International Journal of Engineering Trends and Technology
ISSN: 2231–5381 / https://doi.org/10.14445/22315381/IJETT-V72I11P107

Volume 72 Issue 11, 55-60, November 2024

Original Article

The Development of Laminate Composites Reinforced Hybrid Fiber Musa Acuminata Stem and Bamboo as Flooring Parquete

Sujita Sujita[1], Nasmi Herlina Sari[2], Ahmad Zainuri[3]

[1,2,3]*Department of Mechanical Engineering, University of Mataram, Indonesia.*

[1]*Corresponding Author : sujita@unram.ac.id*

Received: 12 September 2024 Revised: 08 November 2024 Accepted: 14 November 2024 Published: 29 November 2024

Abstract - *The disadvantages of natural fiber reinforced laminate composite materials are reviewed from their mechanical properties (impact toughness, flexibility), so they do not meet the requirements to be applied as raw materials for parquet flooring. Parquet flooring made of Stone Plastic Composite (SPC) and wood plastic composite (WPC) also have limitations. Namely, they contain heavy metals, have low absorption capacity, and are not heat resistant, so they are not suitable for outdoor use, are easy to peel, and are not environmentally friendly. The characterization of polyester composites reinforced with hybrid fibers of Musa Acuminata Stem Fiber (MASF)-Bamboo fiber (BF) with a Polyurethane Resin (PR) matrix has been carried out. The variations of bamboo types used are apus bamboo (BA) (Gigantochloa apus) and wulung bamboo (BW) (Gigantochloa atroviolacea). This study aims to develop the impact toughness and flexibility of laminate composites. The MASF and BF volume fraction variations were: 5%: 25%, 10%: 20% and 15%: 15%. The results showed that the use of BA bamboo fiber in laminate composite materials reinforced with MASF-BF hybrid fibers with PR had better mechanical properties (impact toughness and flexibility) compared to using wulung bamboo fiber, so it is important to be further developed as a material for making parquet flooring.*

Keywords - *Laminate composite, Musa Acuminata Stem Fiber, Bamboo Fiber, Polyurethane Resin, Impact toughness, Flexibility.*

1. Introduction

Scientists have begun to pay attention to studying natural fibers, or biofibers, as reinforcements for laminated composite materials. According to N. M. Nurazzi et al. [1], natural fibers are less expensive, have a lower density, and are recyclable, biodegradable, and non-toxic than synthetic fibers like nylon, fiberglass, kevlar, and boron. As demonstrated by the findings of the studies by M. Vishwas et al. [2] and W. H. John Summerscales et al. [3], laminate composites reinforced with natural fiber have better impact energy absorption qualities than laminate composites reinforced with synthetic fiber. Parquet flooring (parquet flooring), classic flooring, is now back in vogue and marks a revival for the flooring industry. Parquet flooring originated in France in the late 17th century and quickly became a symbol of luxury and elegance. However, parquet flooring made of Stone Plastic Composite (SPC) and wood plastic composite (WPC) has limitations contains heavy metals, has low absorption capacity, is not heat resistant, so it is not suitable for outdoor use, is easy to peel and is not environmentally friendly. The new breakthrough in parquet flooring is made of natural fiber reinforced laminate composite material, which is more environmentally friendly than SPC and WPC. The disadvantages of natural fiber reinforced laminate composite material are its low impact toughness, flexibility, and heat resistance, so it does not yet meet the requirements to be applied as a raw material for parquet flooring (parquet flooring). Research has been conducted on the characterization of natural fibers (banana and bamboo fibers) as laminate composite reinforcements so that they can be applied as materials for parquet flooring. M. D. Y. Milani et al. [4] have shown that the microstructure, morphology and thermal behavior of banana fibers differ for each type of banana plant variety. The study by R. A. S. João et al. [5] that Ambun bananas (Cavendish AAA), Ambul (Mysore AAB), Kolikuttu (Silk AAB), Seenikesel (Awak Banana ABB), Alukesel (ABB) which are banana varieties in Sri Lanka investigated by XRD, FTIR, SEM and Differential Scanning Calorymetry (DSC) testing. Lignin content affects the bond strength between natural fibers and the matrix. Plasma treatment using air or oxygen effectively removes the lignin layer on natural fibers. The ratio of FTIR signals associated with lignin (1508 cm^{-1}) and cellulose (1317 cm^{-1}) decreased 10-fold for fibers treated with air plasma and 20-fold for samples treated with oxygen plasma so that the tensile strength increased by 300% and the elastic modulus increased by 20-fold.

Research on the effect of banana tree fibers and matrix types on tensile strength, flexural strength, water absorption and strain at fracture has been carried out by K. Z. M. A. Motaleb et al. [6]. Variations of banana tree fibers used, outer middle and inner fibers. Variations of matrices used, such as epoxy and polyester. To determine the differences in morphological structure and chemical composition, testing was carried out with FTIR and (SEM). The study results of composites reinforced with outer banana tree fibers showed that the tensile strength, flexural strength, and water absorption were higher than composite materials reinforced with other banana tree fibers. However, the strain at fracture was the lowest. Furthermore, investigations into the characteristics of bamboo laminate composite structures began by G. B. Veeresh Kumar et al.[7]. In his research activities, bamboo fibers were woven for bamboo laminate composites. A roller was used to smooth the resin on the surface for uniform pressure. In conclusion, the bamboo laminate composite has better flexural, tensile and compressive strength than other natural fiber reinforced composites such as ramie, linen, and kenaf.

Research interest in polymer composites has increased due to bamboo fiber's outstanding qualities. N. Santhosh et al. [8] have investigated polyester composites' morphological, dynamic, and static properties reinforced with bamboo fiber. Therefore, adding more bamboo fiber to the specimen's weight enhances its flexural, tensile, impact, and damping properties. According to microstructural analysis, bamboo fibers were uniformly distributed throughout the resin, and morphological analyses of fractured specimens revealed that matrix cracks, rather than bamboo fiber bonding, were mainly to blame. N. Mohd Yusof et al. have studied the shear stress performance of bamboo laminate composites [9]. Bamboo species, adhesive type and lamination configuration, influence the shear stress performance of bamboo laminate composites. Semantan bamboo (Gigantochloa scortechinii) and Beting bamboo (Gigantochloa levis) bamboo species from Malaysia were bonded with PRF and PUR adhesives and various layup pattern configurations and strip arrangements. The study showed that PRF binder had superior shear performance compared to PUR, but PUR bonding had better bonding strength and a low delamination composite.

Research to improve the impact toughness and flexibility of laminate composites reinforced natural fiber has not been successful. Impact toughness and flexibility are still below parquet flooring made of Wood Plastic Composite (WPC). Likewise, shrinkage due to heat is also greater. The main molecules that make up the fiber (cellulose, hemicellulose, lignin) have not been able to form interfacial bonds with polyester. As a result, the interfacial bonds formed are imperfect/defective. Defects that arise include debonding, agglomeration (polyester clumping), and the appearance of voids that affect the mechanical properties of laminate composites with polyester matrices. Therefore, research on developing laminate composite materials reinforced with hybrid fibers MASF-BF and PR matrices is very important.

2. Materials and Methods

The type of bamboo (various fiber diameters), the type of matrix or adhesive, the volume proportion of the matrix, and the reinforcing fiber are all independent variables in the fully randomized research design. Mechanical characteristics (flexural strength and impact toughness) are dependent factors. Specimens for flexural strength testing in accordance with ASTM D790 standards and impact tests in accordance with ASTM A370 standards.

Bamboo (apus, wulung) and the stems of Musa acuminata were used as research materials. Emanating from North Lombok Regency's Pemenang District. The matrix used is polyurethane resin (PR) and supporting materials to make laminated composites. The leading research equipment is impact test equipment, flexibility test equipment, and an optical microscope. Scanning Electron Microscope (SEM-EDAX, supporting mold making and composite specimens in the laboratory.into headed subsections if several methods are described.

MASF's physical characteristics include a relatively high tensile strength (ranging from 200 to 400 MPa) and lightweight (density ranges from 1.3 to 1.5 g/cm³). The physical characteristics of bamboo vary depending on the variety, fiber extraction technique, and processing circumstances. Its density typically ranges from 0.6 to 1.1 g/cm³, and its tensile strength ranges from 140 to 800 MPa. The MASF and BM fibers' tensile strength ratings suggest they could be used as reinforcing materials in composite materials or other structural applications. MASF and BM bamboo fibers were treated with alkali by soaking them in 5% NaOH solution for 6 h at room temperature. Then, the fibers were removed from the solution and washed with water, repeated 3-4 times to remove the remaining solution on the fiber surface.

(a) (b) (c)

Fig. 1 Fiber reinforced laminate composites. (a) Bamboo apus fibere, (b) Bamboo wulung fiber, (c) Musa acuminate stem fiber

The washed fibers were dried in an oven at 80 ◦C for 8 h to reduce the water content and then stored in a desiccator (ZKF040, Shanghai Experimental Instrument Factory Co., Ltd., Shanghai, China) in sealed polyethylene bags. The laminated composites consist of 3 layers (MASF, matrix, BF) with a fiber width of 2 cm each. The manufacturing technique uses the hand layup method. Preparing the raw materials, cleaning them, treating and impregnating them, pressing, curing, and finishing are the steps in creating composite laminate specimens. A press tool is used to apply pressure between 1 and 5 MPa. Curing takes place for 24 hours at room temperature. The resulting laminated composite is a plate with dimensions of 0.5 m x 0.5 m and a thickness of 1.5 cm. Then, the impact test specimen was cut according to the ASTM A370 standard, and the flexural strength test was conducted according to the ASTM D790 standard, as shown in Figure 2.

3. Results and Discussion

3.1. Impact Toughness of Laminate Composites Reinforced Hybrid Fiber Musa Acuminata Stem Fiber -Bamboo Fiber with Polyurethane Resin Matrix

An impact test was conducted to determine the absorbed energy (impact energy) and impact toughness of MASF-BF hybrid fiber laminate composite material. Variations of bamboo fiber: apus bamboo (BA), wulung bamboo (BW) with the Matrix used: polyurethane resin (PR), and MEXP catalyst. The impact test results are shown in Figure. 3. Impact energy is the energy the specimen absorbs when subjected to shock/impact load. The greater the energy absorbed, the higher the impact toughness and ductility. The highest impact energy is 18.444 J, the highest impact toughness value in the specimen is 0.106 Joule/mm^2 with the addition of 15% MASF banana fiber volume fraction, 15% BA apus bamboo fiber and PF matrix. On the other hand, the lowest impact energy is 7.482 J, and the lowest impact toughness is 0.043 Joule/mm^2 with the addition of 5% MASF banana fiber volume fraction, 25% BW apus bamboo fiber and PF matrix.The physical properties of apus bamboo are more ductile than those of wulung bamboo, which causes the impact energy and impact toughness of the laminated composite to be higher. According to the research results of M. Bahrami et al. [10], the bond between the matrix and the fiber is not good, so when the composite is given tensile stress, the matrix cracks and the fiber is released from the matrix (fiber pull out or debonding), this also makes the tensile strength value low while the strain value is large so that the impact energy is also large. In previous research, S. Darmo et al. [11] the addition of MASF15% volume fraction and 10% CTBN filler only increased the impact energy by 9.135 J.

Fig. 2 Laminate composites reinforced hybrid fiber musa acuminata stem fiber (MASF)-bamboo fiber (BF) with a polyurethane resin (PR) matrix

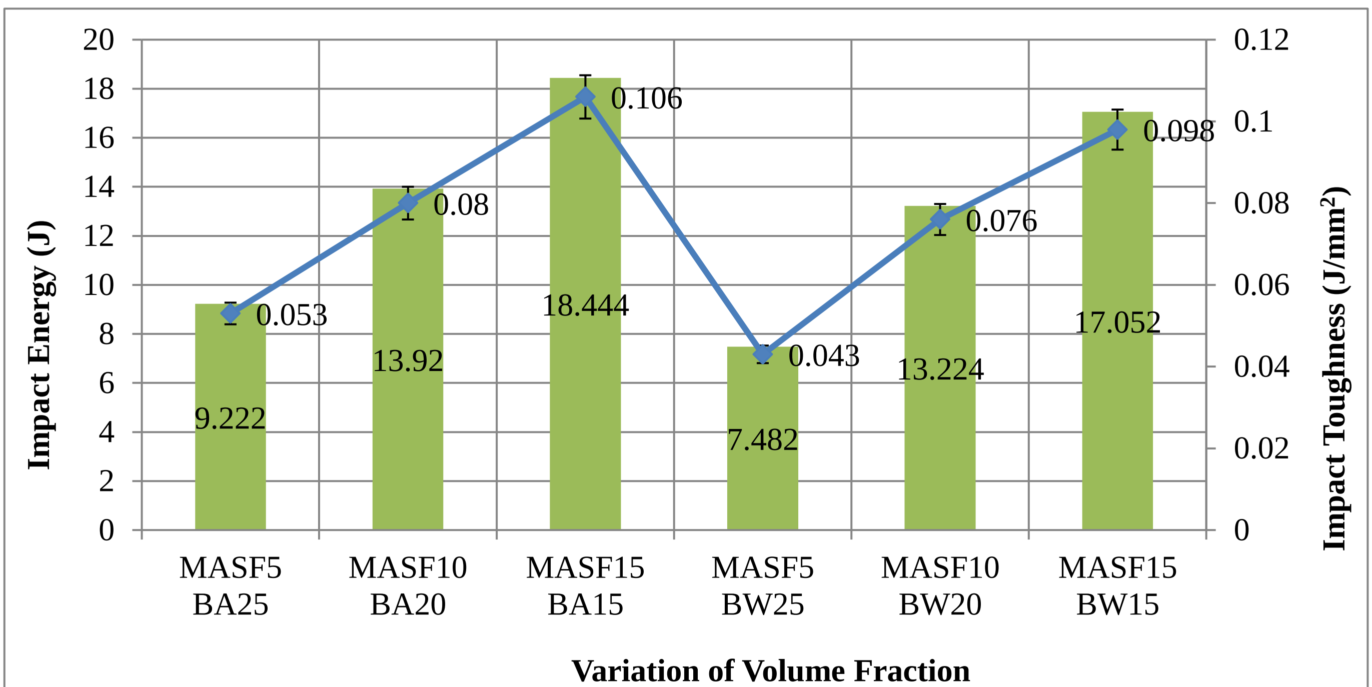

Fig. 3 Impact energy, impact toughness of specimen laminate composites

Specimens with MASF-BA hybrid fibers and PF matrices tend to increase higher impact toughness compared to specimens with MASF-BW. The mechanical properties of BW bamboo are stiffer than BA bamboo, as seen in Figure 3. Furthermore, the increase in impact toughness is proportional to the increase in impact energy, as shown in Figure 3.

The increase in impact toughness is caused by an increase in ductility due to the bond between the PR matrix and BA, followed by the bond between MASF and PR. The physical properties of the PR matrix that binds the MASF-BA hybrid fibers impact the increase in impact toughness.

This is in accordance with the research results of W. Chonkaew et al. [12], which concluded that the addition of Carboxyl-Terminated Butadiene-Acrylonitrile rubber (CTBN) increases the impact strength and wear resistance of epoxy composites with organoclay fillers. The CTBN variations used were 2.5 and 15 phr (parts per hundred). CTBN is a telechelic copolymer containing polar nitrile groups (–CN) in its main chain. The nitrile group has a strong chemical bond with PR and epoxy resin, so liquid CTBN is compatible with both and can be evenly dispersed in PR.

3.2. Flexural Strength of Laminate Composites Reinforced Hybrid Fiber Musa Acuminata Stem Fiber -Bamboo Fiber with Polyurethane Resin Matrix

The dimensions of the flexural strength test specimens are in accordance with the ASTM D790 standard. The results of the flexural strength test show that adding MASF volume fraction affects the flexural strength of laminate composite material reinforced hybrid fiber MASF-BF with variations in bamboo types (BA, BW) and PR matrix, as shown in Figure 4. The highest flexural load value on the specimen is 61 KN, which occurs in the specimen by adding 5% MASF volume fraction, 25% BW and PR matrix. On the other hand, the lowest flexural load is 41 KN, in addition to a 15% SPS volume fraction of 15% BA. The greater the flexural load, the lower the flexibility and the lower the flexural load, the greater the flexibility. Figure 4 shows that the MASF15 BA15 specimen with the PR matrix has the highest flexibility, and the specimen with the lowest flexibility is the MASF5 BW5 with the PR matrix. Based on the two-way analysis of variance, shown in Table 1, F count > F critical, meaning that there is a very significant influence (with an error of 5%) between the type of bamboo, the volume fraction of bamboo on toughness and energy impact.

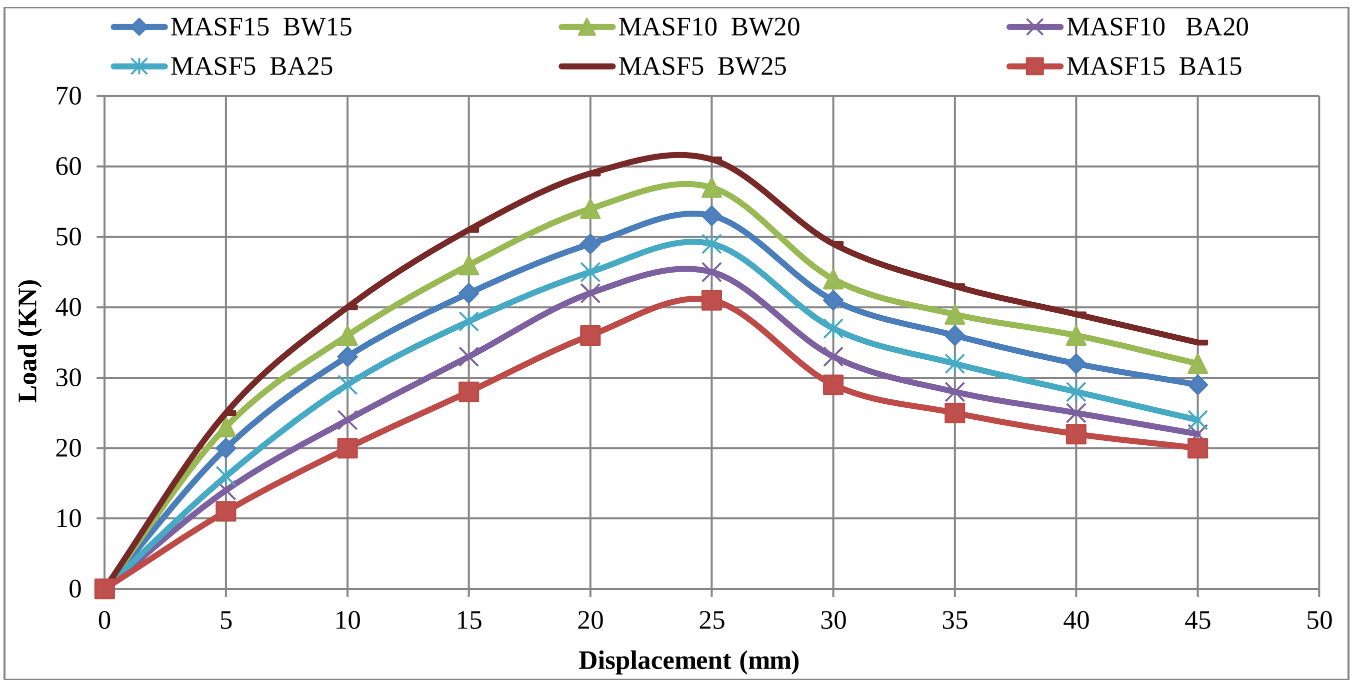

Fig. 4 Flexural strength of specimen laminate composite

Table 1. Analysis of variance

Source of Variation	*SS*	*df*	*F*	*P-value*	*F crit*
Sample	1071.225	1	4.113165	0.035028	4.799335
Columns	442.225	1	4.113165	0.167833	1.98127
Interaction	0.025	1	4.113165	0.991614	0.000112
Within	8035.3	36			
Total	9548.775	39			

The flexibility of laminate composites comprised of reinforced hybrid fiber MASFBF is also impacted by the type of bamboo used. Using Apus Bamboo (BA) requires a load of 41 KN at a 25 mm flexibility, while wulung bamboo (BW) requires a weight of 61 KN with a PR matrix. The flexibility of BA bamboo is higher than that of BW wulung bamboo. According to previous studies, BW bamboo has a flexural strength of 52 MPa, while BA has a flexural strength of 42 MPa. The BA has greater flexibility than the BW based on its flexural strength.

3.3. Heat Resistance Characteristics of Laminate Composites Reinforced Hybrid Fiber Musa Acuminata Stem Fiber-Bamboo Fiber with Polyurethane Resin Matrix

The heat resistance of laminate composite material reinforced hybrid fiber MASF-BF with various types of bamboo (BA, BW) and PR matrix was determined by observing the decomposition process. The results of the decomposition test (mass reduction) of the specimen are shown in Figure 5. The mass reduction was obtained from the thermogravimetry test (TGA). The TGA test was carried out with a sample weight of around 20 mg, with inert gas (Argon), with a heating rate of 10 °C/min.

Figure 5 shows that the decomposition of the sample is a chemical reaction process that releases heat and shows the occurrence of thermal decomposition of the organic material of the sample R. P. B. Kocharla et al. [13]. From the decomposition curve due to the thermal degradation of all samples, there are 4 main steps associated with degradation due to the decomposition reaction of the laminate composite material reinforced hybrid fiber MASF-BF with the PR matrix. The laminate composite with BA apus bamboo fiber is more resistant to heat degradation than the laminate composite with BW wulung bamboo. Heat resistance is indicated by the amount of weight loss that occurs. The lower the weight loss value, the better the heat resistance.

The weight loss of laminated composites that occurs at a constant rate up to a temperature of 500 °C, about 75.16%, MASF15 BA15, 78.18% for MASF10 BA20 laminated composites, 81.37% for MASF5 BA25 laminated composites, about 87.02%, MASF15 BW15, 94.15% for MASF10 BW20 laminated composites, and 99.127% for MASF5 BW25 laminated composites. The heat resistance of SPS-SB hybrid fiber laminated composites with PR matrix, apus bamboo type, is higher than wulung bamboo, as shown in Figure 5.

Based on the results of the experiment by S. Suluh et al. [14], the comparison of the calorific value obtained briquettes apus bamboo has a calorific value of 5025 cal/gram and wulung bamboo has a calorific value of 4873 cal/gram. While the results of the combustion experiment in the furnace showed that the combustion efficiency value in the furnace showed that the efficiency of wulung bamboo briquettes was 49.96%, and the efficiency value of apus bamboo briquettes was 35.48%. The lower the combustion efficiency value, the better the heat resistance (the more difficult it is to burn). The heat resistance of apus bamboo is better than that of wulung bamboo.

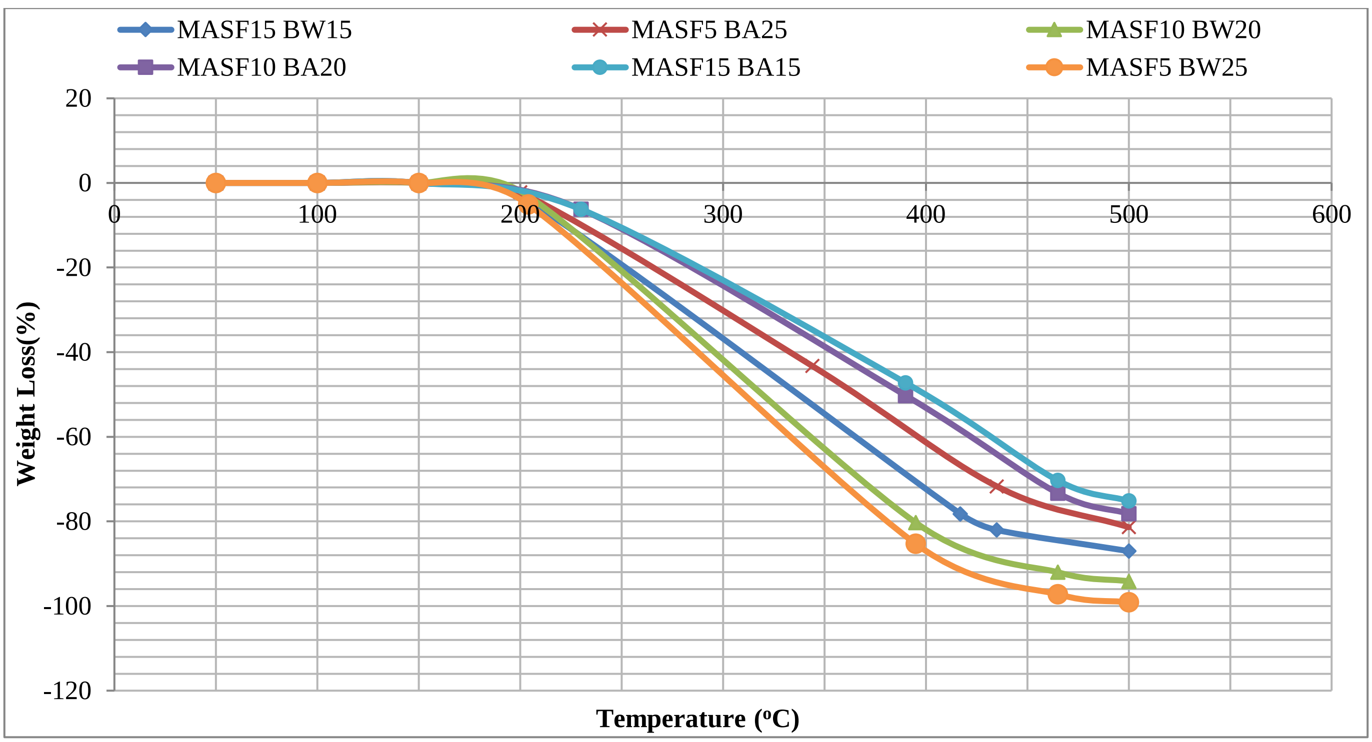

Fig. 5 Heat resistance characteristics of specimen laminate composite

4. Conclusion

The impact energy, toughness, flexural strength, and heat resistance of laminated composite specimens reinforced hybrid fiber MASF-BF with matrix PR are all impacted by the Musa Acuminata Stem Fiber (MASF) volume percentage variations.

Its impact energy and toughness rise with increasing MASF volume fraction, whereas its flexural strength decreases and its heat resistance rises. The impact energy, toughness, flexural strength, and heat resistance of specimens are also impacted by the variety of bamboo species. When apus bamboo is used, the specimen's flexural strength tends to decrease while its energy, impact toughness, and heat resistance tend to increase. Consequently, laminated composite specimens reinforced hybrid fiber MASF-BF with matrix PR with apus bamboo fiber generally have superior mechanical qualities, making them appropriate for parquet flooring.

Funding Statement

Publication of articles based on the results of Fundamental Research funded by the Directorate General of Higher Education, Minister of Education, Culture, Research and Technology of Indonesia with Contract No. [3039/UN18.L1/PP/2024].

Acknowledgments

As coauthors, the authors thank Prof. Dr Nasmi Herlinasari, ST., MT., Ahmad Zainuri, ST., and M. Eng, who have helped with research activities and manuscript preparation. Prof. Dr Ir. Sukartono, M.Agr., Head of the Institute for Research and Community Service, University of Mataram.

References

[1] N.M. Nurazzi et al., "A Review on Mechanical Performance of Hybrid Natural Fiber Polymer Composites for Structural Applications," *Polymers*, vol. 13, no. 13, pp. 1-47, 2021. [CrossRef] [Google Scholar] [Publisher Link]

[2] M. Vishwas, S. Joladarashi, and S.M. Kulkarni, "Comparative Study of Damage Behavior of Synthetic and Natural Ber-Reinforced Brittle Composite and Natural Ber-Reinforced Exible Composite Subjected to Low-Velocity Impact," *Scientia Iranica*, vol. 27, no. 1, pp. 341-349, 2020. [CrossRef] [Google Scholar] [Publisher Link]

[3] John Summerscales, Amandeep Virk, and Wayne Hall "A Review of Bast Fibres and their Composites: Part 3 – Modelling," *Composites Part A: Applied Science and Manufacturing*, vol. 44, pp. 132-139, 2013. [CrossRef] [Google Scholar] [Publisher Link]

[4] M.D.Y. Milani et al., "Study the Structure, Morphology, and Thermal Behavior of Banana Fiber and Its Charcoal Derivative from Selected Banana Varieties," *Journal of Natural Fibers*, vol. 13, no. 3, pp. 332-342, 2016. [CrossRef] [Google Scholar] [Publisher Link]

[5] João Gabriel Guimarães de Farias et al., "Surface Lignin Removal on Coir Fibers by Plasma Treatment for Improved Adhesion in Thermoplastic Starch Composite," *Carbohydrate Polymers.*, vol. 165, pp. 429-436, 2017. [CrossRef] [Google Scholar] [Publisher Link]

[6] K. Z. M. Abdul Motaleb et al., "Innovative Banana Fiber Nonwoven Reinforced Polymer Composites: Pre-and Post-Treatment Effects on Physical and Mechanical Properties," *Polymers*, vol. 13, no. 21, pp. 1-23, 2021. [CrossRef] [Google Scholar] [Publisher Link]

[7] G.B. Veeresh Kumar et al., "Investigation on StructuralCharacteristics of Bamboo-Laminates," *Proceedings International Conference on Materials, Mechanical and Energy Engineering (ICMMEE 2021), IOP Conference Series: Materials Science and Engineering*, vol. 1185, no. 1, pp. 1-10, 2021. [CrossRef] [Google Scholar] [Publisher Link]

[8] N. Santhosh et al., "Experimental Investigations on Static, Dynamic, and Morphological Characteristics of Bamboo Fiber-Reinforced Polyester Composites," *International Journal of Polymer Science*, vol. 2022, pp. 1-11, 2022. [CrossRef] [Google Scholar] [Publisher Link]

[9] Norwahyuni Mohd Yusof et al., "Effects of Adhesive Types and Structural Configurations on Shear Performance of Laminated Board from Two Gigantochloa Bamboos," *Forests*, vol. 14, no. 3, pp. 1-15, 2023. [CrossRef] [Google Scholar] [Publisher Link]

[10] Mohsen Bahrami, "Hybridization Effect on Interlaminar Bond Strength, Flexural Properties, and Hardness of Carbon-Flax Fiber Thermoplastic Bio-Composites," *Polymers*, vol. 15, no. 24, pp. 1-18, 2023. [CrossRef] [Google Scholar] [Publisher Link]

[11] Darmo Sujita and Sutanto Rudy, "The Development of Composite Reinforced Hybrid Fiber Musa Acuminata Stem-Hibiscus Tiliaceust Bark with Filler Liquid Rubber as Vehicle Bumper," *Eastern-European Journal of Enterprise Technologies*, vol. 123, no. 1, pp. 33-40, 2023. [CrossRef] [Google Scholar] [Publisher Link]

[12] Wunpen Chonkaew, Narongrit Sombatsompop, and Witold Brostow, "High Impact Strength and Low Wear of Epoxy Modified by a Combination of Liquid Carboxyl Terminated Poly(Butadiene-Co-Acrylonitrile) Rubber and Organoclay," *European Polymer Journal*, vol. 49, no. 6, pp. 1461-1470, 2013. [CrossRef] [Google Scholar] [Publisher Link]

[13] Ravi Prakash Babu Kocharla et al., "Investigation on the Mechanical and Thermal Properties of Jute/Carbon Fiber Hybrid Composites with the Inclusion of Crab Shell Powder," *Journal of Composites Science*, vol. 8, no. 8, pp. 1-16, 2024. [CrossRef] [Google Scholar] [Publisher Link]

[14] Sallolo Suluh et al., "An Analysis of the Use of Local Bamboo as an Alternative Energy Source," *Proceedings 5th International Symposium on Material, Mechatronics and Energy, IOP Conference Series: Materials Science and Engineering*, Gowa, South Sulawesi, Indonesia, vol. 619, no. 1, pp. 1-4, 2019. [CrossRef] [Google Scholar] [Publisher Link]