Musa acuminata stem is an agricultural waste that has good economic potential. For this reason, efforts are needed to increase the saba banana tree not only as waste, but also to increase its function into natural fiber raw materials for polyester matrix composite reinforcement. The purpose of this study was to determine the characteristics of Musa acuminata stem fibre (MASF) from North Lombok Regency, Indonesia Country as a reinforcement for polyester matrix composites. In this study, the fiber (specimen), taken from pseudo stem Musa acuminata, which consists of three layers: outer, middle and inner stem. The ratting process is done mechanically using a fiber extraction machine. To remove impurities in the fiber, alkaline treatment was carried out, by soaking for 24 hours in a 5 % NaOH solution. To determine the characteristics, a scanning electron microscopy (SEM) test was carried out for MASF morphology analysis, chemical compound content testing, heat resistance testing, and fiber tensile strength testing. The results showed that the MASF of the outer layer pseudo-stem has a strong character. Fiber morphology is different, between the outer, middle and inner layers pseudo-stems. The cellulose content (73.12 %) was higher than the fiber of Fimbristylis globulosa, hemp, jute, rice straw, wheat straw, seaweed, sorghum straw, coir, and alpha grass. Less resistant to heat degradation because mass loss occurs at a constant rate up to 245 °C. The highest MASF, in the outer pseudo-stem layer it is 40–50 cm from the base stem. Its characteristics are better than other natural fibers so that its potential can be further developed as a reinforcement for polymer matrix composites

Keywords: Musa acuminata, stem fibre, pseudo-stem, layer stem, polyester matrix composite, reinforcement

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THE GREATNESS OF THE CHARACTERISTICS FIBER PSEUDO STEM OUTER LAYER OF MUSA ACUMINATA ORIGIN LOMBOK INDONESIA AS REINFORCING POLYESTER COMPOSITE

Sujita Sujita
Corresponding author
Doctor of Technical Sciences, Senior Lecturer*
E-mail: sujita@unram.ac.id
Nasmi Herlina Sari
Professor Tehnical Sciences, Senior Lecturer*
*Department of Mechanical Engineering
University of Mataram
Jalan Majapahit str., 62, Mataram, Nusa Tenggara Barat, Indonesia, 83125

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1. Introduction

Natural fiber-reinforced polyester matrix composite materials have received the attention of scientists and industry in recent years. Because natural fibers are cheap, low density, biodegradable, recyclable, non-toxic compared to synthetic fibers, fiberglass, kevlar, boron and nylon [1]. Study [2] showed that natural fiber-reinforced polyester matrix composites exhibit superior properties compared to conventional composites. Natural fibers commonly used as reinforcement for polyester matrix composites include: Fimbristylis globulosa, hemp, jute, rice straw, wheat straw, seaweed, shorgum straw, coir, and alpha grass fibers , cotton, flax, sanseviera fibers, and sisal [3]. These natural fibers are expensive to cultivate, have a long life, so they are less effective when used as reinforcing fibers for composite materials.

The using of Musa acuminata stem fiber (MASF) is more effective and beneficial. Because the stems of Musa acuminata are still considered as agricultural waste, their presence is very abundant, especially in North Lombok Regency, West Nusa Tenggara Province, Indonesia.

The mechanical properties of the polyester matrix composite material are influenced by the chemical content, tensile strength and heat resistance of the reinforcing fiber [4]. The occurrence of voids, fiber pull out, shrinkage due to heat, low strength is caused because there is no strong bond between the matrix and fiber. Therefore, for the purposes of MASF reinforcing fiber, it is necessary to test the physical and mechanical characteristics in the form of: chemical content testing, fiber morphology, heat resistance and fiber tensile strength. Actually the Musa acuminata stem is a biofiber, which contains lignin, hemicellulose and cellulose [5], whose characteristics must be known in order to be used as a reinforcing fiber for polyester matrix composites. The research has been carried out to determine its characteristics, so that it can be used as a composite polyester matrix reinforcement. Research to improve the mechanical properties of natural fiber reinforced polyester matrix composites, natural fiber hybrid synthetic fibers often fails, because the main molecules making up the fiber (cellulose, hemicellulose, lignin) have not yet been characterized for their physical and chemical properties. Therefore, research devoted to the development of this and that is relevant.

2. Literature review and problem statement

The paper [6] presents the results of research biofibers such as natural fibers from renewable resources to be used as reinforcement in polymer composite materials. Shown, that the adverse environmental impact has diverted attention from the use of synthetic fibers to natural fibers. Although polymer composite materials are reinforced with synthetic fibers such as glass, carbon and aramid, their stiffness and strength are higher than those of natural fibers.

Based on research [7], optimal properties were achieved at a fiber content of 40 % by weight with an increase in tensile and flexural strength of 36 % and 33 % for needle-punched banana fiber composites (NPBFC) compared to random banana fiber composites (RBFC). The reinforcing fiber was extracted from the pseudo-stem of the nendran banana plant. Then made a non-woven fabric composite consisting of banana fiber reinforced with an unsaturated polyester (UPE) matrix with a needle punching technique. The fiber is taken from the stem in general, the layer has not been justified, because the banana stem is layered.

In this work [8] banana fiber stem reinforced composite 20 % by weight fraction. Banana fiber is cut with the same average length of 10 and 20 mm. The variation of the weight fraction of the epoxy resin is 0, 5, 10, 15 and 20 %. The experimental results showed that the tensile, flexural and impact strengths of the bio-composite up to 15 % by weight were increased compared to the epoxy without banana fiber reinforcement.

Work [9] explored the thermal, mechanical, and degradation behavior of banana fiber reinforced polypropylene composites treated with alkali. Composites incorporating BF (20 % w) treated with aqueous solution of NaOH (5 % w) were developed using an extrusion injection molding process. After chemical treatment, the tensile, flexural and impact strengths of the composites increased by 3.8 %, 5.17 %, and 11.50 %, respectively. Electron microscopy (SEM) observations of the tested specimens confirmed fiber tensile and fiber fracture as the main reasons for the failure of the developed composites under tensile and impact loads.

The addition of 20 % volume fraction of MASF, can increase the impact toughness of 14.69 %. Based on the results of the SEM test the bond between fiber and matrix is very good, there are no voids. In addition, the addition of MASF can increase tensile strength, modulus of elasticity and wear resistance based on research results [10]. Although the use of MASF has been able to improve tensile strength, impact toughness, but it is not yet feasible for automotive bumper raw materials, flexibility and heat resistance are still low.

Based on the results of the study [6, 7], composite materials with natural fiber reinforcement such as bamboo, sisal, hemp, and banana have been applied in the automotive world as reinforcement for door panels, rear seats, dashboards, and other interior devices. Its use is only limited to parts of the structure that do not support the load directly.

Research [11] used woven banana stem and banana leaf midrib as reinforcement for composite materials with epoxy and polyester matrices. Fiber treatments in the form of alkali, water repellent on nonwovens and gamma radiation on composites were applied to investigate their effect on composite properties such as water absorption, tensile strength (TS), flexural strength (FS) and elongation at break (Eb %). Epoxy composites were found to have 16 % lower water absorption, 41.2 % higher TS and 39.1 % higher FS than the average polyester composites. The effect of the position of the fiber layer on the banana stem, the distance from the banana stem base(hump) has not been discussed.

It is shown that the use of natural fibers, especially banana tree fibers, can increase water absorption, tensile strength, flexural strength and elongation at break.

But there were unresolved issues related to defects (imperfect interfacial bonds between polyester and banana tree fibers) that occur during the manufacture of banana fiber reinforced polyester matrix composite materials. Defects that occur such as debonding, agglomeration (clumping of polyester), the appearance of gaps (Void)) will reduce the mechanical properties of the polyester composite material. The reason for this may be objective difficulties related to the shrinkage of the fibers by temperature degradation, the fundamental impossibility of the dimensions of the unit cells that make up the fiber; cellulose, hemicellulose, lignin, part of the expensive cost in terms of measuring the diameter of the unit cell making up the fiber which makes the relevant research impractical. A way to overcome these difficulties can be by alkali treatment of the banana fiber. This approach was used in [9], but because the main molecules that make up the fiber (cellulose, hemicellulose, lignin) have not been characterized for their physical and chemical properties. as a result, the interfacial bond between polyester and natural fibers is imperfect/defective. However, all this suggests that it is advisable to conduct a study on the characteristics fiber pseudo-stem layer of Musa acuminata origin Lombok Indonesia as reinforcing polyester composite

3. The aim and objectives of the study

The aim of the study is determine the physical and mechanical characteristics of Musa acuminata stem fiber (MASF) so that it can be used as a reinforcing fiber for polyester matrix composite materials.

To achieve this aim, the following objectives are accomplished

– to observe the morphology of Musa acuminata stem fiber;

– to determine the Musa acuminata stem fiber chemical content;

– to determine the heat resistance character of Musa acuminata stem fiber;

– to determine the tensile strength distribution of Musa acuminata stem fiber.

4. Materials and methods

The research method is an experimental method carried out at the Materials Engineering Laboratory, Department of Mechanical Engineering, University of Mataram. The object of this research is the pseudo stem-fiber of Musa acuminata. They comes from the plantation of North Lombok Regency, which is 13 months old. The fiber extraction process is schematically presented in Fig. 1.

The main hypothesis of this research is that the position of the layer and the distance from the hump (base stem) affect the physical and chemical characteristics of the Musa acuminata stem fiber (MASF).

The assumption made in this work is that the pseudo stem of Musa acuminata consists of three layers, namely the outer stem, middle stem and inner stem or can be called outer, middle and inner layers.

The simplification applied in the work of Musa acuminata (MASF) stem fiber used as a sample is the outer layer. To reduce the moisture content, the stems are pressed with a metal tube, then dried in the sun for about 15 days.

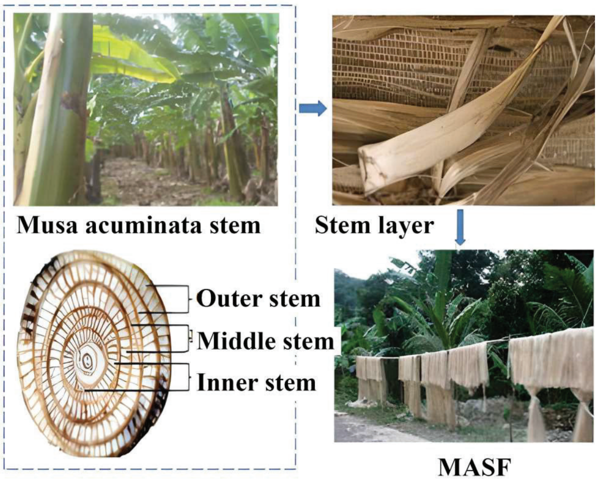

Fig. 1. Schematic diagram of Musa acuminata stem fiber (MASF) extraction process

Before testing, the specimens were alkali treatment, because the newly extracted MASF still contains various impurities such as fat, wax, pectin and so on. To remove these impurities, the MASF was immersed in 5 % NaOH solution, for 24 hours at room temperature. The fibers are rinsed with clean water and dried again after alkaline treatment.

The morphology microstructure of the MASF surface was investigated by with SEM-EDX (Cam Scan MV2300-Canada) equipped with energy dispersive X-ray (EDX), respectively. To remove internal moisture prior to testing, the samples were dried at 100 °C for 10 min to remove moisture inside before testing. The microscope eyepiece has a measurement scale in micron meters (1/1000 mm) and the total magnification of the microscope used is 400 x.

To observe the appearance of chemical content and chemical functional groups in MASF treated with alkali, Perkin Elmer Spectrum FTIR Spectrometer was used. This tool is used in the Materials Engineering laboratory, Department of Mechanical Engineering, University of Mataram Indonesia. FTIR spectra were investigated in the range of 4000–500 cm^{-1} (32 scans at 4 cm^{-1}).

The thermal resistance characteristics of MASF were studied by Thermogravimatric analysis (TGA) test. Specifications for TGA tool PT 1000, USA, with temperature range up to 1100. Thermogravimatric analysis is a thermo analytical technique, which measures changes in sample weight at a certain time and temperature, to determine the effect of temperature on Weight-Loss.

The mechanical properties, tensile strength of single MASF were obtained using Grafil Test Method 101.13 on an Instron 1026 universal testing machine (serial number H2709) with an Instron 2511-101 500 g load cell (serial number UK953, calibrated with 50 g weights) at a crosshead speed of 0.5 mm/min.

5. Results of the research on the characteristics of musa acuminata stem fiber

5. 1. Morphology of Musa acuminata stem fiber

The results of the SEM test of Musa acuminata banana stem fiber (MASF) are shown in Fig. 2. The morphology of the MASF is rough surface, hollow tip which is a characteristic of banana stem fiber. In the picture it is clear that the difference between the outer layer fibers (Fig. 2, *a*), the middle layer fibers (Fig. 2, *b*), the inner layer fibers (Fig. 2, *c*) pseudo-stem Musa acuminata. The increase in fiber surface area, rough surface and hollow structure is advantageous, if applied as a polyester composite reinforcement is very good, the surface is rough, the surface area is large, the presence of cavities causes a strong bond between polyester and MASF.

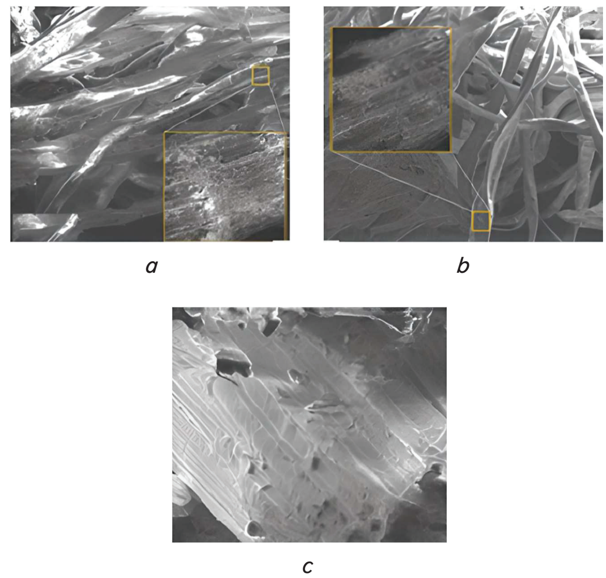

Fig. 2. Scanning elecrone microscopes micrograph of Musa acuminta stem fiber: *a* – outer pseudo stem; *b* – middle pseudo stem; *c* – inner pseudo stem of Musa a cuminata

The sample analyzed by SEM was the surface of three layers of pseudo stem of Musa acuminata, after alkaline treatment, and cleaned the surface with water. Micrograph descriptions of the SEM observations are presented in Fig. 2. The first micrograph Fig. 2, *a* shows the microscopic surface appearance of the pseudo-stem outer layer fibers. Micros copic description of the fiber surface of the middle layer of the pseudo stem of Musa acuminata, is presented in Fig. 2, *b*, *c*. shows the microscopic surface appearance of the pseudo-stem inner layer fibers.

5. 2. Musa acuminata stem fiber chemical content

From the results of chemical composition testing, it is known that MASF fiber contains 73.12 % cellulose, 20.6 % hemicellulose, 4.4 % lignin, 1.88 % extractive compounds/others and a moisture content of 7–8 %. When compared with the chemical content of other fibers, MASF fiber has a higher cellulose content than the Fimbristylis globulosa, hemp, jute, rice straw, wheat straw, seaweed, shorgum straw, coir, and alfa grass fibers but lower than the cotton, flax, sanseviera fibers, and sisal fiber as shown in Table 1.

It has a higher hemicellulose content than the Fimbristylis globulosa, cotton, flax, sanseviera fibers, hemp, sisal, and coir fibers but lower than the jute fiber, seaweed, and wheat straw fiber. It's higher lignin content than the the Fimbris tylis, cotton, flax, sanseviera fibers, but lower than the hemp, jute, rice straw, seaweed, sorghum stem, wheat straw, sisal, coir, and alfa grass fiber. The moisture content is higher than Fimbristylis globulosa, sanseviera, and wheat straw, but lower than the cotton, flax, hemp, rice straw, seaweed, sorghum stem, wheat straw, sisal, coir, and alfa grass fiber.

Table 1

The chemical composition of MASF and other natural fibers

Natural Fiber	Cellulose (%)	Hemi cellulose (%)	Lignin (%)	Others (%)	Moisture Content (%)	Reference
MASF	73.12	20.6	4.4	1.88	7–8	[10]
Fimbris tylis globulosa	72.14	20.2	3.44	4.2	4.2–5.2	[12]
Cotton	85–90	1–3	0.7–1.6	5.4–13.3	8–10	[13]
Flax	85	9	4	2	8.76–10	[13]
Sansevieria	79.7	10.13	3.8	0.09	6.02	[14]
Hemp	58.7	14.2	6	21.1	12	[14]
Jute	58–63	20–24	12–15	16.5	10.99	[14]
Rice straw	64	–	8	28	9.8	[13]
Sea weed	57	28	5	10	–	[14]
Sorghum stem	65.1	–	5.5	29.4	9.5	[15]
Wheat straw	38.8	39.5	17.1	4.6	5	[13]
Sisal	78	19	8	3	10.22	[12]
Coir	32–43	0.15–0.25	40–45	3–4	8	[13]
Alfa grass	33–38	–	17–19	33–40	10.2	[14]

5. 3. Heat resistance character of musa acuminata stem fiber

The heat resistance of the musa acuminata stem fiber (MASF) is determined by observing the decomposition process. Test results MASF decomposition is shown in Fig. 3. The decrease in mass was obtained from the thermogravimetric test (TGA). The TGA test was carried out with a sample weight of about 20 mg MASF, with an inert gas (Argon), at a heating rate of 10 °C/min.

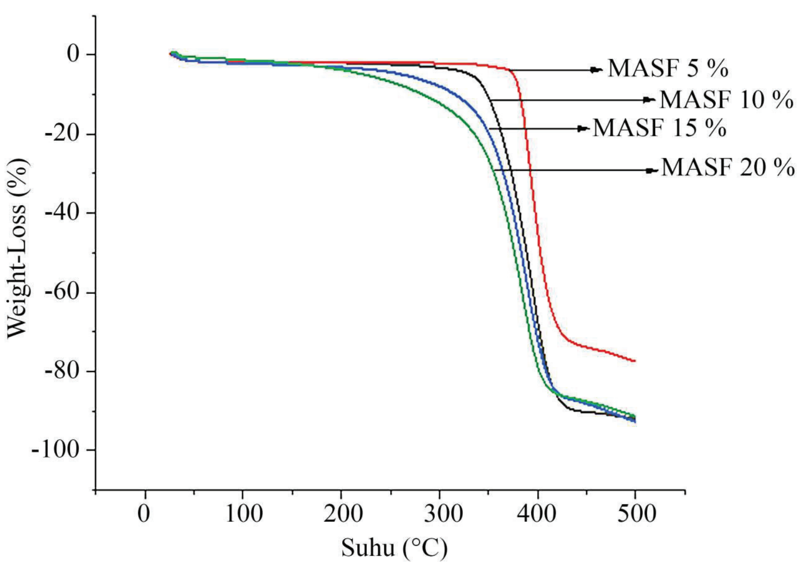

Fig. 3. Thermogravimetric (TGA) test results of Musa acuminata stem fiber and other natural fibers

In Fig. 3 it can be seen that the decomposition of the sample is a chemical reaction process that releases heat and shows the occurrence of thermal decomposition of the sample organic matter [7]. From the decomposition curve due to thermal degradation of the entire sample, there are 4 main steps associated with the degradation due to the decomposition reaction of MASF.

MASF is the most resistant to heat degradation, compared to other natural fibers such as Hibiscus Tiliaceust Bark Fiber (HTBF), Corn Fiber (CF) and coir. Heat resistance is indicated by the amount of weight lost that occurs. The lower the weight lost value, the better the heat resistance. Mass lost of MASF that occurs at a constant rate up to a temperature of 500 °C, about 71.87 %, Hibiscus Tiliaceust Bark Fiber (HTBF). 77.37 %, Corn Fiber (CF) 83.65 % and coir 87.24 %, based on research results [9]. Compared to other natural fibers, MASF's weight loss is the lowest.

5. 4. The tensile strength distribution of musa acuminata stem fiber

Physically the stem of Musa acuminata is round with a stem diameter of 15–20 cm and a height of up to 2.5 m. The tree in the form of pseudo-stems, with a layered pseudo-stem structure with a curved layer shape. To facilitate the characterization of the stem fiber of Musa acuminata, it was classified into three layers, namely the outer, middle and inner pseudo stem layers. The fiber samples tested for tensile were derived from the three layers of the pseudo-stem. To determine the distribution of the tensile strength of the MASF along the rod, a tensile test was carried out. The tensile test results are shown in Fig. 4.

In Fig. 4 it can be seen that the highest MASF tensile strength is 105.7 N, in the outer pseudo-stem layer, it's a distance of 40–50 cm from the base stem (hump) and the lowest tensile strength is 44.8 N, in the inner pseudo-stem layer it's a distance of 140–150 cm from the base stem.

The outer Musa fiber with a distance of 40–50 cm from the stem base is recommended as a reinforcement for polyester matrix composites, because it has the highest strength, water content, low shrinkage and better heat resistance than the middle and inner layers.

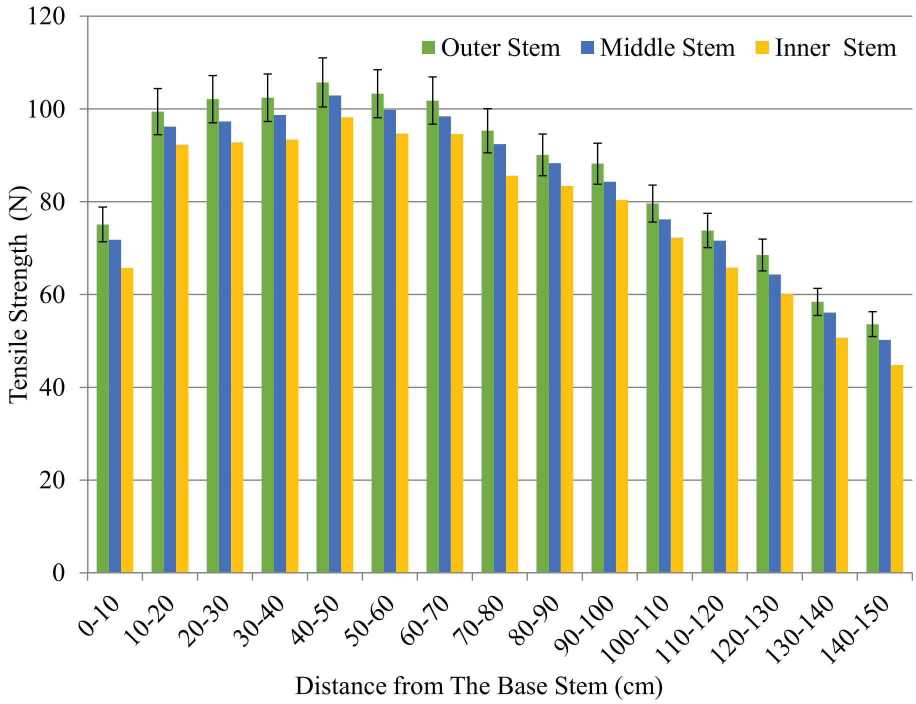

Fig. 4. The tensile strength distribution at Musa acuminata stem fiber

6. Discussion of the characteristics fiber pseudo stem outer layer of Musa acuminata origin Lombok Indonesia

The results of observations with SEM-EDX outer pseudo-stem fiber morphology, are shown in Fig. 2, *a*. the roughest surface, irregular fiber bundle orientation, presence of amorphous regions in the fiber, compared, pseudo-stem middle fiber morphology, is shown in Fig. 2, *b* and the pseudo-stem inner fiber morphology, shown in Fig. 2, *c*. However, this rough fiber surface provides the advantage of strong interlocking between the fibers, increasing the adhesion between the fibers and the matrix. From the micrograph presented in Fig. 2, *c*, indicates the smoothest surface, compared to the surface, outer and middle layers.

Based on the results of the chemical composition test using FTIR, which are shown in Table 1, MASF contains 73.12 % cellulose, 20.6 % hemicellulose, 4.4 % lignin, 1.88 % extractive/other compounds and 7–8 % water content. MASF has a higher cellulose content (73.12 %) than Fimbristylis globulosa fiber, hemp, jute, rice straw, wheat straw, seaweed, sorghum straw, coir, and alpha grass. The strength and stiffness of natural fibers are produced by the cellulose components through hydrogen bonds and other bonds [5]. In the structure of biofiber cellulose serves as a reinforcement, hemicellulose and lignin as a matrix. If MASF is applied as a reinforcement to polyester composites, the strength is higher if compared to other fibers such as: Fimbristylis globulosa fiber, hemp, jute, rice straw, wheat straw, seaweed, sorghum straw, coir, and alpha grass. Because the cellulose content in MASF is higher.

Fig. 3 shows stage I is early devolatilization, characterized by the presence of a first depression on the reduction rate curve. This stage is associated with the release of very light moisture and volatile compounds [9]. Devolatilization in the MASF occurs at a temperature of about 150 °C. Stage II is a transitional stage which is indicated by a relatively stable rate of mass decline which indicates the release of volatile compounds has begun to decrease and the fiber begins to degrade slowly. This stage occurs up to a temperature of 211 °C. In step III, the fiber decomposes rapidly and the decomposition of all biomass occurs at a temperature of 245 °C, then the fiber also decomposes completely to a temperature of 280 °C. Stage IV is a slow combustion reaction of the residue accompanied by a very slow decomposition which is characterized by a very small mass reduction rate and a relatively stable mass amount up to a temperature of 500 °C. It can be seen that MASF is resistant to heat degradation, due to weight lost that occurs at a constant rate up to a temperature of 500 °C, the lowest is about 71.87 %, compared to other natural fibers. Weight lost Hibiscus Tiliaceust Bark Fiber (HTBF) 77.37 %, Corn Fiber (CF) 83.65 % and coir 87.24 %, based on research results [9].

Based on Fig. 4, the tensile strength of the MASF, at a certain distance from the base of the stem (hump), as well as the fibers in the outer, middle, and inner layers of the pseudo stem of Musa acuminata are also different.

Taking into account the variation of the data, the Musa acuminata stems has a fairly homogeneous strength up to a length of 20–70 cm from the base stem with a coefficient of variation less than 5 %. At the distance from the base stem 0–10 cm and 70–150 cm, the tensile strength of the MASF has a variation that is too high (>20 %). From these results it can be used as a reference that to obtain homogeneous strength results, it is better if the length of the MASF used is up 20–70 cm from the base stem.

The limitation of this study is that it is difficult to measure the dimensions of the MASF unit cell. The individual cell dimensions of natural fibers in plants depend on the type of species, maturity and location of the fibers in the plant and the conditions of fiber extraction. The dimensions and orientation of the unit cells in the fiber determine the structure and also affect the mechanical properties of the fiber. To eliminate it, using a sample of fiber species, the same location and measuring the unit cell diameter with the Raman apparatus. The road map for further research activities that must be carried out in the future is research activities with the aim of knowing the relationship between the distance from the base of the stem and the tensile strength of the fiber, and the relationship between fiber orientation and the strength of the polyester composite matrix and making mathematical simulations.

7. Conclusions

1. The morphology of Musa acuminata stem fiber (MASF) in the outer layer of pseudo stem is the more rough surface, hollow structure, wide fiber surface, compared to the middle and inner of them. The surface of the rough fiber, the hollow shape, when used as a polyester reinforcement, will form a strong interfacial bond.

2. MASF fiber contains about cellulose (73.12 %), hemicellulose 20.6 %, lignin 4.4 %, extractive compounds 1.88 % and water content 7–8 %. MASF has a higher cellulose content than Fimbristylis globulosa fiber, hemp, jute, rice straw, wheat straw, seaweed, sorghum straw, coir, and alpha grass. The cellulose content in the fiber is very important, it plays a role in increasing the strength of the polyester composite material.

3. MASF is resistant to heat degradation, as weight loss occurs at a constant rate up to a temperature of 500 °C, as low as 71.87 %, compared to other natural fibers. If used as a reinforcement, it will prevent deformation of the polyester composite.

4. The highest MASF tensile strength is 105.7 N, in the outer pseudo-stem layer it is 40–50 cm from the base stem and the lowest tensile strength is 44.8 N, in the inner pseudo-stem layer it is 140–150 cm from the base stem.

Conflict of interest

The authors declare that they have no conflict of interest in relation to this research, whether financial, personal, authorship or otherwise, that could affect the research and its results presented in this paper.

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References

1. Aditya, P., Kishore, K., Prasad, D. (2017). Characterization of Natural Fiber Reinforced Composites. International Journal of Engineering and Applied Sciences (IJEAS), 4 (6), 26–32. Available at: https://www.ijeas.org/download_data/IJEAS0406011.pdf
2. Gudayu, A. D., Steuernagel, L., Meiners, D., Gideon, R. (2021). Characterization of the dynamic mechanical properties of sisal fiber reinforced PET composites; Effect of fiber loading and fiber surface modification. Polymers and Polymer Composites, 29 (9_suppl), S719–S728. doi: https://doi.org/10.1177/09673911211023032
3. Malviya, R. K., Singh, R. K., Purohit, R., Sinha, R. (2020). Natural fibre reinforced composite materials: Environmentally better life cycle assessment – A case study. Materials Today: Proceedings, 26, 3157–3160. doi: https://doi.org/10.1016/j.matpr.2020.02.651
4. Summerscales, J., Virk, A. S., Hall, W. (2020). Fibre area correction factors (FACF) for the extended rules-of-mixtures for natural fibre reinforced composites. Materials Today: Proceedings, 31, S318–S320. doi: https://doi.org/10.1016/j.matpr.2020.01.552
5. Mohanty, A. K., Misra, M., Hinrichsen, G. (2000). Biofibres, Biodegradable Polymers And Biocomposites: An overview. Macromolecular Materials and Engineering, 276-277 (1), 1–14. doi: https://doi.org/10.1002/(sici)1439-2054(20000301)276:1<1::aid-mame1>3.0.co;2-w
6. Li, M., Pu, Y., Thomas, V. M., Yoo, C. G., Ozcan, S., Deng, Y. et. al. (2020). Recent advancements of plant-based natural fiber–reinforced composites and their applications. Composites Part B: Engineering, 200, 108254. doi: https://doi.org/10.1016/j.compositesb.2020.108254
7. Kenned, J. J., Sankaranarayanasamy, K., Binoj, J. S., Chelliah, S. K. (2020). Thermo-mechanical and morphological characterization of needle punched non-woven banana fiber reinforced polymer composites. Composites Science and Technology, 185, 107890. doi: https://doi.org/10.1016/j.compscitech.2019.107890
8. Balaji, A., Purushothaman, R., Udhayasankar, R., Vijayaraj, S., Karthikeyan, B. (2020). Study on Mechanical, Thermal and Morphological Properties of Banana Fiber-Reinforced Epoxy Composites. Journal of Bio- and Tribo-Corrosion, 6 (2). doi: https://doi.org/10.1007/s40735-020-00357-8
9. Komal, U. K., Verma, V., Ashwani, T., Verma, N., Singh, I. (2018). Effect of Chemical Treatment on Thermal, Mechanical and Degradation Behavior of Banana Fiber Reinforced Polymer Composites. Journal of Natural Fibers, 17 (7), 1026–1038. doi: https://doi.org/10.1080/15440478.2018.1550461
10. Darmo, S., Sutanto, R. (2021). Characteristics Of Musa Acuminata Stem Fibers Reinforced Polyester Matrix Composite Fiberglass. Int. J. Res. Eng. Sci., 9 (2), 21–27.
11. Motaleb, K. Z. M. A., Ahad, A., Laureckiene, G., Milasius, R. (2021). Innovative Banana Fiber Nonwoven Reinforced Polymer Composites: Pre- and Post-Treatment Effects on Physical and Mechanical Properties. Polymers, 13 (21), 3744. doi: https://doi.org/10.3390/polym13213744
12. Suryanto, H., Solichin, S., Yanuhar, U. (2016). Natural Cellulose Fiber from Mendong Grass (Fimbristylis globulosa). Fiber Plants, 35–52. doi: https://doi.org/10.1007/978-3-319-44570-0_3
13. Leppänen, K., Andersson, S., Torkkeli, M., Knaapila, M., Kotelnikova, N., Serimaa, R. (2009). Structure of cellulose and microcrystalline cellulose from various wood species, cotton and flax studied by X-ray scattering. Cellulose, 16 (6), 999–1015. doi: https://doi.org/10.1007/s10570-009-9298-9
14. Beckermann, G. W., Pickering, K. L. (2009). Engineering and evaluation of hemp fibre reinforced polypropylene composites: Micro-mechanics and strength prediction modelling. Composites Part A: Applied Science and Manufacturing, 40 (2), 210–217. doi: https://doi.org/10.1016/j.compositesa.2008.11.005
15. Davies, P., Morvan, C., Sire, O., Baley, C. (2007). Structure and properties of fibres from sea-grass (Zostera marina). Journal of Materials Science, 42 (13), 4850–4857. doi: https://doi.org/10.1007/s10853-006-0546-1