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Musa acuminata stem is an agricultural waste that has UDC 621 good economic potential. For this reason, efforts are need- DOI: 10.15587/1729-4061.2022.261921 ed 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 THE GREATNESS OF of this study was to determine the characteristics of Musa acuminata stem fibre (MASF) from North Lombok Regency, THE CHARACTERISTICS Indonesia Country as a reinforcement for polyester matrix composites. In this study, the fiber (specimen), taken from FIBER PSEUDO STEM pseudo stem Musa acuminata, which consists of three lay- ers: outer, middle and inner stem. The ratting process is done mechanically using a fiber extraction machine. To remove OUTER LAYER

OF MUSA impurities in the fiber, alkaline treatment was carried out, by soaking for 24 hours in a 5 % NaOH solution. To deter- ACUMINATA ORIGIN mine the characteristics, a scanning electron microscopy (SEM) test was carried out for MASF morphology analysis, LOMBOK INDONESIA chemical compound content testing, heat resistance testing, and fiber tensile strength testing. The results showed that the AS REINFORCING 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 %) POLYESTER COMPOSITE was higher than the fiber of Fimbristylis globulosa, hemp, S u j i t a S u j i t a jute, rice straw, wheat straw, seaweed, sorghum straw, coir, Corresponding author and alpha grass. Less resistant to heat degradation because Doctor of Technical Sciences, Senior Lecturer* 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 E-mail: sujita@unram.ac.id base stem. Its characteristics are better than other natural N a s m i H e r l i n a S a r i fibers so that its potential can be further developed as a rein- Professor Tehnical Sciences, Senior Lecturer* forcement for polymer matrix composites *Department of Mechanical Engineering Keywords: Musa acuminata, stem fibre, pseudo-stem, University of Mataram layer stem, polyester matrix composite, reinforcement Jalan Majapahit str., 62, Mataram, Nusa Tenggara Barat, Indonesia, 83125 Received date 01.07.2022 How to Cite: Sujita, S., Sari, N. H. (2022). The greatness of the characteristics fiber pseudo stem outer layer of Musa acum- Accepted date 21.08.2022 inata origin Lombok Indonesia as reinforcing polyester composite. Eastern-European Journal of Enterprise Technologies, Published date 26.08.2022 1. Introduction Natural fiber-reinforced polyester matrix composite ma- terials 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 com- posites exhibit superior properties compared to conventional composites. Natural fibers commonly used as reinforcement for polyester matrix composites include: Fimbristylis globu- losa, 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 acumina- ta 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 com- posite material are influenced by the chemical content, ten- sile strength and heat resistance of the reinforcing fiber [4]. The occurrence of voids, fiber pull out, shrinkage due to 4 (12 (118)), 38–43. doi: https://doi.org/10.15587/1729-4061.2022.261921 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 phys- ical 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 bio- fiber, 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 re- search has been carried out to determine its characteristics, so that it can be used as a composite polyester matrix rein- forcement. 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 nee- dle-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 av- erage length of 10 and 20 mm. The variation of the weight frac- tion 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 com- pared to the epoxy without banana fiber reinforcement. Work [9] explored the thermal, mechanical, and degra- dation 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 pro- cess. After chemical treatment, the tensile, flexural and im- pact strengths of the composites increased by 3.8 %, 5.17 %, and 11.50 %, respectively. Electron microscopy (SEM) ob- servations 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 in- crease 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 mate- rials 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 radia- tion 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 (im- perfect 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 Indo- nesia 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 fi- ber (MASF) so that it can be used as a reinforcing fiber for polyester matrix composite materials. To achieve this aim, the following objectives are accom- plished – 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 sche- matically 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 acumi- nata (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-Can- ada) equipped with energy dispersive X-ray (EDX), respec- tively. 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 mea- surement 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 laborato- ry, 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. Specifi- cations for TGA tool PT 1000, USA, with temperature range up to 1100. Thermogravimatric analysis is a thermo analyt- ical 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 cross- head 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 ba- nana stem fiber (MASF) are shown in Fig. 2. The mor- phology 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 fi- bers (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 com- posite 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. a b c 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 sur- face appearance of the pseudo-stem outer layer fibers. Mi- cros 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/ot- hers 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 Fimbristy- lis 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 low- er 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 MASF is the most resistant to heat degradation, com- stem fiber pared to other natural fibers such as Hibiscus Tiliaceust The heat resistance of the musa acuminata stem fi- Bark Fiber (HTBF), Corn Fiber (CF) and coir. Heat ber (MASF) is determined by observing the decomposi- resistance is indicated by the amount of weight lost that tion process. Test results MASF decomposition is shown occurs. The lower the weight lost value, the better the heat in Fig. 3. The decrease in mass was obtained from the ther- resistance. Mass lost of MASF that occurs at a constant mogravimetric test (TGA). The TGA test was carried out rate up to a temperature of 500 °C, about 71.87 %, Hibiscus with a sample weight of about 20 mg MASF, with an inert Tiliaceust Bark Fiber (HTBF). 77.37 %, Corn Fiber (CF) gas (Argon), at a heating rate of 10 °C/min. 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 facil- itate 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 distri- bution 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 Fig. 3. Thermogravimetric (TGA) test results of Musa acuminata stem fiber outer pseudo-stem layer, it's a distance of and other natural fibers 40–50 cm from the base stem (hump) and the lowest tensile strength is 44.8 N, in the In Fig. 3 it can be seen that the decomposition of the inner pseudo- stem layer it's a distance of 140–150 cm from sample is a chemical reaction process that releases heat the base stem. and shows the occurrence of thermal decomposition of the The outer Musa fiber with a distance of 40–50 cm sample organic matter [7]. From the decomposition curve from the stem base is recommended as a reinforcement for due to thermal degradation of the entire sample, there are polyester matrix composites, because it has the highest 4 main steps associated with the degradation due to the strength, water content, low shrinkage and better heat decomposition reaction of MASF. resistance than the middle and inner layers. 120 Outer Stem Middle Stem Inner Stem degrade slowly. This stage occurs up to a temperature of 211 °C. In step III, the fiber decompos- 100 es rapidly and the decomposition of all biomass occurs at a tem- perature of 245 °C, then the fiber T ensile Strength (N) 80 also decomposes completely to a temperature of 280 °C. Stage IV is a slow combustion reaction of 60 the residue accompanied by a very slow decomposition which is char- acterized by a very small mass re- 40 duction rate and a relatively stable mass amount up to a temperature of 500 °C. It can be seen that 20 MASF is resistant to heat degra- dation, due to weight lost that oc- curs at a constant rate up to a tem- perature of 500 °C, the lowest is 0 about 71.87 %, compared to other natural fibers. Weight lost Hibis- cus Tiliaceust Bark Fiber (HTBF) Distance from The Base Stem (cm) 77.37 %, Corn Fiber (CF) 83.65 % and coir 87.24 %, based on re- Fig. 4. The tensile strength distribution at Musa acuminata stem fiber search results [9]. Based on Fig. 4, the tensile strength of the MASF, at a cer- 6. Discussion of the characteristics fiber pseudo stem tain distance from the base of the stem (hump), as well as outer layer of Musa acuminata origin Lombok Indonesia the fibers in the outer, middle, and inner layers of the pseudo stem of Musa acuminata are also different. The results of observations with SEM-EDX outer pseu- Taking into account the variation of the data, the Musa do-stem fiber morphology, are shown in Fig. 2, a. the rough- acuminata stems has a fairly homogeneous strength up to a est surface, irregular fiber bundle orientation, presence of length of 20–70 cm from the base stem with a coefficient of amorphous regions in the fiber, compared, pseudo-stem variation less than 5 %. At the distance from the base stem middle fiber morphology, is shown in Fig. 2, b and the pseu- 0–10 cm and 70–150 cm, the tensile strength of the MASF do-stem inner fiber morphology, shown in Fig. 2, c. However, has a variation that is too high (>20 %). From these results this rough fiber surface provides the advantage of strong it can be used as a reference that to obtain homogeneous interlocking between the fibers, increasing the adhesion strength results, it is better if the length of the MASF used between the fibers and the matrix. From the micrograph is up 20–70 cm from the base stem. presented in Fig. 2, c, indicates the smoothest surface, com- The limitation of this study is that it is difficult to measure pared to the surface, outer and middle layers. the dimensions of the MASF unit cell. The individual cell Based on the results of the chemical composition test using dimensions of natural fibers in plants depend on the type of FTIR, which are shown in Table 1, MASF contains 73.12 % species, maturity and location of the fibers in the plant and the cellulose, 20.6 % hemicellulose, 4.4 % lignin, 1.88 % extractive/ conditions of fiber extraction. The dimensions and orientation other compounds and 7–8 % water content. MASF has a higher of the unit cells in the fiber determine the structure and also cellulose content (73.12 %) than Fimbristylis globulosa fiber, affect the mechanical properties of the fiber. To eliminate it, hemp, jute, rice straw, wheat straw, seaweed, sorghum straw, using a sample of fiber species, the same location and mea- coir, and alpha grass. The strength and stiffness of natural fibers suring the unit cell diameter with the Raman apparatus. The are produced by the cellulose components through hydrogen road map for further research activities that must be carried bonds and other bonds [5]. In the structure of biofiber cellulose out in the future is research activities with the aim of knowing serves as a reinforcement, hemicellulose and lignin as a matrix. the relationship between the distance from the base of the If MASF is applied as a reinforcement to polyester composites, stem and the tensile strength of the fiber, and the relationship the strength is higher if compared to other fibers such as: Fim- between fiber orientation and the strength of the polyester bristylis globulosa fiber, hemp, jute, rice straw, wheat straw, composite matrix and making mathematical simulations. seaweed, sorghum straw, coir, and alpha grass. Because the cellulose content in MASF is higher. Fig. 3 shows stage I is early devolatilization, characterized 7. Conclusions by the presence of a first depression on the reduction rate curve. This stage is associated with the release of very light 1. The morphology of Musa acuminata stem fiber moisture and volatile compounds [9]. Devolatilization in the (MASF) in the outer layer of pseudo stem is the more rough MASF occurs at a temperature of about 150 °C. Stage II is surface, hollow structure, wide fiber surface, compared to a transitional stage which is indicated by a relatively stable the middle and inner of them. The surface of the rough fiber, rate of mass decline which indicates the release of volatile the hollow shape, when used as a polyester reinforcement, compounds has begun to decrease and the fiber begins to will form a strong interfacial bond. 2. MASF fiber contains about cellulose (73.12 %), hemicel- lulose 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 cel- lulose 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 oc- curs 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 reinforce- ment, 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 pseu- do-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, au- thorship or otherwise, that could affect the research and its results presented in this paper. Acknowledgments The authors thank Prof. Rudy Soenoko, Prof. Wahyono Suprapto are acknowledged for invaluable endless collabora- tions. Prof. I.G.N Wardhana Director Postgraduated Doc- tor Mechanical Engineering Program Brawijaya University permission to use of laboratory and other resource materials References 1. Aditya, P., Kishore, K., Prasad, D. (2017). Characterization of Natural Fiber Reinforced Composites. International

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