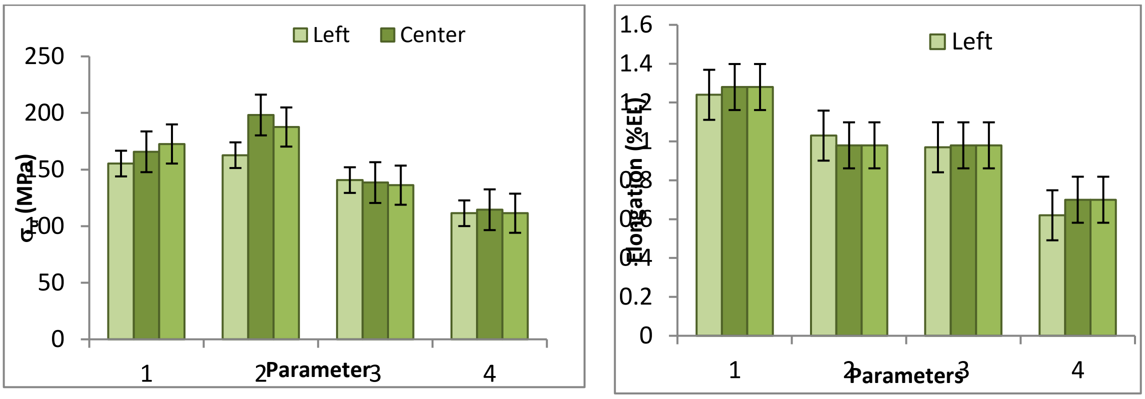
The value of tensile strength and elongation of variation composites can be seen in Table 6 and Table 7.. Figure 9b Composite variations have tensile strength values. Variation parameter 3 has the highest tensile strength value, namely 262.7 MPa. Figure 8a shows that the tensile strength value for composite variation 3 is 225.22 MPa compared to the other specimens. This tensile strength is caused by the influence of the dense fiber layers. The component tensile strength study standard is 270 MPa. Figure 8b shows that composite fibers increase their ductility after increasing the number of layers of narural fiber. in variation 1 has the highest ductility of 2.81% EL. However, the tensile strength and elongation decreased after reducing the weight percent of genemo 4 and 5 fibers. This was due to the formation of a new phase with lower mechanical properties, the growth of smaller air bubbles. In addition, the gas trapped in the composite dough decreases the mechanical properties.

Tabel 3. The value of Tensile Strength composites

Materials	Parameter	Tensile Strength (MPa)			σ_u
		Left	Center	Right	(MPa)
Carbon +	1	144.3	132.5	131.4	137.8
Gnemon +	2	207.3	193.9	181.9	194.6
Ramie +	3	164.5	60.4	45.2	104.8
Aramid	4	104.9	94.8	85.7	95.3
Carbon +	1	155.3	165.7	172.6	164.0
Gnemon +	2	262.7	198.2	187.6	225.2
Ramie +	3	140.7	138.5	136.2	138.5
Aramid	4	111.4	114.5	111.4	111.4

Tabel 4. The value of Elongation composites

Materials	Parameter	Elongation (%EL)			Average %EL
		Left	Center	Right	
Carbon +	1	3.24	1.28	1.28	2.26
Gnemon +	2	1.30	0.98	0.98	1.14
Ramie +	3	0.97	0.98	0.98	0.97
Aramid	4	0.62	0.70	0.70	0.66
Carbon +	1	2.19	3.44	3.44	2.81
Gnemon +	2	3.75	1.25	1.25	2.50
Ramie +	3	1.06	1.44	1.44	1.25
Aramid	4	0.91	0.85	0.85	0.88



(a) (b)

FIGURE 3. Graph (a) density, (b) the level of porosity composit natural fiber

4. Conclusions

Several tests have been conducted on Gnetum gnemon fibers. Experimental investigation shows that an inverse correlation between the tensile strength and the equivalent fiber diameter. In this study it can be concluded that the test results were influenced by the addition of a layer of genemon gnetum fiber. Here the highest porosity value in specimen variation 4 is 6.76%. The hardness value of the composite variation specimen will increase with the addition of fiber. The highest tensile strength value in parameter variation 3 was 225.22 MPa. The microstructure showed differences in grain size in parameter 3 specimens which were given a layer of persetasi gnetum genemon. The tensile strength of Gnetum gnemon fiber is only slightly lower than that of Cotton, Jute, and Ramie fibers. A microstructural analysis offers a possible mechanism related to defects, flaws and irregularities as well as the composition of the fiber, as responsible for the mechanical properties of the fibers. Based on the tensile tests, microstructure observation, and spectroscopy analysis results, there is a good potential for Gnetum gnemon fiber as a competitor to the predecessor natural fibers used in composite materials for the industry of defense, if given special chemical treatment to increase their initial mechanical properties. Further investigations are required for any special treatments to the fibers, fabrication of the new eco composite, followed by a series of verification tests through impact ballistics testing and characterization on composite specimens that have been processed to get the best performance in terms of protection.

References

[1] Ogale, A.A.; Zhang, M.; Jin, J. Recent advances in carbon fibers derived from biobased precursors. J. Appl. Polym. Sci. 2016,133, app.43794.

[2] Hashin Z, Rotem A. A fatigue failure criterion for fiber reinforced materials. J Compos Mater 1973;7:448e64.

[3] Liu PF, Zheng J. Progressive failure analysis of carbon fiber/epoxy composite laminates using continuum damage mechanics. Mater Sci Eng A 2008;485:711e7.

[4] Xu P, Zheng J, Liu P. Finite element analysis of burst pressure of composite hydrogen storage vessels. Mater Des 2009;30:2295e301.

[5] Eka Irianto Bhiftime, Rando Tungga Dewa and Arief Nur Pratomo. Proposed Novel Eco-Friendly Natural Fiber of Gnetum Gnemon for Military Grade Applications”. Jurnal Rekayasa Mesin p-ISSN: 1411-6863, e-ISSN: 2540-7678

Vol.17, No.1, April 2022, hal. 189-194.

[6] Barua C C, Haloi P, Barua I C."Gnetum gnemon Linn. : A Comprehensive Review on its Biological, Pharmacological and Pharmacognostical Potentials. International Journal of Pharmacognosy and Phytochemical Research 2015; 7(3); 531-539.

[7] Y. Du, N. Yan, and M.T. Kortschot. The use of ramie fi bers as reinforcements in composites University of Toronto. Canada.

[8] Tao Yu, Ning Jiang, Yan Lia. Study on short ramie fiber/poly(lactic acid) composites compatibilized by maleic anhydride". Composites: Part A 64 (2014) 139–146.

[9] J.P. Siregar, M. Zalinawati, T. Cionita, M.R.M. Rejab, I. Mawarnie, J. Jaafar, M.H.M. Hamdan. Mechanical properties of hybrid sugar palm/ramie fibre reinforced epoxy composites". Materials Today: Proceedings. 2020.

[10] J.A. Bencomo-Cisneros, A. Tajeda-Ochoa, J.A. Garcia-Estrada, C.A. Herrera-Ramirez, A. Hurtado-Macias, R. Martinez-Sanchez, J.M. Herrera-Ramirez, J. Alloys and Comp. 536S (2012) S456-S459.

[11] Thingujam Jackson Singha, Sutanu Samanta. Characterization of Kevlar Fiber and Its Composites: A Review Materials Today: Proceedings 2 (2015) 1381 – 1387.

[12] Shan-shan Shi, Zhi Sun, Xiao-zhi Hua, Hao-ran Chen. "Carbon-fiber and aluminum-honeycomb sandwich composites with and without Kevlar-fiber interfacial toughening". Composites: Part A 67 (2014) 102–110.

[13] John Keyte, Ketan Pancholi and James Njuguna. "Recent Developments in Graphene Oxide/Epoxy Carbon Fiber-Reinforced Composites".Frontiers in Materials October 2019.Volume 6- 224.