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Regular Research Article

Arenga pinnata Merr. Reinforced Polyester Biocomposite as a Candidate Material for Fishing Vessel Hull: Mechanical Properties Analysis

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Abstract: Arenga pinnata Merr (APM) has excellent strength compared to other natural fibers. However, until now its application in the industrial sector is still very low. This study is an experimental study aimed at analyzing the mechanical properties of Arenga pinnata Merr "ijuk" reinforced polyester biocomposite and its potential as a basic material for fiber ship hulls with alkalization treatment on the fiber. This research method is based on mechanical testing of several specimens with fiber content of 0, 5, 10, 15, to 20%wt soaked in 2% NaOH solvent for 3 hours, temperature 70^{o}C. Furthermore, tensile testing of single fiber and biocomposite, bending test, hardness test, and Impact test were carried out with 5 repetitions each. The results obtained include a single fiber tensile strength of 1.1 GPa. For the highest composite tensile strength at 15%wt fiber of 61.27 MPa. The highest Elongation value at 20%wt fiber (3.19%). The highest bending strength at 0%wt fiber is 93.21 MPa. The highest hardness value at 5%wt fiber is 83.7 HD and the impact toughness value on the composite with 20%wt fiber is 1.31 J/mm^2. Based on the results of the biocomposite mechanical test, if the biocomposite material is used as the basic material for making fiber ship hulls, then based on BKI standards, the mechanical strength value of the polyester-APM biocomposite does not comply with BKI standards.

Keywords: Arenga pinnata Merr., Biocomposite, Mechanical Properties, Palm Fiber, Polyester

1. Introduction

Indonesia is an archipelagic country with Nusantara characteristics with territories whose boundaries and rights are regulated by law [1] with an area of waters reaching 6,315,222 km2 and Indonesian land area of 1,890,739 km^2 [2]. With a very large ocean and land area, Indonesia has a wealth of resources both marine and land resources [3] and Indonesia is home to various flora and fauna wildlife, most of whose natural resources have not been optimally utilized.

One of the abundant natural materials in Indonesia is natural fiber. One of the abundant natural fibers is Arenga pinnata Merr (APM) or often called Ijuk fiber. So far, APM has often been used as a raw material for making brooms and water filters, besides that APM is also used as a natural roofing material [4]. APM is a natural fiber that comes from the sugar palm tree and has very good strength compared to other natural fibers. With the existence of technology, broom manufacturers currently use many synthetic materials in making brooms. Many consumers also choose synthetic brooms when compared to ijuk brooms. In fact, APM has many advantages, including being durable for hundreds or even thousands of years, resistant to acids and sea water, and preventing rotting of subterranean termites. This is not much

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different from coconut fiber, which conventionally functions as a broom and fuel to smoke coconut contents to produce copra.

Several studies of APM biocomposites, including Erlina (2020) in her study on the effect of adding APM on the strength of paving block concrete mortar concluded that the addition of APM to paving block cement did not meet the strength requirements for compressive strength, flexural strength, or water absorption [5]. Ramadhan et al (2021) in their research conducted a toughness test on APM composites for motorcycle body cover applications and obtained the results that the longer the fiber, the higher the impact strength with the highest impact of 0.1953 J/mm^2 [6]. Ulfiyah et al. (2021) also conducted a hybrid test of palm fiber, straw fiber, and fiberglass fiber. The results obtained were a maximum tensile strength of 20.12 MPa with an impact value of 0.0144 J/mm^2 [7].

When compared with the results of mechanical testing on synthetic fibers, the mechanical strength of natural fiber composites is still smaller than synthetic fibers. Oerbandono et al. (2014) in their research obtained data on the tensile strength of synthetic fiber composites from woven fiberglass roving type of 346.2 MPa [8]. Other studies report impact test data for GFRP composites of 405 MPa [9]. Research was also conducted on 220 carbon fiber which produced a tensile test value of 211.15 MPa and a bending strength of 104.46 MPa [10].

To increase the mechanical strength of natural fiber composites, several studies have innovated to create hybrid fibers, namely combining several different natural fibers, natural fibers and natural particles, or natural fibers with synthetic fibers. The studies include hybrid coconut stem sawdust - coconut fiber with a tensile strength of 95.953 MPa, 0.068 J / mm^2 [11], hybrid sago pulp fiber and coconut fiber with a toughness value of 0.178 J / mm^2 and a bending strength of 97.354 MPa [12], and fiberglass type roving and coconut dust have a tensile strength of 106.05 MPa with an impact of 15.09 J / mm^2 [13]. From the results of these strengths, it can be seen that there is an increase in mechanical strength in fibers with hybrid arrangements.

Research related to pure natural fibers, hybrids, and synthetic fibers has been widely conducted and published, but sustainable utilization is still lacking, even untouched except in woven production. Several possible causal factors are the lack of socialization of research results to the community, there is a barrier between researchers at universities or research institutions and the general public in remote areas, even though the potential amount of palm fiber and coconut fiber is very large in the area. Community service activities utilizing natural fibers (palm fiber and coconut fiber) as composite materials for certain products are very rarely carried out. So far, the relationship between community service regarding natural fibers is about how to separate fibers from their flesh, how to produce fibers, and the sale of semi-raw fibers.

Another factor that influences the lack of utilization of palm fiber is that people do not yet know how to make products from natural fiber composite materials and the potential economic value generated. For entrepreneurs or workers who already understand the utilization of composites, synthetic fibers are still the main material in making products. In addition to the fact that the utilization of natural fibers has not been informed to workers, the use of synthetic fibers is still easier to apply and is available on the market even though it is expensive.

Until now, some of the weaknesses of natural fibers when applied in product manufacturing are low mechanical strength compared to synthetic fibers. For this problem, the minimum value rule for product utilization can be used. If a particular product is utilized and only requires a mechanical strength of 50 MPa, then a hybrid composite can be used. The next weakness is in terms of use, especially coconut fiber which has a curly fiber type so it is difficult to shape. Furthermore, the density of the fiber is not much different from polyester resin. The density of coconut fiber from several studies is 0.9 - 1.5 gr / cm^3 [14]–[16]. APM has a straighter shape than coconut fiber, but the drawback is that it is stiff so it will be problematic for utilization using long fibers. The density of palm fiber from several studies is 1.13 - 1.29 gr / cm^3 [17], [18].

If we look at the matrix specifications, both polyester and epoxy matrices, based on references to previous studies, the density of polyester is 1.1 - 1.43 gr / cm^3 [19], [20]. Other studies state that the density of resin is 1.15 gr / cm^3 and the density of epoxy resin is 1.17 gr / cm^3 [21]. Other researchers obtained data on the density of BQTN 157-EX type polyester resin of 1,215 gr / cm^3 [22], [23]. For the density of E-glass type fiberglass, it is 2.5 gr / cm3 with a tensile strength value of 1,800 MPa, elastic modulus of 69-73 GPa, diameter 5 - 25 mm, and maximum strain 2.5 - 3%. In another study, the tensile strength of E-Glass was up to 3,500 MPa and S-Glass was 4,600 MPa with a tensile modulus of 72-85 GPa [24]. Companies in the field of structural and non-structural applications choose glass fiber composites because they have a high stiffness to weight ratio and a high strength to weight ratio compared to conventional materials. However, this material has several disadvantages such as recycling problems, disposal, and expensive. The difference in both density and mechanical strength between natural and synthetic fibers is certainly a question for all of us. If we look at the main content of calcium aluminum fiber - borosilicate glass with low alkali content and also silicon dioxide [25], [26] which is a ceramic material. While natural fibers generally consist of cellulose, hemicellulose, lignin, pectin, wax, and other organic compounds which are natural polymer materials. Functional requirements for fibers as reinforcement in composite structures include: high elastic modulus, high breaking strength, uniform strength between fibers, stability in the production process, and uniform fiber diameter.

Mechanical testing of natural fiber composite materials, such as tensile testing, hardness testing, and impact testing, are essential to determine the properties and performance of natural fiber composite materials. Tensile testing helps determine the maximum tensile strength that a material can withstand before failure, and provides information about the modulus of elasticity, which indicates the stiffness of the material and its toughness through elongation to break. Hardness testing measures the resistance of a material to permanent deformation under load, which is important for determining resistance to scratches, wear, and surface damage, and provides an early indication of the quality and wear resistance of the material. Impact testing, on the other hand, assesses the material's ability to absorb energy and withstand sudden impacts without failure, which is important for ensuring the material's durability under extreme conditions and its application in situations where shock or impact may occur.

Based on the potential amount of natural fibers such as coir and the lack of utilization of these fibers and the potential of fibers as reinforced thermoset polymer matrices, further and in-depth research is needed into the causes of the low mechanical strength of natural fibers that have been studied previously, possible ways to increase mechanical strength in both fiber and composite forms, and research on product applications that can be produced with minimum specification feasibility standards that can be exceeded by natural fiber reinforced composites. Product applications are expected to be applied in various fields, both in industry, tourism, and construction.

This research is very important to be carried out as a form of continuation and application of research that has been carried out previously by looking at all aspects that can improve the properties of natural fiber materials. The results of this study are expected to be applied directly to the community and be able to open up business opportunities for the community both in terms of providing natural fiber raw materials, to products that can be sold.

2. Materials and Methods

Yukalac BQTN 157 Polyester Resin (1.21 kg/cm^3) was obtained from a store in Bitung City, Indonesia. NaOH (40 gr/mol) Pro analysis Merck was obtained from an online store. Arenga pinnata Merr fiber (APM) “ijuk” was obtained from sugar palm trees in Bitung City, North Sulawesi. The catalyst used was MEPOXY catalyst with a catalyst concentration of 1% weight to polyester.

Preparation of APM, namely the obtained ijuk fibers, was then washed and dried at a temperature of 70°C for 24 hours. In general, the division of treatment on APM is divided into two types. First, APM without treatment (APM-Untreated). Second, ijuk fiber soaked in 2% NaOH solution by weight at a temperature of 70°C for 3 hours (APM-Na). The soaking of ijuk fiber can be seen in Figure 1.

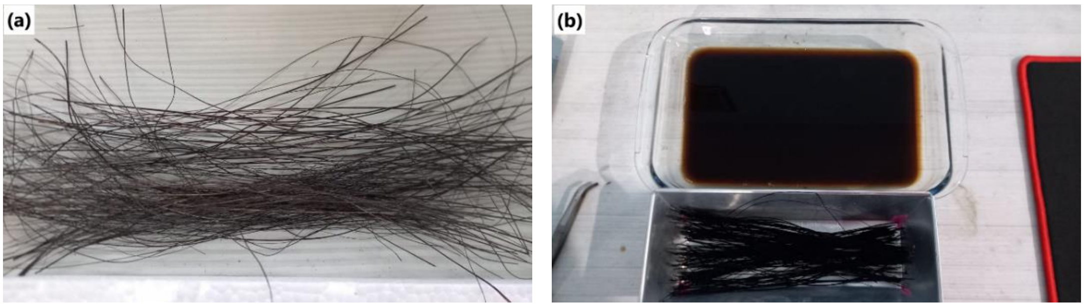

Figure 1. Palm fiber (a) after washing, (b) after soaking in NaOH solution for 3 hours, 70°C

For tensile testing using an UTM tensile machine type Zwick / Roell Z100 with a maximum load of 100 kN according to ASTM D3039 standards. For hardness testing using a Shore D Hardness tester according to ASTM D785 standards. Bending tests using a Zwick / Roell Z100 type Tensile testing machine with a maximum load of 100 kN According to ASTM D790 standards. For Impact testing using a Charpy type Impact Testing machine with the Zwick / Roell type According to ASTM D6110 standards.

3. Results

3.1 Preparation of APM

Alkali solutions such as NaOH function to remove lignin, pectin, and impurities attached to APM. After the alkalization process, the specimen making process is continued. APM is tested mechanically both in single fiber conditions, and already mixed with polyester resin to form a biocomposite with a fiber ratio in the composite of 0, 5, 10, 15, and 20% by weight.

3.2 Single Fiber Tensile Test Results

Table 1. Maximum Tensile Strength of Palm Fiber

No	Types of Fiber	Max Tensile Strength (MPa)
1	APM-*Untreated*	631.12
2	APM-Na	1100.42

Table 1 shows a comparison of the maximum tensile strength of two types of APM with different treatments. APM-Untreated has a maximum tensile strength of 631.12 MPa, indicating a relatively low tensile strength of the fiber. Meanwhile, the fiber soaked in NaOH solution (APM-Na) experienced a significant increase in tensile strength, reaching 1.1 GPa. The NaOH solution functions to remove lignin and hemicellulose in the fiber, which ultimately increases the mechanical strength of the fiber. NaOH is effective in improving the cellulose structure, making the fiber stronger and more resistant to tensile force.

3.3 Mechanical Test Results of APM Biocomposites

Table 2 shows the relationship between APM content (%) and mechanical strength of palm fiber biocomposites that have been treated with two types of chemical treatments, namely APM-untreated (without treatment) and APM-Na. The measured tensile strength indicates the extent to which the fiber composite can withstand tensile force before breaking, which is an important indicator of the strength of the material.

Table 2. Mechanical Strength of APM Biocomposites

No	Fiber Content (%)	Tensile Strength (MPa)		Elongation at Break (%)		Bending Strength (MPa)		Hardness (HD)		Impact Toughness (J/mm^2)	
		APM	APM-Na	APM	APM-Na	APM	APM-Na	APM	APM-Na	APM	APM-Na
1	0	45.07	45.07	3.09	3.09	93.21	93.21	75.6	75.6	0.120	0.120
2	5	55.65	54.35	3.17	2.93	60.40	77.16	78	83.7	0.413	0.612
3	10	58.34	57.71	3.09	3.04	56.09	56.67	77.4	83.4	0.656	1.120
4	15	55.55	61.27	2.95	3.14	54.58	54.80	76.6	83.2	0.921	1.240
5	20	53.15	59.22	2.87	3.19	50.17	51.72	75.9	78.6	0.811	1.310

At a fiber content of 0%wt (without fiber), all samples, both untreated and NaOH treated, have the same tensile strength, which is 45.07 MPa. This shows that at zero fiber content, the composite is not affected by any treatment because there is no APM involved in the material. When the fiber content increases to 5%wt, there is little change in tensile strength in each type of treatment. In the APM-untreated treatment, the tensile strength increases slightly to 55.65 MPa, while in APM-Na, the tensile strength decreases slightly to 54.35 MPa. At a fiber content of 10%wt, the APM-Na treatment shows a slightly higher tensile strength, which is 57.71 MPa, while APM-untreated has a tensile strength of 58.34 MPa. At a fiber content of 15%wt, the composite soaked in NaOH solution has a more significant increase, with a tensile strength reaching 61.27 MPa, while APM-untreated has a tensile strength of 55.55 MPa.

At 20%wt fiber content, although there was a decrease in all treatments compared to 15%wt fiber content, the composite treated with NaOH still showed the highest tensile strength, which was 59.22 MPa, compared to APM-untreated (53.15 MPa). This decrease was due to the less than optimal interaction between the fiber and the matrix at higher fiber content. In addition to stress, material strain measurements were also carried out as shown in Table 2.

Based on Table 2, the elongation at Break data on the APM composite shows changes in elongation values. At a fiber content of 0%wt, all treatments have the same elongation at Break value, which is 3.09%. However, at a fiber content of 5%wt, there is a decrease in elongation in APM-Na (2.93%) compared to APM-untreated (3.17%). At a fiber content of 10%wt, the elongation at Break in APM-Na (3.04%) is slightly lower than APM-untreated (3.09%), which indicates that the NaOH solution has a better effect. At a fiber content of 15%wt, APM-Na produces the highest elongation (3.14%) compared to APM-untreated (2.95%). The peak occurs at a fiber content of 20%wt, where APM-Na produces an elongation of 3.19%, which is the highest among the other treatments. Table 2 also shows the effect of APM content on the bending strength of composites treated with various types of chemical treatments. In general, the results show that higher fiber content causes a decrease in the bending strength of the composite, both for APM-Na and APM-untreated. At a fiber content of 0%wt, the bending strength value is 93.21 MPa, which indicates that without the addition of fiber, the mechanical properties of the composite are not affected by chemical treatment. At a fiber content of 5%wt, APM-Na shows a better value compared to APM-untreated, which is 77.16 MPa respectively. At higher fiber content, such as at 10% and 15%wt, an increase in bending strength due to NaOH treatment can be observed, although the difference is not significant. At a fiber content of 20%, NaOH treatment actually shows a significant decrease in bending strength compared to APM-untreated, with a value of 51.72 MPa, which is lower than the value at lower fiber content. This shows that at very high fiber content, the mechanical properties of the composite can decrease, even though it has been soaked with NaOH.

Table 2 presents data on the hardness values (in Hardness Degree or HD) of APM composites with various fiber content (%) and different chemical treatments, namely APM-untreated (untreated) and APM-Na (NaOH treatment). In general, the data show that the addition of fiber content increases the hardness value of the composite, but the effect of chemical treatment on hardness varies. At a fiber content of 0%wt, the APM-untreated composite has the same hardness value, which is 75.6 HD. At a fiber content of 5%wt, APM-Na shows a significant increase in hardness (83.7 HD) compared to APM-untreated (78.0 HD). The same thing is also seen at fiber content of 10% and 15%wt, where APM-Na produces higher hardness values compared to other treatments. NaOH treatment provides a more consistent hardness strengthening effect, with a hardness value of 83.4 HD at a fiber content of 10%wt and 83.2 HD at a fiber content of 15%wt. At 20% fiber content, although NaOH treatment still gave the highest hardness value (78.6 HD), the hardness value of APM-untreated decreased to 75.9 HD.

Table 2 also shows the impact toughness values (in J/mm²) of APM composites with variations in fiber content (%) and different chemical treatments, namely APM-untreated (without treatment) and APM-Na (NaOH treatment). Impact toughness measures the ability of a material to absorb energy before being damaged, which is an important indicator of the material's resistance to impact loads.

At 0%wt fiber content, the impact toughness value is 0.120 J/mm². At 5%wt fiber content, NaOH treatment significantly increases the impact toughness. APM-Na shows an impact toughness value of 0.612 J/mm². At 10% and 15%wt fiber content, the impact toughness continues to increase along with the addition of fiber and chemical treatment. APM-Na produced a greater increase. At 10%wt fiber content, the impact toughness value for APM-Na was 1,120 J/mm². The same thing happened at 15%wt fiber content, with APM-Na giving the highest impact toughness value (1,240 J/mm²). At 20%wt fiber content, although there was a slight decrease in impact toughness compared to 15%wt fiber content, APM-Na still showed better results compared to APM-untreated. At this fiber content, APM-Na produced an impact toughness of 1,310 J/mm². The addition of APM content generally increased the impact toughness of APM composites, and chemical treatment showed a positive trend, with NaOH tending to be more effective at medium to high fiber content.

4. Discussion

4.1 Analysis of Single Fiber Tensile Test Results

The increase in the tensile strength of single fibers in APM-Na indicates that lignin and other organic compounds that have been separated from APM are able to increase the tensile strength of the fiber, because with the release of other organic compounds, the cross-sectional area of the fiber decreases, but the fiber strength remains the same as without treatment. As a result, the tensile stress value increases as shown in the tensile strength value in Table 1.

4.2 Analysis of Biocomposite Mechanical Test Results

At a fiber content of 5%wt for APM-Untreated, the tensile strength increased slightly while at APM-Na, the tensile strength decreased slightly. The decrease in tensile strength in NaOH indicates that although the fiber content increased, chemical treatment did not have a positive effect on the material at lower fiber content. At higher fiber content, APM-Na gave better results in increasing the tensile strength of APM biocomposites. At higher content (20%wt), there was a decrease in tensile strength. This decrease was due to less than optimal interaction between the fiber and the matrix at higher fiber content.

The highest peak elongation value occurred at a fiber content of 20%wt, where APM-Na produced the highest elongation among the other treatments. This indicates that at higher fiber content, APM-Na increases the flexibility and breaking resistance of the palm fiber composite more significantly compared to APM-untreated. APM-Na is able to increase the elongation at Break of the palm fiber composite at higher fiber content. This shows that NaOH is able to increase the mechanical strength and flexibility of the palm fiber composite, especially at higher fiber content.

In the bending test, higher fiber content causes a decrease in the bending strength of the composite, both for APM-Na and APM-untreated. At a fiber content of 0%wt, the bending strength value of APM-untreated is 93.21 MPa, which shows that without the addition of fiber, the mechanical properties of the composite are not affected by chemical treatment. From this test it can also be concluded that the interfacial bond between APM and the polyester matrix is not formed properly, resulting in a weak bond. Chemical treatment can increase the bending strength of the palm fiber composite at low fiber content, but at high fiber content, there is no increase, even decreases. In general, the hardness test data shows that the addition of fiber content increases the hardness value of the composite, but the effect of chemical treatment on hardness varies. The addition of fiber content increases the hardness value of the APM composite, and chemical treatment can modify the hardness properties. APM-Na tends to provide a more consistent increase in hardness at medium fiber content. The effectiveness of this chemical treatment is highly dependent on the fiber content and the type of treatment used.

Impact toughness measures the ability of a material to absorb energy before failure, which is an important indicator of a material's resistance to impact loads. At a fiber content of 5%wt, APM-Na significantly increased the impact toughness. This increase indicates that both chemical solutions play a role in increasing the impact energy absorption capacity of the APM biocomposite. At fiber content of 10% and 15%wt, the impact toughness continued to increase with the addition of fiber and chemical treatment. APM-Na produced a greater increase. This indicates that APM-Na tends to be more effective in increasing impact toughness at higher fiber content. At a fiber content of 20%wt, although there was a slight decrease in impact toughness compared to 15%wt fiber content, APM-Na still showed better results compared to APM-untreated. At this fiber content, APM-Na produced an impact toughness of 1,310 J/mm² indicating that despite the decrease in toughness at very high fiber content, this chemical treatment still showed significant value on the impact toughness of the composite.

4.3 Comparative Analysis of Mechanical Test Results to BKI Standards

Table 3 shows significant variations in the mechanical strength values of the tested materials based on the fiber content and the type of chemical treatment applied. In general, the tensile strength test results at a fiber content of 0%wt meet the BKI standards for pure resin and Mat Glass. However, when the fiber content is increased, both in the APM-untreated and APM-Na treatments, the tensile strength values of the material no longer meet the BKI standards. This indicates that increasing the fiber content, especially in certain chemical treatments, has not succeeded in increasing the tensile strength of the material according to expectations. Likewise, in the elongation at break parameter, although the elongation value increases slightly with increasing fiber content, there is no clear standard to compare the results at higher fiber content. For Young's modulus, the material with a fiber content of 0%wt shows a value much lower than the BKI standard, and chemical treatment at higher fiber content has also failed to increase the elasticity of the material as expected.

Table 3. Comparison of Highest Mechanical Test Result Data Against BKI Standards

No	Mechanical Properties	Fiber Content (%)	The highest score	Material Type	Value According to BKI Standard	Meets/Does Not Meet	References
1	Tensile strength (MPa)	0	45.07	General	40 MPa (Pure Resin) 75.36 MPa (Mat Glass)	Meets	[27]
		5	55.65	*APM-Untreated*		Does Not Meet	
		10	58.34	*APM-Untreated*		Does Not Meet	
		15	61.27	APM-Na		Does Not Meet	
		20	59.22	APM-Na		Does Not Meet	

2	Elongation at Break (%)	0	3.09	General	2% (Pure Resin)	Meets	[27]
		5	3.17	*APM-Untreated*		Not Mentioned	
		10	3.09	*APM-Untreated*		Not Mentioned	
		15	3.14	APM-Na		Not Mentioned	
		20	3.19	APM-Na		Not Mentioned	
3	Bending Strength (MPa)	0	93.21	General	80 MPa (Pure Resin) 138.18 MPa (Mat Glass)	Meets	[27]
		5	77.16	APM-Na		Does Not Meet	
		10	56.67	APM-Na		Does Not Meet	
		15	54.80	APM-Na		Does Not Meet	
		20	51.72	APM-Na		Does Not Meet	
4	Hardness Value (HD)	0	75.6	General	80 HD	Does Not Meet	ASTM D2240
		5	83.7	APM-Na		Meets	
		10	83.4	APM-Na		Meets	
		15	83.2	APM-Na		Meets	
		20	78.6	APM-Na		Does Not Meet	
5	Impact Toughness (J/mm^2)	0	0.12	General	0.025 J/mm^2	Meets	ASTM D6110
		5	0.612	APM-Na		Meets	
		10	1.12	APM-Na		Meets	
		15	1.24	APM-Na		Meets	
		20	1.31	APM-Na		Meets	

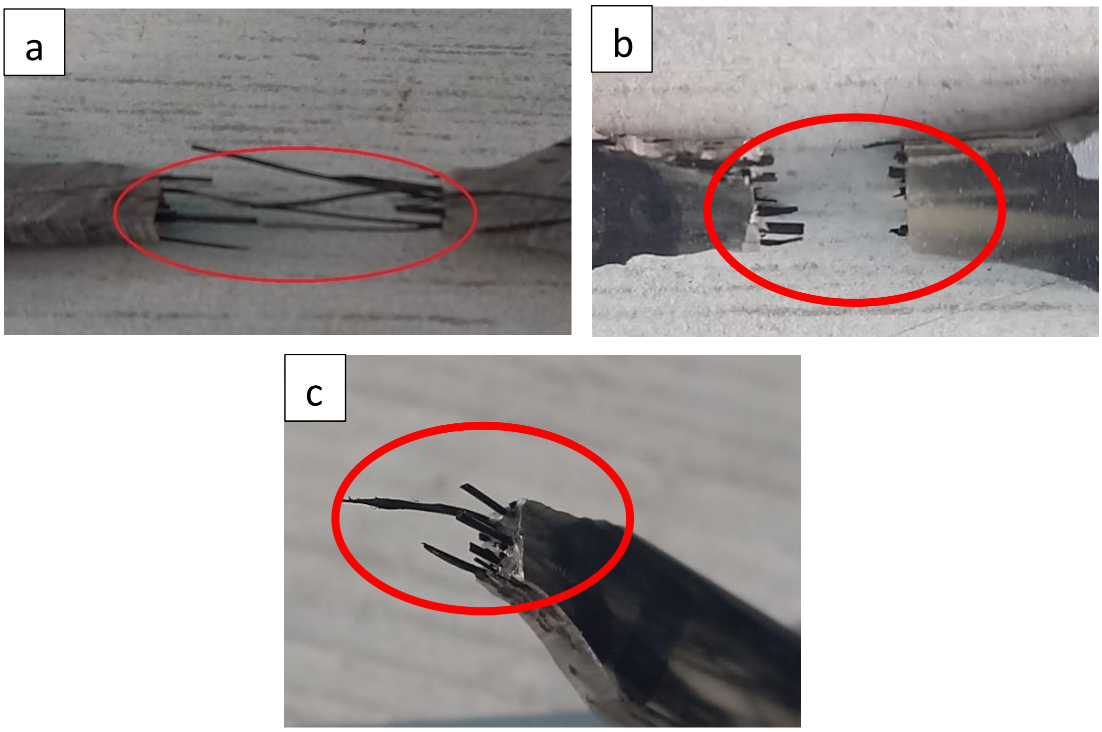

Figure 2. Damaged test specimens of palm fiber composites: (a) APM-Untreated, (b) and (c) APM-Na.

The bending strength at 0%wt fiber content showed results that met the standard, but at higher fiber content, the material could not meet the set standards. This shows that chemical treatment is not effective in increasing flexural strength at high fiber content. In terms of hardness, the material at 0%wt fiber content did not meet the BKI standard, but treatment with NaOH at 5%, 10%, and 15%wt fiber content was able to increase the hardness of the material and meet the standard. For impact toughness, the results showed that all treatments using NaOH solution resulted in a significant increase in toughness at higher fiber content, with values far exceeding the set standards. The test results showed that although higher fiber content can improve some material properties such as impact toughness, not all mechanical parameters meet the BKI standard, especially in tensile strength, elastic modulus, and bending strength. The main cause is the low adhesive bond between the fiber and the polyester resin matrix. Some evidence can be seen in Figure 2 in the form of fractures after mechanical testing was carried out.

Based on Figure 2, it can be observed that a mechanical bond has not been formed between the APM and the polyester matrix, such as the bond between fiberglass and the polyester matrix, which affects the low mechanical strength of the composite.

5. Conclusions

Some things obtained from the results of the research that has been done:

1. Overall, the use of APM as a natural fiber composite reinforcement has not been able to meet the standard values set by BKI, especially in tensile strength, elongation, and elastic modulus, although it can be used in other applications.
2. Based on the fracture results of the specimen after impact and tension, the composite is still brittle and a strong mechanical bond has not formed between the APM and the polyester matrix, so that the attached fibers can still be separated from the polyester matrix.
3. The impact toughness of the composite has a high value, so that in order for this composite to be applied, further engineering is needed on the composite so that the tensile strength value increases and meets BKI standards.
4. The tensile strength value of single fibers is very high, but in the form of low composites.

Author contributions:

Author 1: Conducted research and data collection in the Laboratory and compiled the research article

Author 2: Conducted research and specimen testing

Author 3: Analyzed the results of the data testing

Author 4: Conducted research and assisted in compiling the research article

Author 5: Analyzed data to be included in the research article

Author 6: Conducted testing and took the main material of APM fiber

Author 7: Was a laboratory assistant who participated in conducting research in the form of preparing specimens to be tested

Competing interests: Through this writing we declare that we have no competing interests.

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