Jurnal Rekayasa Mesin
p-ISSN: 1411-6863, e-ISSN: 2540-7678
Vol.17, No.1, April **2022**, hal. 189-194

Proposed Novel Eco-Friendly Natural Fiber of Gnetum Gnemon for Military Grade Applications

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Diterima: 13-03-2022; Direvisi: 20-04-2022; Dipublikasi: 30-04-2022

Abstrak

Makalah ini menyelidiki kekuatan tarik dan karakterisasi struktur mikro *Gnetum gnemon* sebagai serat alami ramah lingkungan yang baru diusulkan sebagai pengikat pada material komposit baru. Serat alam sangat menarik bagi para peneliti, insinyur dan ilmuwan sebagai penguat alternatif pada komposit. Hal ini dikarenakan memiliki biaya yang relatif rendah, terbarukan (mudah tersedia), dan *biodegradable*. Sistem produksinya membutuhkan peralatan yang sederhana dan hemat energi serta dapat dimanfaatkan sebagai pengganti serat konvensional, seperti *Kevlar* untuk perlindungan personel di militer. Kekuatan *Gnetum gnemon* ditemukan hamper setara dengan komposit serat alam yang ada. Bentuk serat yang ditemukan bergantung pada lignin, hemiselulosa, benzena, dan pengotor lainnya, sehingga membuatnya lebih besar dan tidak seragam. Hasil ini menunjukkan potensi besar sebagai pesaing serat alam pendahulunya yang digunakan dalam material komposit pada material pelindung, jika diberikan perlakuan kimia khusus untuk meningkatkan sifat mekanik awalnya..

Kata kunci: *Gnetum Gnemon*; Komposit, Material Pelindung; Serat Alam

Abstract

This paper investigates a tensile strength and microstructure characterization of Gnetum gnemon as a newly proposed eco-friendly natural fiber for composites reinforcement. Natural fibers have recently become attractive to researchers, engineers and scientists as an alternative reinforcement for composites. It has relatively low cost, renewable (easily available), and biodegradable. The production system requires simple and energy-efficient equipment and can be exploited as a replacement for the conventional fiber, such as Kevlar for personnel protection. The strength of Gnetum gnemon was found to be comparable with existing new composites. The form of fiber was found to be depended on the lignin, hemicellulose, benzene, and other impurities, thus made it larger and not uniform. These results show great potential as a competitor to the predecessor natural fibers used in composite materials of armor materials, if given special chemical treatment to increase their initial mechanical properties.

Keywords: *Armor; Composite; Gnetum Gnemon; Natural fiber*

1. Introduction

In the military field, ammunition and weaponry technology is developing very rapidly. Therefore, technological advances in the development of new materials as protection from the ballistic impact of bullets are needed. One of the protective personnel is a combat helmet which functions as a protector of the most important human organs, namely the head and brain. A combat helmet is a basic protective device to protect soldiers and security forces from the impact of ballistic bullets which cause major injuries [1]. In the case of ballistic tests, the protective material (e.g., armor material) must be able to absorb the kinetic energy rate of the bullet or with a minimum indentation according to the applicable standards. High strength materials are also needed with high energy absorption properties (toughness) and lightweight for armor materials. Currently, some of the materials that are popularly used are synthetic fibers (Kevlar) as the main material for combat helmets to protect against the ballistic impacts of 5.56 - 7.62mm bullets [2]. However, to look for renewable materials with the potential for better, more economical, and eco-friendly properties, candidate for synthetic fiber replacement will be invetigated in this study.

Existing natural fibers that can be extracted from plants are one of the candidates for composite reinforcing materials because of their continuous availability and their comparative advantage over synthetic fibers [3-5]. Natural fibers are relatively low cost, renewable (easily available), and biodegradable. The production system requires simple and energy-efficient equipment such as the efficiency of the resulting carbon emissions. The main idea is the incorporation of natural fibers into the composite material can significantly improve mechanical properties [6]. From several natural fibers developed, one of the researchers' concerns is the Gnetum gnemon fiber, which has the potential to become a prime candidate for natural fiber reinforced composite material. This fiber is widely available in Southeast Asia forest and can be used as the primary material for personnel protection. The density is quite light, that is 1.2087 g/cm³ - 1.8069 g/cm³. The chemical composition of Gnetum gnemon fiber is hemicellulose is approx. 25%, alpha cellulose of 40%, lignin of 10% and extractive benzene of 3-5% [7]. Because of this fiber has a continuous fiber structure and a strong natural webbing, its utilization is still very limited. Special treatment such as alkali treatments in Gnetum gnemon can increase the strength of the fiber [8].

In this paper, an initial study will be carried out on the characterization of the mechanical properties of raw Gnetum gnemon fiber. Tensile tests will be carried out on Gnetum gnemon fiber. Thus, the fiber surface morphology was observed using Scanning Electron Microscopy (SEM), further testing of FT-IR is utilized to characterize the chemical reaction on the fiber. It is expected from this research to obtain a novel natural fiber candidate to fabricate an eco composite with several advantages of mechanical properties, economical aspects, environmental friendliness, and the self-sufficiency of producing the proposed multilayered armor systems material in the industry of defense.

2. Methods and Procedures

Experimental procedure begins with Gnetum gnemon fibers extraction from the branches with a diameter of more than 5 cm. To homogenize the physical properties of the fiber, the age of the Gnetum gnemon tree is adjusted around 5 years old. The fibers were soaked in the water for 3-4 days to remove the wood cells, then the fibers were dried in the open air. The disadvantage of natural fiber-based composites is the incompatibility between the hydrophobic polymer matrix and hydrophilic fibers. This results in weak interface bonding, with that causing low adhesive properties of the substances. Fig. 1 shows Gnetum gnemon fibers.

To meet the criteria, Gnetum gnemon fibers must also undergo a series of tensile test using the Universal Testing Machine (UTM) designated for small fibers. To determine the tensile strength and elongation, it refers to the composite tensile test standard [9].

SEM observations were carried out to analyze the microstructure of the Gnetum gnemon fibers. EDS analysis is carried out to determine the chemical composition after fracture because it is one of a destructive test. FTIR is a spectroscopic technique using light waves which is often used as a means of non-destructive test for organic molecules. FTIR analysis is carried out to determine the chemical phase changes that occur in the Gnetum gnemon fibers.

Figure 1. The extraction of raw Gnetum gnemon fibers

3. Results and Discussions

3.1. Tensile Properties

Series of tensile test was carried out on raw Gnetum gnemon fibers to obtain specifically their ultimate tensile properties. Fig. 3 shows the results of the tensile test on the Gnetum gnemon fibers. 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 with the shape parameter of 3.54 (according to Fig. 4. Fig. 5 is a typical engineering stress-strain diagram of the Gnetum gnemon fibers. The curve shows a typical brittle fiber with linear hardening and rapid drop after failure.

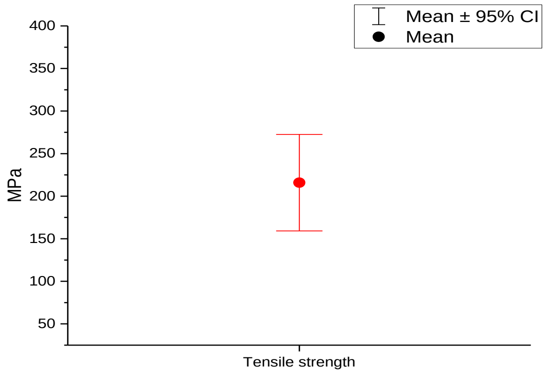

Figure 2. Gnetum gnemon fiber tensile test curve

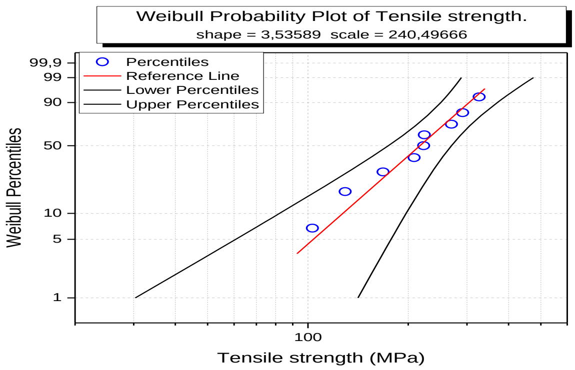

Figure 3. Weibull probability curve

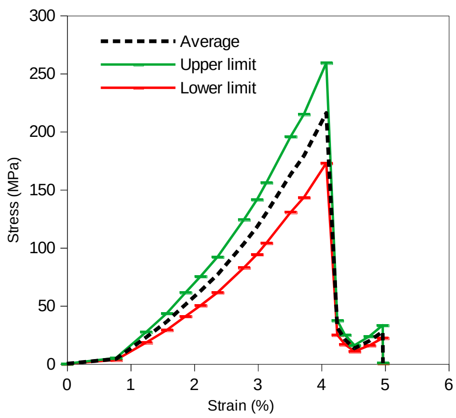

Figure 4. Typical engineering stress-strain curve of Gnetum gnemon fiber.

The upper and lower limit of the curve were added to clearly exhibit statistical representation of their tensile strength. Based on the results on the Table 1, raw Gnetum gnemon fibers has only slightly lower tensile strength in comparison with Cotton, Jute, and Ramie fibers. These results show great potential as a competitor to the predecessor natural fibers used in existing composite materials [10]. If given special chemical treatment to increase their initial mechanical properties such as alkali treatments [11-12]. The tensile strength of the Gnetum gnemon fibers is one of the most important characteristic to fabricate a reinforced material of the composite, besides the light density, structure of the fibers, and also these fibers are largely available in the Southeast Asia.

Tabel 1. Properties of selected natural and manmade fibers [10]

Fiber	Density (g/cm3)	Tensile Strength (MPa)
Cotton	1.5-1.6	400
Jute	1.3	393-773
Flax	1.5	500-1500
Hemp	1.47	690
Kenaf	1.45	930
Ramie	N/A	400-938
Sisal	1.5	511-635
Coir	1.2	593
Glass	2.5	3000-4000
Aramid	1.4	3000-3150
Carbon	1.4	4000

3.2. Microstructure Analysis

Fig. 3 shows SEM image of Gnetum gnemon fiber. Fiber diameter was measured using SEM and Image software. The fiber diameter is calculated to be around 18-20µm. The large diameter in the fiber is caused by a layer of lignin and wax covering the fiber. the uniformity of the diameter of the fiber (density of each fiber) can cause the low mechanical properties of the fiber. Based on the image analysis, lignin layers and other impurities are attached to the fiber. This lignin, wax and impurity layer makes the fiber diameter larger and not uniform. It is expected that the alkali treatment will break the hydrogen bonds of the cellulose, hemicellulose and lignin and leads to defibrillation, the breakdown of the fiber bundle into smaller fibers. This change increases the effective surface area and it compatibility with matrix to enhance the future composite properties [11].

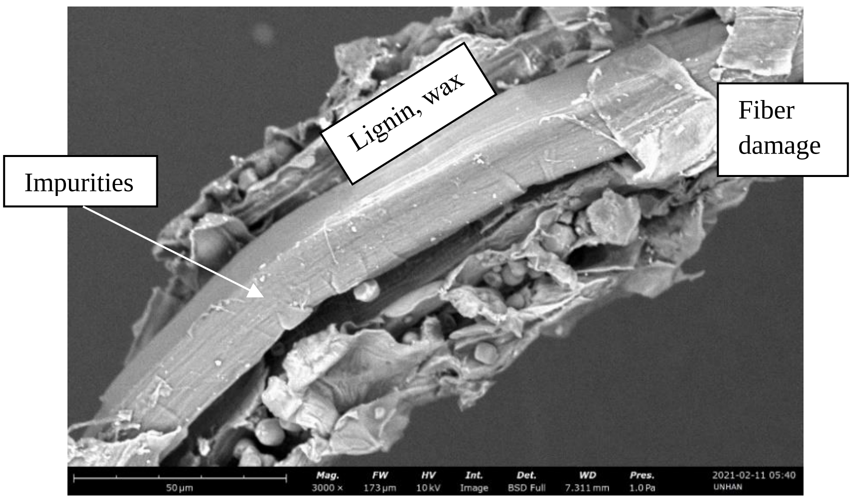

Figure 3. SEM image of The extraction of raw Gnetum gnemon fiber.

p-ISSN: 1411-6863, e-ISSN: 2540-7678
Vol.17|No.1|189-194|April|2022

Gnetum gnemon fibers were analyzed by FT-IR spectroscopy using an attenuated total reflectance scan. Fig. 4 shows the FTIR spectrum analysis of Gnetum gnemon fiber. The scanning range is from 4000 cm^{-1} to 500 cm^{-1}. The spectrum shows many peaks with different absorbance. The C-H hydrocarbon absorption band was visible at 2913 cm^{-1}. The Carbonyl group (C=O) at the peak of 1606 cm^{-1} was significantly seen on the fiber, this was in line with the decrease in hemicellulose on the fiber surface. The strong peak intensity of the C-OH group formed by the acetyl group (i.e., ester, alcohol, and carboxylic acid) of lignin stretched at 1016-1331 cm^{-1} in the fiber. The results obtained are very much in accordance with previous researches [13-14]. This analysis is also an efficacy technique for surface and interface characterization of the fibers and allow further interpretation of the nature of adhesion between lignocellulosic and other substance (e.g., composite matrix). From the database, a strong correlation can be established between the nature of hydrogen bonds and mechanical properties of cellulose [15].

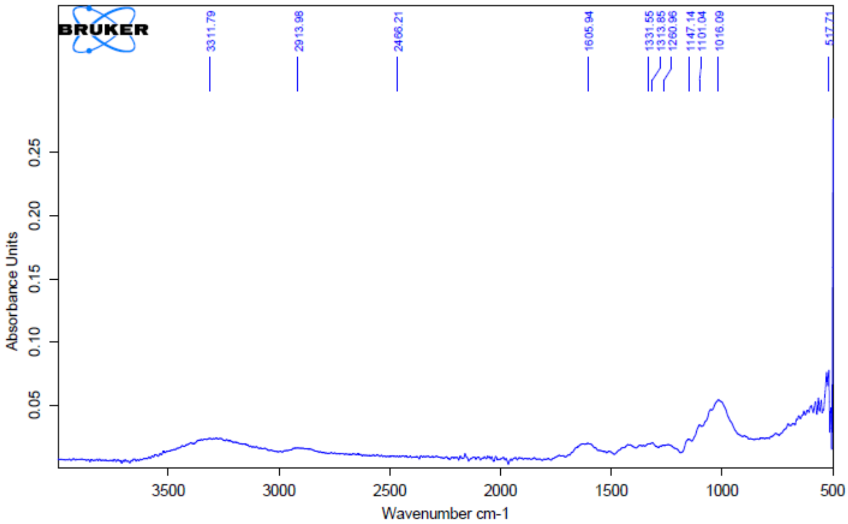

Figure 4. The FT-IR spectrum analysis of Gnetum gnemon fiber.

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. 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.

Acknowledgement

The authors would like acknowledge that this research was fully funded by Indonesia Defense University.

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