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Effect of Fibre Volume Fraction and Sodium Hydroxide Treatment on Mechanical Properties of Palm Fibre /Unsaturated Polyester Composite

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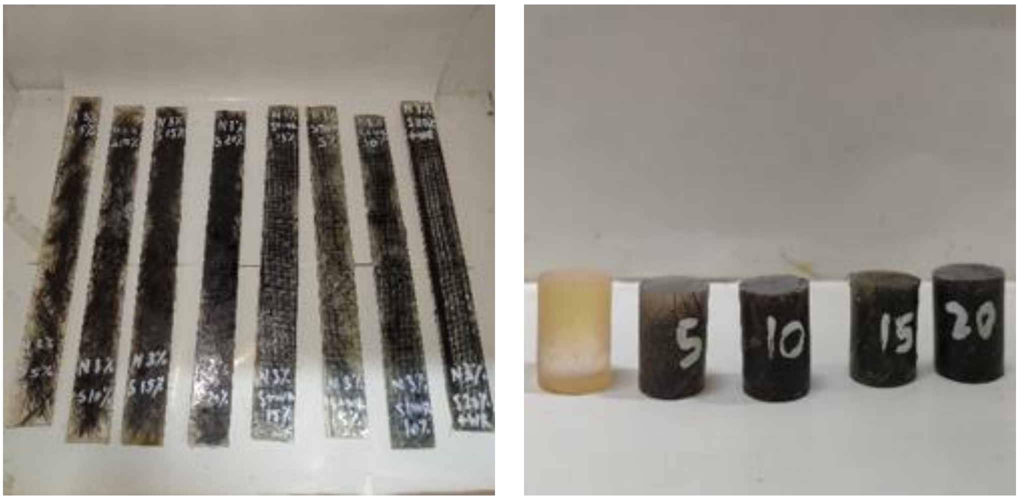
Abstract
Wood has some weaknesses, such as susceptibility to weathering, easily attacked by termites, and low water resistance. An alternative material such as Natural Fibre-Reinforced Polymer (NFRP) composite should overcome those weaknesses. This research aims to make a composite with palm fibre and unsaturated polyester resin. Palm fibres immerse for 2 hours in NaOH solution with varying concentrations of 3%, 5%, and 7%. The volume fraction of palm fibre are 0%, 5%, 10%, 15%, and 20%. Woven roving fibreglass was added to compare the tensile strength of composite with or without natural fibre. The density of composites increased with the increase of fibre volume fraction. The highest tensile strength was obtained for 15% of fibre volume fraction, namely 23.8483 MPa. In contrast, the highest compressive strength was obtained for 5% of fibre volume fraction, namely 94.76 MPa. NaOH removed the impurities and waxy substances from the fibre surface and created a rougher surface topography after alkalization. The highest tensile strength was obtained with 7% NaOH, namely 14.674 MPa. The highest water absorption value was obtained at 3% NaOH concentration and 15% of fibre volume fraction, namely 1.445%. The addition of woven roving as reinforcement to natural fibre composite can increase tensile strength by 210%, from 13.882 MPa to 43.123 MPa.
Keywords: Palm fibre, unsaturated polyester, NaOH concentration, volume fraction, water absorption.

1. Introduction
Wood is a material that is widely used in manufacturing houses. Unfortunately, wood has some weaknesses, such as being susceptible to weathering, easily attacked by termites, and low water resistance. An alternative material such as composite should overcome those weaknesses. Indonesia is a country which has abundant natural fibres, such as coir, pineapple leaf, bamboo, sugar cane, and palm fibre. Natural Fibre-Reinforced Polymer (NFRP) composite should be suitable to substitute materials from the wood. The tensile strength of palm fibre is 276.6 MPa [1], more excellent than coir which has a tensile strength of 131–175 MPa [2]. Besides that, palm fibre is resistant to acid, sea salt, and termites attack [3].

Mechanical properties of NFRP composite can be affected by volume or mass fraction of fibre, the orientation of fibre, the chemical composition of fibre, length of the fibre, and interface bonding between fibre and matrix [4]. Fibres contain cellulose, hemicellulose, lignin, pectin, and waxy substances. Chemical or physical fibre treatment must be carried out to produce a rough fibre surface for adhesion between fibre and matrix [5] and to reduce moisture absorption and hydrophilic groups on the fibre [6]. Alkalization treatment using NaOH solution is widely used in the natural fibre processing industry and artificial cellulose fibres [7]. Research on the treatment of hemp fibres such as NaOH, silane coupling agent, maleic anhydride, and acetic anhydride showed that treatment of fibre with NaOH solution gave the highest tensile strength and Young’s modulus, namely 598 MPa and 33.8 GPa, respectively [8]. Immersion treatment of sugar palm fibres for 2 hours in 5% NaOH solution gave the



(a) (b)

Figure 1. Specimen for (a) tensile test and (b) compressive test.

highest result of bending stress, modulus of elasticity, and elongation is 176.77 MPa, 1.267 GPa, and 24.05%, respectively [9].

Research on 40% palm fibre volume fraction with epoxy resin gave the highest tensile strength of 5.128 kg/mm^2 [10]. Palm fibre-phenolic composite gave the highest compressive strength of 60 MPa with a 30% fibre volume fraction [11]. Tensile and impact strength of polyester composite increased along with increasing weight fraction of palm fibre. The highest tensile and impact strength were obtained with a 9% fibre weight fraction, namely 4.21 kg/mm^2 and 32.7 kJ/m^2, respectively. The density of this composite decreased along with the increasing weight fraction of palm fibre [12]. The mechanical properties of NFRP composites can be improved by combining them with fibreglass. Research on fibreglass added to sugar palm fibre composites shows that tensile strength increases from 23 MPa to 43 MPa [13]. Research on palm fibre orientation in epoxy composite obtained tensile strength of 33.14 MPa for random, 29.71 MPa for cross, 21.97 MPa for continuous, and 16.08 MPa for woven fibre orientation [14].

This research aims to make NFRP composite with palm fibre and unsaturated polyester. Palm fibres immerse for 2 hours in NaOH solution with varying concentrations of 3%, 5%, and 7%. The volume fraction of palm fibre are 0%, 5%, 10%, 15%, and 20%. Woven roving fibreglass will also be added to compare the tensile strength of composite with or without natural fibre. In addition, the optimum parameters will be known to obtain a better composite with high tensile strength, compressive strength, and water resistance to composite.

2. Method

This research used polyester resin (SHCP 2668 WNC), methyl ethyl ketone peroxide as the catalyst, palm fibres, woven roving (600 E-glass), and sodium hydroxide (NaOH). Palm fibres were cut into 2.5 cm sizes, washed with water, and dried. Palm fibre soaked in 0%, 3%, 5%, and 7% NaOH solutions for 2 hours. Volume fraction of fibres were 0%, 5%, 10%, 15%, and 20% with and without woven roving. Composite samples were prepared based on ASTM D3039 for the tensile test with a size of 250 mm × 25 mm × 3 mm, as shown in Figure 1a. At the same time, based on ASTM D695 for the compressive test with a diameter and height of 12.7 mm and 25.4 mm, respectively, as shown in Figure 1b. Manufacturing of composite used hand lay-up method. NFRP composites were made from unsaturated polyester (UP) matrix with palm fibre (PF) as reinforcement in a random orientation, and with addition of woven roving (WR) fibreglass.

The tensile test was performed to determine composite samples' tensile strength and elastic modulus using the universal testing machine Shimadzu AG-IS. The compressive test was carried out to determine composite samples' compressive strength using the universal testing machine AG-X Plus. The fracture of composite samples after tensile testing was characterized using FE-SEM. The water absorption test was carried out by immersing the composite sample in water according to the ASTM D570 standard.

Table 1. Density of composite.

Volume fraction of fibre (%)	Density (g/cm^3)	
	UP/PF	UP/PF/WR
5	1.2837	1.4021
10	1.2876	1.4023
15	1.3413	1.4031
20	1.3521	1.5679

3. Result and Discussion

3.1. Effect of Fibre Volume Fraction

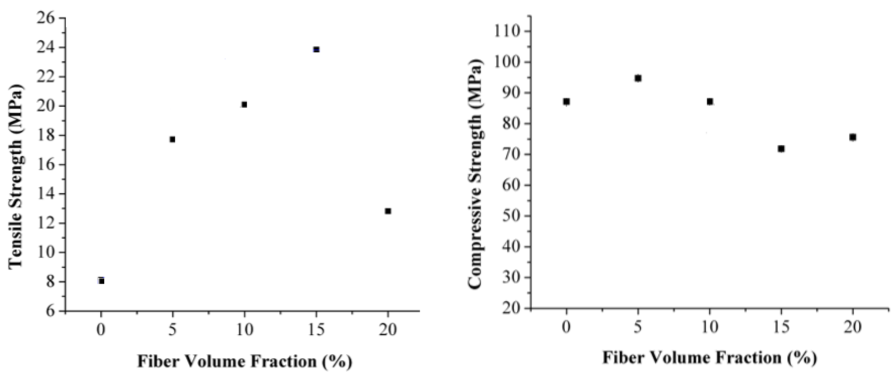
Table 1 shows the density of each composite by variation of fibre volume fraction. The density of composites increased with increasing fibre volume fraction. UP/PF/WR composite has a greater density than UP/PF composite due to the density of each component like unsaturated polyester, palm fibre, and woven roving fibreglass having the value of 1.1 g/cm^3, 1.2015 g/cm^3, and 3 g/cm^3 respectively.

Tensile strength is influenced by matrix and fibre properties. The final properties of composites are a combination of matrix' and reinforcement properties, so when more fibres are added as reinforcement, as long as the matrix can cover the fibres properly, the tensile strength will increase. Figure 2a shows that increasing of fibre volume fraction will increase the tensile strength of the composite. Tensile strength of composite with 0%, 5%, 10%, 15%, and 20% of fibre volume fraction were 8.129 MPa, 17.717 MPa, 20.094 MPa, 23.8483 MPa, and 12.815 MPa, respectively. Palm fibre has high strength but is somewhat brittle, so if the composite has more fibre volume fraction, it will be more brittle. That is why the tensile strength of composite with 20% of fibre volume fraction decreased. Decreasing tensile strength with higher fibre volume fraction can also be caused by the weak interfacial bond between fibre and matrix [10].

The compressive strength of composites is also affected by reinforcement and matrix. Figure 2b shows that compressive strength increased from 87.21 MPa to 94.76 MPa by 5% fibre volume fraction, then decreased by 10%, 15%, and 20% fibre volume fraction at 87.17 MPa, 71.86 MPa, and 75.59 MPa, respectively. The addition of 5% fibre achieved a maximum good homogeneity [15]. High compressive strength is obtained with a small amount of fibre. Compressive strength decreased with the increasing number of fibre as the porosity and air voids increased, causing inadequate compaction between fibre and matrix. It can be related to the composite density, as shown in Table 1, where decreasing porosity and air voids caused increasing density and decreased compressive strength [16].

3.2. Effect of Pre-treatment Fibre with NaOH Concentration

Fibre treatment using NaOH aims to improve fibre compatibility at the fibre-matrix interface by increasing roughness, dispersing the fibre, and producing better interface adhesion by increasing mechanical interlocking. So, it can also improve the mechanical properties of composite [17] and change fibre properties from hydrophilic to hydrophobic by dissolving hydrophilic components such as hemicellulose [18].



(a) (b)

Figure 2. (a) Tensile strength and (b) compressive strength of composite with variation of fibre volume fraction

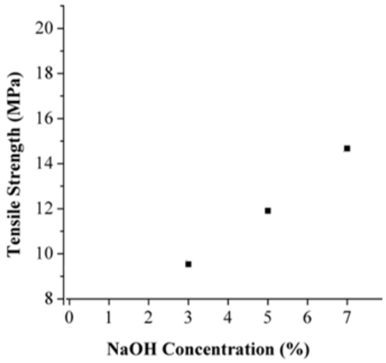
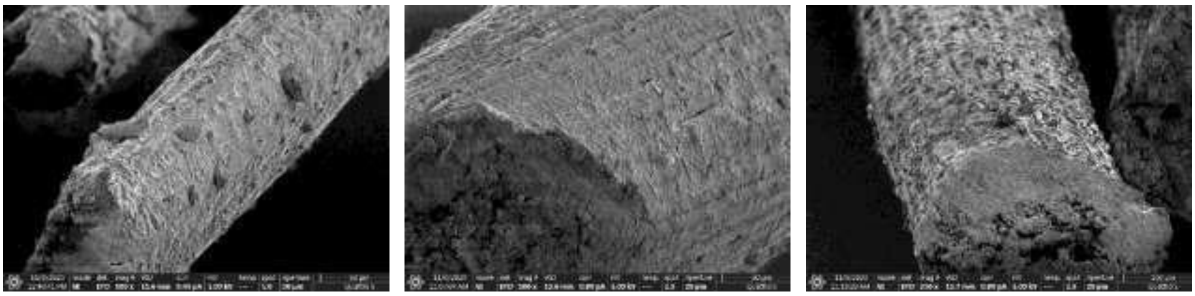


Figure 3. Effect of NaOH concentration to tensile properties.

Figure 3 shows that tensile strength increases with increasing of NaOH concentration. NaOH improved fibre dispersion in the matrix, which increased the fibre aspect ratio. It increases fibre's reinforcement effectiveness and hence increases the strength of composites. On the other hand, the contact area of fibre with matrix will increase the interaction between fibre and matrix [19]. Tensile strength of composite using fibre already treated with 3%, 5%, and 7% NaOH concentration, namely 9.533 MPa, 11.906 MPa, and 14.674 MPa, respectively.

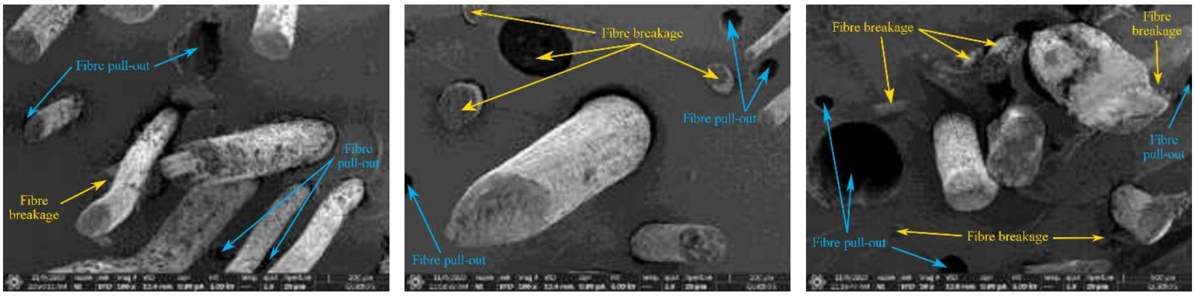
NaOH removed the impurities and waxy substances from the fibre surface and created a rougher surface topography after alkalization [19], as shown in Figure 4. FE-SEM results show that the surface of palm fibre with 3% NaOH treatment is still covered by outer layers of hemicellulose and pectin, as shown in Figure 4a. This indicates that treatment with 3% NaOH concentration for 2 hours has not been able to remove the outer layer of the palm fibre. This layer does not have a strong bond with the second layer consisting of lignin and cellulose [20]. Hemicellulose is highly hydrophilic, while the polyester matrix is hydrophobic, so its compatibility is poor [18]. Figure 4b shows that fibre with 5% NaOH concentration treatment has a smoother surface due to the loss of hemicellulose and pectin layers. This certainly increases the compatibility of fibres to the matrix, thereby increasing the value of tensile strength obtained. Figure 4c shows that fibre with 7% NaOH concentration treatment has a rougher surface. The second layer in the form of lignin has begun to break down and increases the surface roughness of the fibre, thereby increasing mechanical interlocking, which makes interface adhesion better and increases tensile strength.

There were holes formed in the fracture and fibres breakage. The holes formed because of pull-out fibre phenomenon which indicates a weak mechanical bond between matrix and fibre. Fibre breakage indicates a strong mechanical bond between unsaturated polyester and palm fibre so that the load was evenly distributed. In the composites with 3% NaOH treatment (Figure 5a) there were many holes and a few fibres breakage. Figure 5b shows fewer holes and more fibres breakage observed with 5% NaOH concentration treatment. Figure 5c shows the number of holes the same as before and the fibres breakage was more than others with 7% NaOH concentration treatment. The results of these observations are in accordance with the results of the tensile test, namely the composite with treatment of palm fibre using 7% NaOH concentration, the most observed fibres breakage obtained the highest tensile strength of 14.674 MPa compared to 3% NaOH concentration, namely 9.533 MPa.



(a) (b) (c)

Figure 4. Surface of palm fibre after treated with NaOH concentration of (a) 3%, (b) 5%, and (c) 7%.



(a) (b) (c)

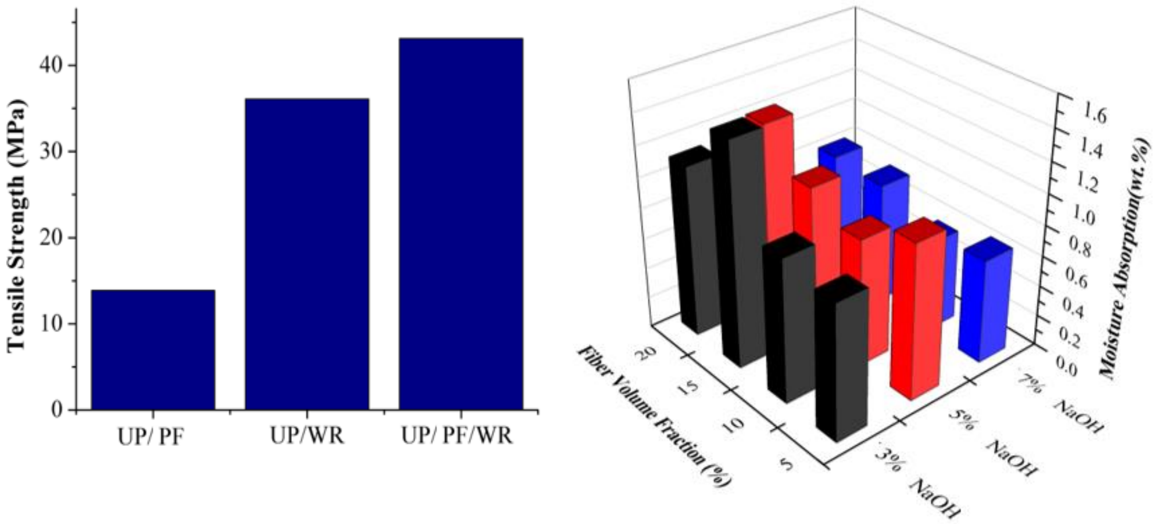
Figure 5. FE-SEM micrograph of composite fracture surface with treatment of NaOH (a) 3%, (b) 5%, and (c) 7%.

3.3. *Effect of Woven Roving Addition to Composite*

Figure 6a shows the tensile strength of unsaturated polyester-palm fibre (UP/PF) composite, unsaturated polyester-woven roving fibreglass (UP/WR) composite, and unsaturated polyester-palm fibre-woven roving fibreglass (UP/PF/WR) composite. Only one layer of woven roving fibreglass was added to the composite. The highest tensile strength was indicated by the UP/PF/WR composite with 43.123 MPa, UP/WR at 36.097 MPa, and UP/PF composite at 13.882 MPa. The addition of woven roving fibreglass in palm fibre composite can increase the tensile strength of the composite by 210%, from 13.882 MPa to 43.123. The addition of woven roving fibreglass without palm fibre in the composite can increase tensile strength by 19%, from 36.097 MPa to 43.123 MPa. The previous research also had the same result that fibreglass's addition in natural fibre composite increased tensile strength by 87% [13].

3.4. *Effect of NaOH Concentration and Volume Fraction of Fibre to Water Absorption Behaviour*

The hydrophilic properties of natural fibres influenced the water absorption behaviour of natural fibre composites. These can be reduced by alkaline treatment to remove the component of hydrophilic hemicellulose, leaving only the fibre component of hydrophobic, such as lignin. In Figure 6b, it was observed that the percentage of water absorption tends to increase with increasing fibre volume fraction. Meanwhile, the effect of NaOH concentration on palm fibre treatment shows that the absorption of water decreases with increasing NaOH concentration due to the NaOH solution changing the surface properties of fibre from hydrophilic to hydrophobic, so that water absorption decreases. Swelling happened to composited when soaked in water for 7 days. The swelling weakened the interfacial bond between fibre and matrix, so the mechanical strength of the composite decreased. The highest water absorption was obtained at 1.445% with 3% NaOH concentration and 15% of fibre volume fraction.



(a) (b)

Figure 6. (a) Tensile strength of UP/PF, UP/WR, and UP/PF/WR; (b) Effect of NaOH concentration and volume fraction of fibre to water absorption behaviour.

4. Conclusion

Based on this research, it can be concluded that the density of composite increased with increasing fibre volume fraction. Increasing fibre volume fraction will increase the tensile strength of the composite, but will decrease the compressive strength of the composite. The highest tensile strength was obtained for 15% of fibre volume fraction, namely 23.8483 MPa, while the highest compressive strength was obtained for 5% of fibre volume fraction, namely 94.76 MPa. Increasing NaOH concentration will increase the tensile strength of the composite. The highest tensile strength was obtained with 7% NaOH treatment for 2 hours at 14.674 MPa. The percentage of water absorption tends to increase with the fibre volume fraction. Nevertheless, it decreases with increasing NaOH concentration. The highest water absorption value was obtained at 3% NaOH concentration and 15% of fibre volume fraction, namely 1.445%. The addition of woven roving as reinforcement to natural fibre composite can increase tensile strength by 210%, from 13.882 MPa to 43.123 MPa.

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References

[1] J. Sahari, S. M. Sapuan, Z. N. Ismarrubie, and M. Z. A. Rahman, "Physical and chemical properties of different morphological parts of sugar palm fibres," *Fibres Text. East. Eur.*, vol. 2, no. 91, pp. 21–24, 2012.

[2] D. B. Dittenber and H. V. GangaRao, "Critical review of recent publications on use of natural composites in infrastructure," *Compos. - A: Appl. Sci. Manuf.*, vol. 43, no. 8, pp. 1419–1429, 2012, doi: 10.1016/j.compositesa.2011.11.019.

[3] M. Sulaiman and M. H. Rahmat, "Kajian potensi pengembangan material komposit polimer dengan serat alam untuk produk otomotif," in *Proc. Seminar Nasional Teknik Mesin (SISTEM) 2018*, Universitas Negeri Jember, Indonesia, 2018, pp. 13–17.

[4] N. M. Nurazzi *et. al.*, "A review: Fibres, polymer matrices and composites," *Pertanika J. Sci. Technol.*, vol. 25, no. 4, pp. 1085–1102, 2017.

[5] M. R. Sanjay *et al.*, "Characterization and properties of natural fiber polymer composites: A comprehensive review," *J. Clean. Prod.*, vol. 172, pp. 566-581, 2018, doi: 10.1016/j.jclepro.2017.10.101.

[6] L. Mohammed, M. N. Ansari, G. Pua, M. Jawaid, and M. S. Islam, "A review on natural fiber reinforced polymer composite and its applications," *Int. J. Polym. Sci.*, vol. 2015, p. 243947, 2015, doi: 10.1155/2015/243947.

[7] N. Le Moigne, B. Otazaghine, S. Corn, H. Angellier-Coussy, and A. Bergeret, *Surfaces and Interfaces in Natural Fibre Reinforced Composites: Fundamentals, Modifications and Characterization*. Cham, Switzerland: Springer, 2018.

[8] B. K. Goriparthi, K. N. S. Suman, and N. M. Rao, "Effect of fiber surface treatments on mechanical and abrasive wear performance of polylactide/jute composites," *Compos. - A: Appl. Sci. Manuf.*, vol. 43, no. 10, pp. 1800–1808, 2012, doi: 10.1016/j.compositesa.2012.05.007.

[9] M. A. Irfai, D. Wulandari, and E. Marsyahyo, "Effect of NaOH treatment on bending strength of the polyester composite reinforce by sugar palm fibers," in *IOP Conf. Ser.: Mat. Sci. Eng.*, vol. 336, no. 1, p. 012008, 2018, doi: 10.1088/1757-899X/336/1/012008.

[10] E. Mahmuda and S. Savetlana, "Pengaruh panjang serat terhadap kekuatan tarik komposit berpenguat serat ijuk dengan matrik epoxy," *J. Ilm. Tek. Mesin*, vol. 1, no. 3, pp. 79–84, 2013.

[11] B. Rashid, Z. Leman, M. Jawaid, M. J. Ghazali, and M. R. Ishak, "The mechanical performance of sugar palm fibres (ijuk) reinforced phenolic composites," *Int. J. Precis. Eng. Manuf.*, vol. 17, no. 8, pp. 1001–1008, 2016, doi: 10.1007/s12541-016-0122-9.

[12] U. B. Surono and Sukoco, "Analisa sifat fisis dan mekanis komposit serat ijuk dengan bahan matrik poliester," in *Proc. Seminar XI Rekayasa Teknologi Industri dan Informasi*, Institut Teknologi Nasional Yogyakarta, Indonesia, 2016, pp. 298–303.

[13] M. R. Ishak *et al.*, "Sugar palm (*Arenga pinnata*): Its fibres, polymers and composites," *Carbohydr. Polym.*, vol. 91, no. 2, pp. 699–710, 2013, doi: 10.1016/j.carbpol.2012.07.073.

[14] M. Muhajir, M. A. Mizar, and D. A. Sudjimat, "Analisis kekuatan tarik bahan komposit matriks resin berpenguat serat alam dengan berbagai varian tata letak," *J. Tek. Mesin*, vol. 24, no. 2, pp. 1–8, 2016.

[15] N. G. Ozerkan, B. Ahsan, S. Mansour, and S. R. Iyengar, "Mechanical performance and durability of treated palm fiber reinforced mortars." *Int. J. Sustain. Built Environ.*, vol. 2, no. 2, pp. 131–142, 2013, doi: 10.1016/j.ijsbe.2014.04.002.

[16] A. Gholampour and T. Ozbakkaloglu, "A review of natural fiber composites: Properties, modification and processing techniques, characterization, applications," *J. Mat. Sci.*, vol. 55, no. 3, pp. 829–892, 2020, doi: 10.1007/s10853-019-03990-y.

[17] M. M. Camargo, E. A. Taye, J. A. Roether, D. T. Redda, and A. R. Boccaccini, "A review on natural fiber-reinforced geopolymer and cement-based composites," *Materials*, vol. 13, no. 20, p. 4603, 2020, doi: 10.3390/ma13204603.

[18] Z. N. Azwa, B. F. Yousif, A. C. Manalo, and W. Karunasena, "A review on the degradability of polymeric composites based on natural fibres," *Mater. Des.*, vol. 47, pp. 424–442, 2013, doi: 10.1016/j.matdes.2012.11.025.

[19] D. Shanmugam and M. Thiruchitrambalam, "Static and dynamic mechanical properties of alkali treated unidirectional continuous palmyra palm leaf stalk fiber/jute fiber reinforced hybrid polyester composites," *Mater. Des.*, vol. 50, pp. 533–542, 2013, doi: 10.1016/j.matdes.2013.03.048.

[20] S. Mahzan, W. M. Bahtiar, and Z. Mohamad, "Investigation on the tensile strength of treated and untreated woven sugar palm fibre reinforced composites," *Appl. Mech. Mater.*, vol. 660, pp. 588–592, 2014, doi: 10.4028/www.scientific.net/AMM.660.588.