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Recent Developments in Oil Palm Empty Fruit Bunch (OPEFB) Fiber Composite

Melbi Mahardika[a,b], Aminatuz Zakiyah[c], Siti Mariyah Ulfa[c,d], Rushdan Ahmad Ilyas[e,f], Mohamad Zaki Hassan[g], Devita Amelia[e], Victor Feizal Knight[h], and Mohd Nor Faiz Norrrahim[h]

[a]Research Center for Biomass and Bioproducts, National Research and Innovation Agency (BRIN), Cibinong, Indonesia; [b]Research Collaboration Center for Nanocellulose, BRIN and Andalas University, Padang, Indonesia; [c]Department of Chemistry, Faculty of Sciences, Brawijaya University, Malang, Indonesia; [d]Synthesis and Catalysis of Natural Product Research Group, Faculty of Science, Brawijaya University, Malang, Indonesia; [e]Faculty of Chemical and Energy Engineering, Universiti Teknologi Malaysia UTM, Johor Bahru, Malaysia; [f]Centre for Advanced Composite Materials, Universiti Teknologi Malaysia UTM, Johor Bahru, Malaysia; [g]Razak Faculty of Technology and Informatics, Universiti Teknologi Malaysia, Kuala Lumpur, Malaysia; [h]Defence Research Institute, Universiti Pertahanan Nasional Malaysia, Kuala Lumpur, Malaysia

ABSTRACT

The materials sector has grown significantly over the last few decades. One from the community worldwide has embraced using natural fibers and biopolymers in many products due to significant problems with petroleum supplies and concerns about using synthetic plastics as biomaterials. The availability of lignocellulosic fiber polymer composites worldwide, in addition to their low carbon emissions and biodegradability, has caught the enthusiasm of scientists and engineers. One of the main crops grown in Indonesia is oil palm, which has the potential to provide lignocellulosic fibers for composites. The increase in fiber increased the mechanical properties of the composite. The compatibility of OPEFB with other materials in the composite is essential to ensure specific applications. There is still a little detailed examination of the mechanical properties of OPEFB biocomposite and factors, including polymer type and fiber size, that can impact mechanical performance. However, according to various articles, OPEFB is a potential raw material for reinforcing material in composites without being continuously developed, so research innovations on OPEFB composites are needed.

摘要

在过去的几十年里，材料行业有了显著的增长. 由于石油供应方面的重大问题以及对使用合成塑料作为生物材料的担忧，来自世界各地的一位社区人士已经接受在许多产品中使用天然纤维和生物聚合物. 木质纤维素纤维聚合物复合材料除了具有低碳排放和生物降解性外，在全球范围内的可用性也引起了科学家和工程师的热情. 印尼种植的主要作物之一是油棕，它有潜力为复合材料提供木质纤维素纤维. 纤维的增加增加了复合材料的机械性能. OPEFB与复合材料中其他材料的兼容性对于确保特定应用至关重要. 对OPEFB生物复合材料的机械性能以及影响机械性能的因素，包括聚合物类型和纤维尺寸，仍有一些详细的研究.　然而，根据各种文章，OPEFB是一种潜在的复合材料增强材料原材料，尚未得到持续开发，因此需要对OPEFB复合材料进行研究创新.

KEYWORDS

Oil palm empty fruit bunch fiber; polymer composite; surface modification; thermoplastic; thermoset

关键词

油棕空果包纤维; 聚合物复合材料; 表面改性; 热塑性塑料; thermoset热固性的

CONTACT Melbi Mahardika melbi.mahardika@brin.go.id Research Center for Biomass and Bioproducts, National Research and Innovation Agency (BRIN), Cibinong 16911, Indonesia; Mohd Nor Faiz Norrrahim faiz@upnm.edu.my Universiti Pertahanan Nasional Malaysia Research Centre for Chemical Defence Kem Perdana Sungai Besi 57000, Kuala Lumpur, Malaysia

Introduction

Indonesia is one of the leading producers of palm oil worldwide. Empty fruit bunches from oil palms are one of the solid wastes produced by the palm oil industry. According to estimations, Indonesia can generate 7 million tonnes of Oil Palm Empty Fruit Bunch (OPEFB) yearly (Anita et al. 2020). Production OPEFB is either 5.29 million tons of dry OPEFB or 17.64 million tons of wet OPEFB (Fatriasari et al. 2021). However, until now, a sizable amount of waste from empty fruit bunches from oil palms has been produced, endangering the environment in many countries, particularly Indonesia. As a result, a study on the efficient use of OPEFB waste is required (Hermawan et al. 2022). The OPEFB fiber structure of the solid residue contains 37.26–63% of cellulose, 14.6–37% of hemicellulose, and 17–31.7% of lignin (Indriati, Elyani, and Dina 2020). OPEFB fiber composition makes it a desirable feedstock for a biorefinery process based on lignocellulosic chemicals (Taylor 2008).

Biological examples of fiber-reinforced composites held together by an amorphous lignin matrix and helically coiled cellulose microfibrils include plant fibers like OPEFB fiber. The mechanical properties of fibers are affected by cellulose composition, as collagen controls the tensile and ligament strengths in animals and the mechanical properties of connective tissue (Goh, Chen, and Liao 2014).

The study of natural fibers instead of synthetic ones as reinforcing components in polymer composites has significantly increased recently. The benefits of natural fibers are their low density, low cost, non-toxicity, and environmental friendliness. They are also renewable and readily available in large quantities. Additionally, they are easy to process and produce minor equipment abrasion. Banana, oil palm, kenaf, jute, hemp, coir, bamboo, and wood are cellulose fibers utilized as composite reinforcement material (Asyraf, Ishak, et al. 2021; R. A. Ilyas, Zuhri, et al. 2022; R. A. Ilyas et al. 2021). OPEFB-based composites can be applied in the fields of automotive, biology, military, adsorbents, floor panels, furniture, and household appliances (Asyraf, Ishak, et al. 2021; Nurazzi, Asyraf, Khalina, et al. 2021).

In recent years, OPEFB's hydrophilicity has been reduced by physical, chemical, or chemical and physical treatment methods (Essabir et al. 2016; Shinoj, Visvanathan, Panigrahi, and Kochubabu 2011). Due to their efficacy, chemical treatments are frequently utilized in developed composite materials (Norrrahim et al. 2021). The general perspective of OPEFB and its composites has been the subject of numerous academic discussions, especially by (Shinoj, Visvanathan, Panigrahi, and Kochubabu 2011). Specific OPEFB used as reinforcing elements in polymer composites have received much attention in reviews (Mahjoub, Yatim, and Sam 2013). Additionally, the majority of analyses of OPEFB fiber biocomposites have applications that emphasize energy absorption (Faizi et al. 2016), structural (Mahjoub, Yatim, and Sam 2013), and furniture design (Suhaily et al. 2012).

Since OPEFB fibers are biodegradable materials, they have been used extensively to reinforce thermoplastics and thermosets and improve their properties. Fabricating microperforated panels, particleboard, medium-density fiberboard, and thermal insulation panels uses OPEFB fibers and polymer composites (Ramlee, Naveen, and Jawaid 2021; Sekar et al. 2021).

In this latest review, we have detailed the characteristics of empty bunch fiber, treatment modifications, and their applications. Moreover, the study examined the most recent OPEFB composite concerns. Researchers working on OPEFB composites will benefit from this innovative publication.

OPEFB fibers

Availability

Most oil produced and consumed worldwide comes from the oil palm plant. The introduction of OPEFB to Indonesia dates back to 1911, and over the subsequent decades, it has experienced remarkable growth, evolving into a pivotal commodity by 1970. According to data obtained from the Ministry of Agriculture of the Republic of Indonesia's Directorate General of Estate Crops, the year 1970 witnessed exclusive management of oil palm plantations by state-owned and commercial enterprises. However, a significant development occurred in 1979 with the initiation of small-scale plant farms, which commenced their operations (Hambali and Rivai 2017). The world's leading palm oil producer, including Indonesia, keeps growing their oil palm crops and production. There are 25 provinces in Indonesia where there are oil palm plantations. However, only five provinces South Sumatera, West Kalimantan, North Sumatera, Riau, and Central Kalimantan are the primary sources of palm oil due to their highest production capacity (Indriati, Elyani, and Dina 2020). Apart from producing crude palm oil, palm oil mills produce by-products in the form of waste. The waste consists of liquid waste from steam and hydro cyclone discharge, solid waste in OPEFB, shells, and sludge, and waste gas resulting from OPEFB or shell combustion (Zahan and Kano 2018). In 2017, 38 million tons of CPO, equal to 190 million tons of OPEFB, were produced in Indonesia. OPEFB might be available for more than 47 million tons annually because OPEFB yielded 20% CPO (Santi, Kalbuadi, and Goenadi 2019). Then in 2019, the total production was 14% more than in 2018, and the entire show was 34.7 million tons of palm oil (Nurazzi, Asyraf, Khalina, et al. 2021). Thus, it can be predicted that there will be an increase in solid waste production, one of which is OPEFB. If the "waste" OPEFB is not used and handled correctly, it will be a huge problem in the future.

Fiber composition

Natural fibers are biodegradable, affordable, sustainable, and have good thermal-physical characteristics. Consequently, many researchers have considered the potential use of thermal isolation for natural fiber processing (Ramlee, Naveen, and Jawaid 2021). The method for processing industrial and agro-industrial waste into lignocellulosic biomass includes using low concentrations of sulfuric acid material for hydrolysis to produce a more effective product because this acid has a more significant number of hydronium ions compared to other strong acids such as hydrochloric acid. Then, the pretreatment of the previous lignocellulosic raw materials, namely by boiling first, follows so that delignification is more effective and minimizes NaOH (Ahmad, Rita, and Noorjannah 2022).

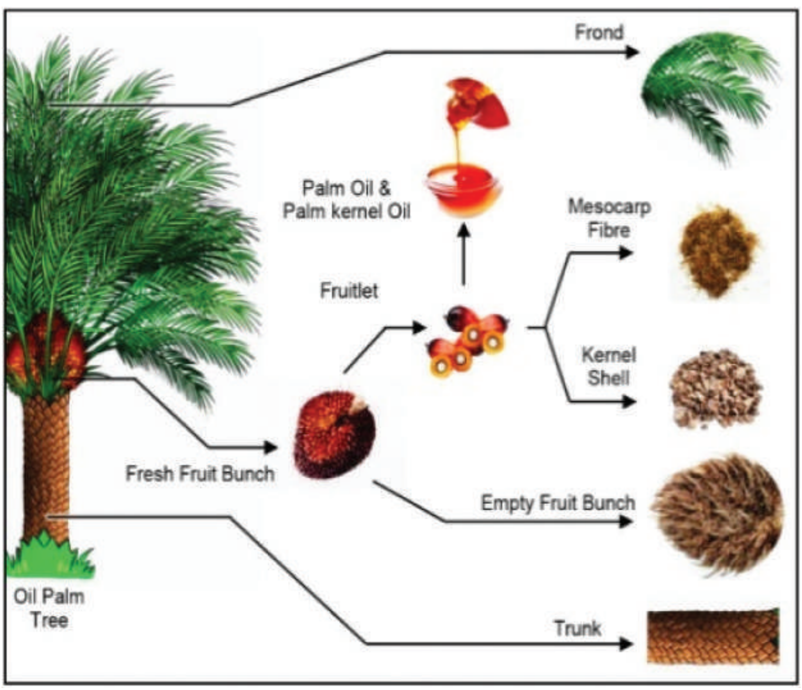

Figure 1. Oil palm biomass and derivatives. Reused with permission from elsevier citing (R. A. Ilyas, Zuhri, et al. 2022).

Table 1. Various studies of fiber composition of OPEFB.

Extractive (%)	Cellulose (%)	Hemicellulose (%)	Lignin (%)	Ash (%)	References
-	45.95	22.84	1.23	0.53	(Ahmad, Rita, and Noorjannah 2022)
1.3–4.2	37.26–63	14.6–37	17–31.7	1.2–6.7	(Indriati, Elyani, and Dina 2020)
7.49 ± 3.27	61.12 ± 2.66	10.56 ± 1.58	19.81 ± 0.09	0.83 ± 0.03	(Anita et al. 2020)
-	44.4	30.9	14.2	-	(Fahma et al. 2010)
1.34	37.26	14.62	31.64	6.69	(Sudiyani et al. 2013)
-	47.60	28.10	13.10	-	(Baharuddin et al. 2012)
-	59.70	22.10	18.10	-	(Abdullah, Sulaiman, and Gerhauser 2011)
1.46 ± 0.09	49.63 ± 0.64	21.32 ± 0.50	19.12 ± 0.42	6.23 ± 0.19	(Almeida et al. 2022)
-	65	-	19	2	(Alonge, Ramli, and Lawalson 2017)
-	48	22	25	-	(Hill and Khalil 2000)
-	47.9	17.1	24.9	-	(Mohanty, Misra, and Drzal 2005)
4.5	49.8	83.5	20.5	2.4	(A. H. P. S. A. K. Khalil, Alwani, and Omar 2006)
-	29.37	14.40	22.66	-	(Puspita et al. 2018)
-	22.5–25.3	24.5–27.8	24.5–27.8	-	(Nomanbhay, Hussain, and Palanisamy 2013)
-	42.85	11.70	24.01	-	(Rahman et al. 2007)
-	43–43.47	22.93–23.67	21.28–22.10	-	(Mardawati et al. 2014)

OPEFB, oil palm trunks, oil palm shells, and oil palm fronds are among the lignocellulosic biomass wastes produced by the palm oil industry, as shown in Figure 1.

Researchers have emphasized the significance of converting the large OPEFB biomass produced from oil palm plantations each year into a useful agricultural end product. Moreover, many researchers have sought to assess oil palm biomass's potential and adaptability in various industries (Omoniyi 2019). Table 1 displays various studies of fiber composition of OPEFB.

Morphology and single-cell dimensions

The morphology of OPEFB can be observed using the SEM method, as shown in Figure 2a (Lai et al. 2021). The SEM images depict the surface structure of OPEFB fiber at various magnification levels. The SEM micrograph of an untreated OPEFB fiber shown in Figure 2a was distorted, and the non-cellulosic materials that served as a protective covering have covered the cellulose microfibrils' surface (indicated by the blue arrow) (as marked by red circles). The cellulose surface was smooth, transparent, and has distinctive rod-like microfibrils, as displayed in Figure 2b.

According to research by Padzil et al. (2020), the isolation of nanocellulose from OPEFB using hydrolysis and continued ultrasonication resulted in a morphological dimension of nanocellulose synthesized at 17.85 nm. Nanocellulose OPEFB fibers produced from the vibration milling times

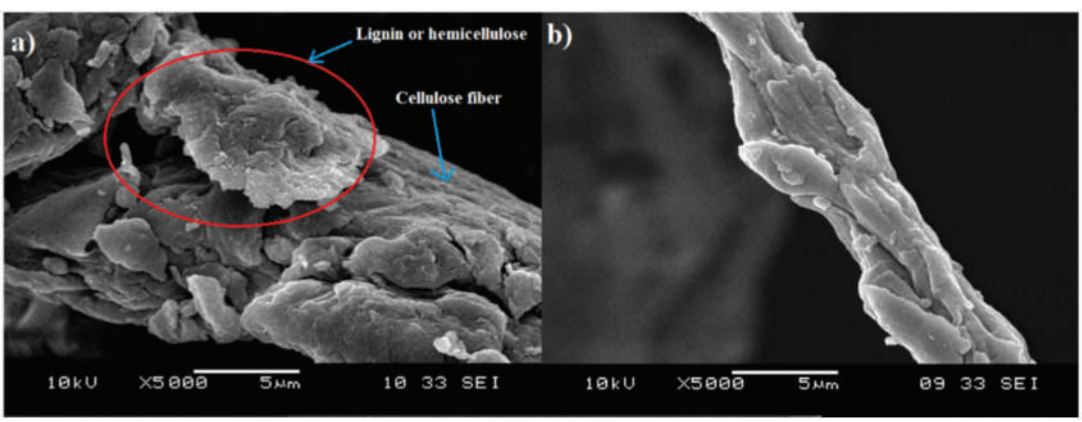

Figure 2. SEM image of (a) raw OPEFB and (b) treated OPEFB cellulose. Reproduced under common creative lisence from (Lai et al. 2021).

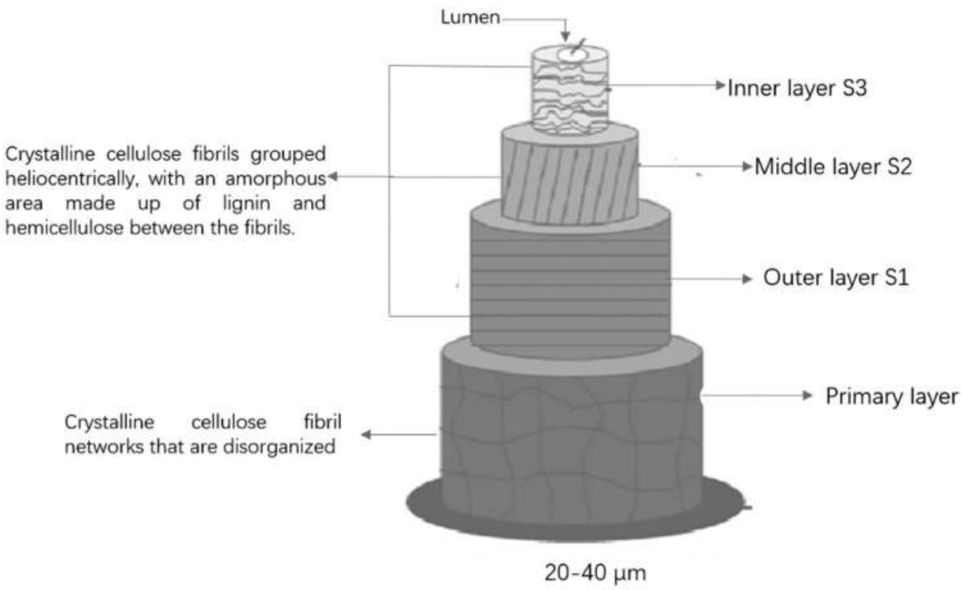

Figure 3. Schematic of OPEFB fiber structure.

Table 2. Structural properties of OPEFB as reported by various researchers.

Property	Range	References
Length, fiber	0.89–0.99 mm	(Jawaid and Khalil 2011)
Diameter, fiber	150–500 µm	(Sreekala and Thomas 2003)
Microfibrillar angle	46 °	(Kalam et al. 2005; R. Rama, Mohan, and Rao 2007; Sreekala and Thomas 2003)
Density	0.7–1.55 g/cm^3	(Kalam et al. 2005; A. H. P. S. Khalil et al. 2007; R. Rama, Mohan, and Rao 2007; Sreekala and Thomas 2003)

method have a size range of 53.72–446.80 nm. The morphology of nanocellulosic fibers has an outer surface that is uneven, irregular, folded, and uneven.

Structure

Figure 3. shows a schematic of the OPEFB fiber architecture. Plant fibers, such as OPEFB, are biological examples of fiber-reinforced composites held together by an amorphous lignin matrix. These composites are composed of helically coiled cellulose microfibrils like collagen that control the mechanical characteristics of connective tissues (Goh, Chen, and Liao 2014).

Table 2 provides an overview of the structural characteristics of OPEFB fibers. The composition table for each component uses data on fiber length, diameter, microfibrillar angle, and density from several sources. Compared to OPEFB fibers, the microfibrils have a 3–4 times smaller diameter, ranging from 10–30 nm, than the OPEFB fibers with 150–500 µm diameter (Gibson 2012).

Properties

Thermogravimetric analysis (TGA)

To ascertain the decomposition mass and thermal performance of the volatile OPEFB components, the change in mass at a constant temperature using the TG/DTG test was carried out (Rajisha et al.

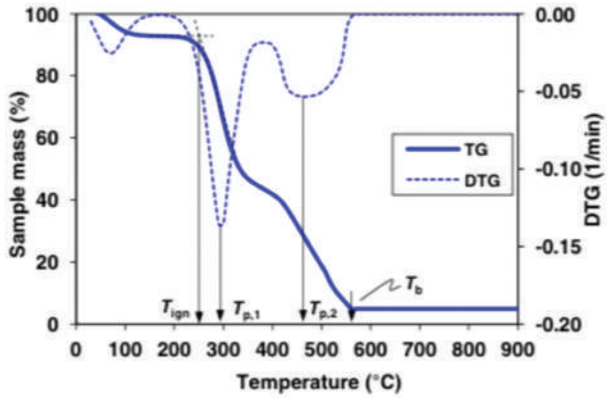

Figure 4. Curve thermogravimetric analysis OPEFB. Reproduced under common creative lisence (Ninduangdee et al. 2015).

2011). Based on Figure 4, the TG/DTG test of the OPEFB reported by Ninduangdee et al. (2015) was conducted at a heating rate of 20°C/min. During the temperature of 160–400°C, the decomposition of hemicellulose, cellulose, and a small amount of lignin occurred. The OPEFB DTG profile showed a peak temperature of 295°C, and in TGA, there was a decrease in peak at 340°C, indicating decomposition was taking place. Mass loss at temperatures exceeding 400°C resulted in (i) charcoal from decomposition decomposing of residual lignin and (ii) more oxidation in the air. The DTG curve stage linked with lignin decomposition had a 480°C maximum degradation rate for biomass. The ignition temperature (T_{ign}) and combustion temperature (T_b) based on examining the TG and DTG curves were 245 and 560°C for OPEFB. At a relatively low temperature of 295 and 340°C, OPEFB has burned efficiently. Thermal OPEFB degradation occurs in three stages: air content at 100°C, cellulose and hemicellulose degradation at 195 to 360°C, and oxidation at higher temperatures (Bhat et al. 2011).

Physical and Mechanical properties

Various authors have reported different mechanical properties for OPEFB fibers; as listed in Table 3. This variation by different factors such as the age of the mother plant and fiber after extraction, the condition of the surface of the fiber, namely exfoliated cells, skin damage, the surface treatment used, the length of the gauge, and variations in pressure in the test grip (Witayakran et al. 2017).

The tensile strength of OPEFB-based fiber reported by Anuar et al. (2019) was measured following the ASTM D3822–01 test method. According to the ISO 527–4:1997 standard, tensile strength was evaluated using a Shimadzu 10 kN universal testing equipment in accordance with the ASTM D638 standard. Furthermore, the flexural strength and modulus at a 2 mm/min crosshead speed followed the ASTM D790 standards. ASTM D3410-compliant composite panel compression testing.

Moisture absorption

The test of moisture absorption did not regulate the relative humidity at room temperature. The samples were dried for 24 hours at 50°C in an oven. Before the absorption test, the samples were

Table 3. Physical and mechanical properties of OPEFB fiber.

Tensile Strength MPa	Elongation at Break %	Young's Modulus MPa	Toughness MPa	Density (gr/ cm^3)	References
100–400	8–18	1000–9000	-	0.7–1.55	(Dungani et al. 2014)
15.9	30	2900	-	1.5	(Anuar et al. 2019)
100–400	14	1000–9000	-	0.7–0.50	(Adam and Asik 2019)
71	11	1703	-	-	(M. Y. Zuhri 2009)
248	14	6700	-	-	(P. R. Rama and Ramakrishna 2021)

weighed to ascertain their original weight. The moisture absorption was calculated using the equation below:

Moisture absorption (%) = $\frac{W_h - W_o}{W_o} x100\%$

Where: W_h is the final weight, and Wo is the initial weight of samples (Abral et al. 2020).

The results reported by Babaee et al. (2015) revealed that OPEFB untreated composites showed lower moisture absorption rates than treated composites. In general, when nanocellulose is under chemical treatment, the nanocellulose becomes more hydrophobic, resulting in a decreased or diminished attraction to moisture. However, Samat et al. (2020) showed that OPEFB composites with fibers longer than 250 μm had a more significant effect on water absorption than other composites. Similar to other lignocellulosic materials, OPEFB contains lignin, hemicellulose, and cellulose. Hemicellulose and cellulose are hydrophilic and linked to polar OH groups, according to Mokhothu and John (2015). This experiment did not include OPEFB fibers without chemical treatment. As a result, the fibers were expected to be longer and contained more hemicellulose and cellulose at a higher fiber load, increasing the interaction between fiber and moisture.

Hydrophilicity

OPEFB fiber contains hydroxyl groups (OH), which makes it hydrophilic (Firmanda et al. 2022). A noteworthy feature is the variation in crystalline black and white cross sections in the untreated material. Untreated specimens have several characteristics with previously reported features. The steps outlined in the literature by Gunawan et al. (2009) described cleansing using fresh or distilled water. The hydration impact occurred on various length scales, including the molecule and whole fiber levels (Kalia et al. 2011).

Figure 5a shows the molecular effect by illustrating a schematic of the molecule interaction with hydrogen bonding. The small size of the water molecule allowed it to permeate into the space between the cellulose and lignin groups. After then, hydrogen-bonded linkages formed between the hydrogen ends of the molecules and the hydroxyl groups in cellulose and the lignin groups in OPEFB fibers. Figure 5b depicts two potential hydrogen types with OPEFB fibers. The capillary action theory explains air entering the OPEFB fiber resulted in a hydrating impact throughout the entire fiber.

Additionally, the air carried to the OPEFB depends on the structure's diameter and gravity (Sreekala et al. 2001). Due to the OPEFB fiber's porous cross-section, capillary action occurred at both ends of the fiber, causing the porous structure on the fiber surface to grow and develop. As a result, when air entered the porous tubular structure of the OPEFB fiber, to achieve a force balance between the air pressure and reactive reactivity on the wall, the philosophy behind the front exerted pressure and forced the tubular construction to stretch radially. The outcome is a considerable increase in cross-sectional area, weight, and density.

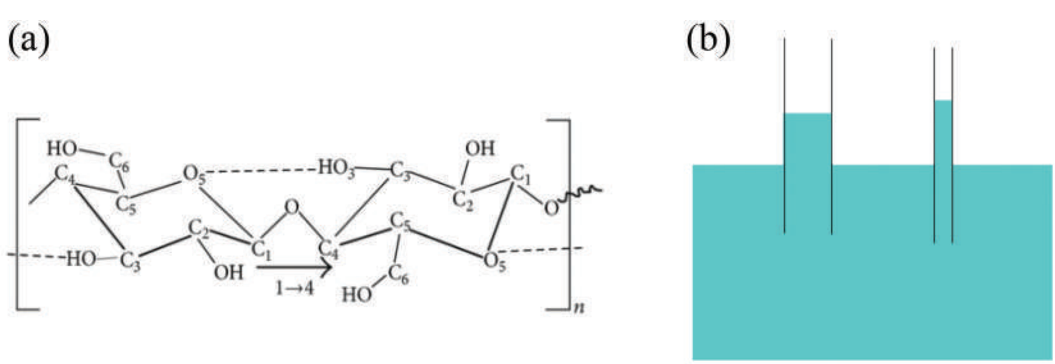

Figure 5. Hydration, a. Interaction between single cellulose chain repeat unit and hydrogen bonding. Reproduced under common creative lisence from (Khazraji and Robert 2013) b. Diagram of capillary action.

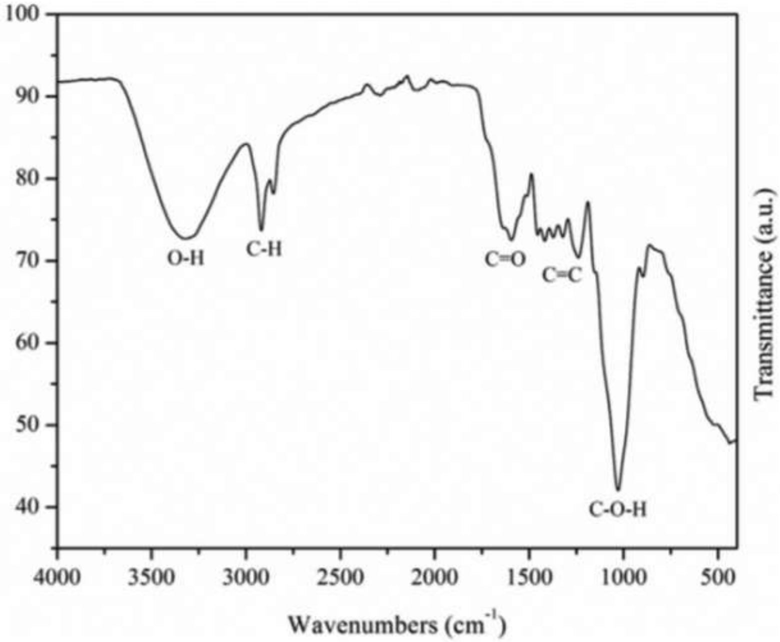

Figure 6. Spectra FTIR raw OPEFB. Reused with permission from elsevier citing (Wong et al. 2020).

Increases in weight and cross-sectional area increase specimen density from a structural perspective (Sreekala and Thomas 2003).

Ftir

The crude OPEFB showed characteristic bands of lignocellulosic based on Figure 6. The broad band at 3327 cm^{-1} corresponded to the O-H stretching mechanism of cellulose, hemicellulose, and lignin. In comparison, some peaks corresponded to the C-H and C=O stretching modes observed at 2918 and 1593 cm^{-1}, respectively. Peaks between 1200–1500 cm^{-1} represent aromatic lignin's C – C stretch (Wong et al. 2020).

Research by Zulkiple, Maskat, and Hassan (2016) reported absorption bandwidth related to the hydroxyl stretching vibration (O-H) around 3329.89 cm^{-1} for samples showing exposure to the cellulose structure. Then another prominent broad band was defined for the cellulose characteristics at 1051–1025 cm^{-1}, corresponding to the C-O-C pyranose stretching mode (Rayung et al. 2014; Zulkifli et al. 2015). The peak at 2900 cm^{-1} with C-H stretching while the small peak at 896 cm^{-1} was cellulose containing β-glycosidic cellulose between glucose units (Cheng et al. 2014; Fahma et al. 2010; Nasution, Yurnaliza, and Sitompul 2017).

Then, data for absorptions band functional group cellulose, hemicellulose, and lignin in other authors' works are listed in Table 4. Absorption bands for functional groups.

Modification of OPEFB fibers

Isolation nanocellulose from OPEFB

Alkali pre-treatment

Alkali is a pre-treatment agent transport technique. Cellulose, hemicellulose, and lignin are the chemical components involved in the interaction between lignocellulose and an alkaline solution (Figure 7). Lignin dissolved and degenerated as a result of the reaction. Alkali pre-treatment can

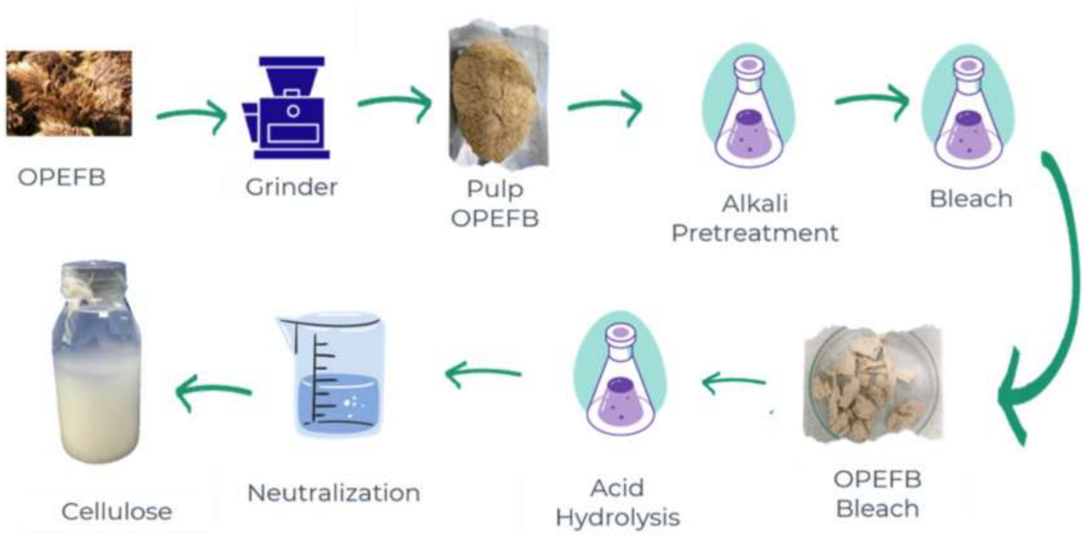

Figure 7. Schema isolation cellulose from OPEFB.

Table 4. Absorption bands for functional groups.

Fiber Component	Wave number (cm^{-1})	Functional group	Compounds
Cellulose	4,000–2,995	OH	Acid, methanol
	2,890	H-C-H	Alkyl, alphatic
	1,640	Fiber-OH	Adsorbed water
	1,270–1,232	C-O-C	Aryl-alkyl ether
	1,170–1,082	C-O-C	Pyranose ring Skeletal
	1,108	OH	C-OH
Hemicellulose	4,000–2,995	OH	Acid, methanol
	2,890	H-C-H	Alkyl, aliphatic
	1,765–1,715	C=O	Keton and carbonyl
	1,108	OH	C-OH
Lignin	4,000–2,995	OH	Acid, methanol
	2,890	H-C-H	Alkyl, aliphatic
	1,730–1,700		Aromatic
	1,632	C=C	Benzene streaching Ring
	1,613, 1,450	C=C	Aromatic skeletal mode
	1,430	O-CH3	Methoxyl-O-CH3
	1,270–1,232	C-O-C	Aryl-alkyl-ether
	1,215	C-O	Phenol
	1,108	OH	C-OH

effectively disrupt ester linkages by crosslinking xylan and lignin by solvation and saponification (Liu et al. 2018).

Isolation of cellulose from various alkaline methods for isolation OPEFB based Chieng et al. (2017) formed nanocrystals with 4 wt.% NaOH solution at 80°C for 3 h, then bleached at 80°C for 4 h using equal parts of acetate buffer of glacial acetic acid, aqueous chlorite, and distilled water. Latip et al. (2018) used 15% (w/v) of NaOH solution at 130 min then the treatment was repeated using two other alkali solutions, which were KOH and ($Al(OH)_3$).

Acid hydrolysis

Acid hydrolysis is now the most used process for producing nanocellulose. It is necessary to consider the kind of acid, its concentration, reaction mechanism, reaction temperature, pace of mixing, and

Table 5. Various pretreatment techniques for cellulose.

Pretreatment method	Method	Advantage	Disadvantage	Ref.
Enzymatic/biological processing of lignification	A set of oxido reductases can degrade undesirable lignocellulosic components like lignin. This system contains peroxidases and laccases with high redox potential that can directly oxidize the structural polymer of lignin or attack the lignin structure by diffusing into the pores of the plant cell wall.	Environmentally responsible method, Low-cost prerequisite, No dangerous chemicals are needed, Under benign reaction circumstances, the less energy-intensive process can be completed.	Slow motion, some components of biomass such as cellulose and hemicelluloses, may be broken down by native or alien microbes.	(Vasco, Ge, and Li 2016)
Chemical pretreatment	Reduces the biomass's degree of plant cell polymerization by using a moderate alkaline or acid to remove lignin and a portion of the hemicellulose.	Under medium pressure and temperature, remove the acetyl and the lignin. The cellulose crystallinity index (CI) being raised	Less economical inappropriate for bioconversion that doesn't harm the environment. High creation and disposal of chemical waste	(Foo et al. 2019; Zianor et al. 2017)
Ionic liquid pretreatment	The pretreatment of biomass with [bmimHSO4] (1-butyl-3- methylimidazolium hydrogen sulfate) is carried out under controlled conditions for one hour at a temperature of about 80 C.	High solvating power, highly chemically and thermally stable biomass extracted.	The used solvent is reasonably pricey.	(Elgharbawy et al. 2016)
Sono-assisted (Ultrasonic) organosolv/ H2O2 pretreatment;	Using liquid peroxide, biomass can be pretreated quickly and at lower temperatures to recover its cellulose. It is commonly combined with 2% aqueous NaOH and 80% ethanol (1:3 v/v) and placed in the ultrasonic cleaning bath at 60C for 60 minutes before being cleaned.	Optimize the inputs of materials and energy. By shortening process times and operating temperatures, you can increase energy efficiency.	Does not considerably increase cellulose output.	(Ofori and Lee 2014)

length of the reaction when carrying out the method. The most often utilized acids among these are hydrochloric and sulfuric (Marakana, Dey, and Saini 2021).

Diverse organic acid and mineral acid-based acid hydrolysis OPEFB are also gaining popularity. Haafiz et al. (2013) used 2,5 N HCl at 105 ± 2°C for 30 min to synthesize microcrystalline cellulose. Septevani et al. (2020) used sulfuric acid and phosphoric acid at 50°C for 3–5 hours to obtain nanocellulose.

Surface modification

Pretreatment method for cellulose production as shown in Table 5.

Chemical treatment

Natural fibers, which get their hydrophilic qualities from lignocellulosic materials, can interact poorly with hydrophobic matrix polymers. Additionally, the hydrophilic nature results in water absorption and fiber deterioration due to microbial attack (A. Khan et al. 2020). Chemically altering the fiber's surface can resolve this issue, replacing part of the hydroxyl groups, which can give the cellulose the necessary hydrophobicity (Indarti, Marwan, and Wanrosli 2019). Chemical fiber modification can also improve the interface bond's compatibility with the fan base matrix reinforcement. To maximize the availability of active OH groups for interlocking with the polymer, fatty acids, undesirable impurities, and other contaminants are removed from the fiber surface using chemical processes such as alkali treatment (A. Khan et al. 2020).

Chemical modification was carried out by Ajazi et al. (2023) using the benzoyl chloride method. Cellulose was reacted with a sodium hydroxide solution mixture and sonicated, then benzoyl chloride was added in an alkaline solution with sodium hydroxide solution. The modified cellulose precipitate was then filtered and dried in an oven.

Mechanical treatment

One of the possible mechanical modifications is superheated steam (SHS) treatment, as done by Warid et al. (2016) by putting OPEFB in a superheated steam oven. The results obtained can denature OPEFB by removing hemicellulose and lignin. This treatment also reduced moisture, removed silica bodies from the surface, and increased the thermal stability of the fibers. Modifying the fiber texture can make it more compatible with the hydrophobic polymer matrix. SHS treatment will be preferred as a non-chemical treatment strategy to produce ecologically acceptable products such as composites as it is a more environmentally friendly procedure.

High-pressure homogenization is the mechanical process of transforming separate cellulose into nanocellulose. It is a successful and efficient method for biomass refinement due to its simplicity, high efficiency, and cautious use of organic solvents. Since cellulose frequently jams the valves of the homogenizer, it must first be processed using a steam explosion, a microfluidizer processor, or some other technique. Ionic liquids (IL) have recently gained popularity due to the exceptional ability of cellulose to dissolve at ambient temperature. Additionally, this component uses cryo-crushing with liquid nitrogen, where the cellulose pulp is frozen using liquid nitrogen and then crushed. To reduce microsized particles to nanosize, high-speed ball milling is a typical mechanical procedure (Marakana, Dey, and Saini 2021).

Physical treatment

The composite can be strengthened by making individual filaments, first dividing the fiber bundles to prevent agglomeration problems. This modification can be done through physical treatment, namely modifying the fiber to maximize compatibility with composite reinforcement applications. One way to avoid agglomeration is using ultrasonication, defined as sound with a frequency above the audible range (above 25 Hz). Longitudinal waves are created in water molecules due to the complete transmission of sound waves through a liquid bath, generating smoothing and compression waves. The shock wave is created by the small bubbles created by the sudden collapse of the compression wave. So, micro-jetting and micro-streaming are two methods used to clean the fiber surface. When the bubbles and fiber surfaces collide in micro-flow, intermolecular tearing occurs. Oscillating bubbles rub the fiber's surface during micro-flow (A. Khan et al. 2020).

Sulaiman et al. (2022) modified the physical treatment using bleached OPEFB fiber and added distilled water to the suspension before ultrasonication. Then, the beaker containing the suspension was placed in an ice bath to minimize overheating of the fiber because fiber samples can burn due to high-intensity waves. Samples were collected by centrifugation and freeze-dried.

Microwave treatment

Microwave treatment is a promising biomass treatment method because it can effectively break down the lignocellulosic structure, which causes the cellulose structure to open so that cellulose access becomes easier during enzymatic hydrolysis. Microwave heating is direct, fast, and uniform. This technology is considered green because it consumes less energy than conventional heating, reduces emissions, and helps protect the environment because it does not produce wastewater, exhaust gases, or other waste products (Gong, Liu, and Huang 2010).

Solihat et al. (2017) modified OPEFB with microwave treatment using OPEFB added with oxalic acid in a Teflon tube and then placed in a microwave oven at a predetermined temperature and time. Furthermore, the suspension was removed from the fraction solution with filter paper and washed until neutral. Then the samples were analyzed.

OPEFB composite

The recent development of the OPEFB composite

Utilizing oil palm wastes has recently become an exciting technique for creating durable polymer matrix composites. But one of the most critical aspects of how these materials perform over time is how they absorb water (Almeida et al. 2022). In various industrial sectors over the past ten years, the usage of natural fibers as reinforcement in polymer matrices has increased. It is essential to prioritize utilizing agroindustrial wastes as raw materials to build ecologically friendly, highly productive, and commercially successful composites; it is preferable to prioritize using agroindustrial wastes as raw materials (Valle et al. 2022).

The three primary categories of polymers, sometimes known as plastics, are thermoplastics, thermosets, and elastomers. Thermoplastics have the property of being easily bent and becoming softer as the temperature rises. Cross chains known as elastomers can grow the number of lateral links until they transform into thermosets. High crosslinking levels prevent thermosets from softening before breakdown occurs (Carmona 2021).

Three critical criteria the matrix, the reinforcement, and the interfacial adhesion are used to categorize composite materials (understood as connectivity). Because the dispersed phase's proportion, size, form, distribution, and orientation impact the ultimate qualities of a composite, it is crucial to have it (Dai and Fan 2013). As a result, the properties of the elements added together include those of the composite.

Oil palm empty fruit bunch (OPEFB) reinforced thermoset composite

A well-established technique for enhancing thermoset polymers' toughness and other fundamental mechanical properties is the introduction of nanoparticles (Marouf et al. 2016). If the nanostructured particles are evenly disseminated throughout the polymer matrix, their huge specific surface areas can create a sizable interfacial area (Zamanian, Ghasemi, and Mortezaei 2021). Due to the ability to alter polymer characteristics in the artificial region, resemblance to molecular form, and nanoscale size of the filler particles, nanofillers interact more strongly with thermoset polymer matrices (Khostavan et al. 2019; Zabihi and Mostafavi 2012). Therefore, the comparatively low filler concentration makes a higher polymer percentage with changed properties possible (Hsissou et al. 2021). In work conducted concurrently, OPS nanoparticles were impregnated using a vacuum pressure approach with OPT and phenol formaldehyde (PF). Because there is less water absorption and a lower expansion coefficient, the resulting composite has a substantially higher anti-swelling efficiency. The flexural, tensile, and impact strengths were more significant than the control samples. The flexural and tensile modulus increased from 4.35 to 4.95 GPa and 2.67 to 3.51 GPa, respectively. The elongation at break was currently nearly steady. OPS nanoparticles were added to the composite; as a result, improving its heat stability. The most significant developments in terms of thermal, physical, and mechanical qualities were from composites that were made that contained 5% OPS nanoparticles (Dungani et al. 2014)

Oil palm empty fruit bunch (OPEFB) reinforced thermoplastic composite

Utilizing waste from palm oil production has recently gained popularity for creating sustainable polymer matrix composites. Valle et al. (2022) noted that OPEFB, which comes in two fiber sizes (605 and 633 μm) was combined with thermoplastic acrylic resin to create a natural fiber-reinforced polymer matrix composite. A filler content of 42 wt.% was maintained for all formulations while the resin and fiber were combined at room temperature. Thermomechanical compression molding was applied at four processing temperatures (80, 100, 120, and 140°C) as a composite production method. After that, all compositions underwent 330 h of salt mist spray aging. Overall, the findings have shown that a simple process for developing composites based on a water-borne acrylic matrix and OPEFB fibers is feasible.

Teixeira et al. (2009) conducted a study to see how adding nanocellulose affected the properties of TPS when glycerol and sorbitol were used as plasticizer. The hydrophilicity of the TPS matrix decreased by adding nanocellulose to it. Fahma et al. (2010) reported that including nanocellulose up to 3% by weight enhanced the tensile strength and crystallinity of thermoplastic cassava starch composite films.

Composite manufacturing methods

Various manufacturing methods exist for successfully developing composites, such as an injection mold for OPEFB fiber-reinforced thermoplastics. The selection of a particular manufacturing process depends on the type of polymer (thermoplastic or thermoset) used to develop OPEFB composites (Mazumdar 2002). The manufacture of thermosetting composites is easy because of lower costs, better fiber wettability, and less heat and pressure required during curing. Thermoplastic composites are very popular in the aerospace and automotive industries (M. Z. R. K. Khan and Srivastava 2018). Table 6. shows different manufacturing methods, processing techniques, and composite characteristics.

Table 6. Manufacturing methods for composite development (M. Z. R. K. Khan and Srivastava 2018).

Methods	Operation	Characteristics
Compression Molding	A compressive load is applied through the top of the mold; The fiber-matrix mixture is placed inside heated closed molds.	Thermoset polymer, high production, multiple part development
Injection Molding	The required amount of matrix and fiber mixture is injected into the mold cavity of the extruder.	High production rates, compability with both type of resin
Hot Press	Stacked thermoplastic dough together between the mold is heated and compressed.	Can be operated by personal
Liquid Transfer Molding Process	The resin is injected into the fiber carrier closed mold with a mold cavity having vacuum pressure.	High fiber volume fraction, heat transfer are the major constraints.
Hand Lay-Up Method	The fiber-matrix mixture is placed manually into the open mold using light pressure by the rollers to remove trapped air.	which is better compatibility with the thermoset, low cost, size constraintss

Circular economy strategy

The concept of a circular bioeconomic emphasizes "'reduce, reuse, and recycle" to eliminate unnecessary waste, including eliminating the use of raw materials, energy, and overall carbon emissions production cycle. This concept includes remanufacturing products for use as raw materials or as part of raw materials and a by-product production to generate income. In other words, it could be wasting waste. The previous concept of linear economics referred only to the conditions of the "take, make, use, dispose of'" model, where raw materials are used to make products, sold for consumption, and disposed of at the end of their life cycle without considering eco-friendly alternatives including reuse, recycling, and waste valuation. The by-products generated in the palm oil industry are mostly reused and recycled. Essential moving toward a more strategic approach is how well these practices are implemented in the industry and how well performance is contributing to sustainability (Cheah et al. 2023).

Properties of OPEFB composite

Compatibility of OPEFB

Both Figures 8 (a) and (b) depict the scanning electron microscopy (SEM) images of the biocomposite films' tensile fracture surfaces at 2 and 4 wt.%, respectively. The fracture surface of biocomposite films had low agglomerations and was well dispersed, as demonstrated by the 2 wt.% of OPEFB contents (Figure 8 (a)). This morphology indicated that the OPEFB particles were present before dissolution and fragmented throughout the process. Since the biocomposite film was homogeneous, it might be presumed that the OPEFB fillers have dissolved and reinforced within the OPEFB matrix. However, as shown in Figure 8 (b), biocomposite films showed a rough surface when the OPEFB content increased. Compared to OPEFB at 2 wt.%, the morphology of RC biocomposite films containing 4 wt.% OPEFB was more irregular. The tensile strength of biocomposite films at 2 wt.% OPEFB contents, which was higher than 4 wt.% OPEFB contents, validated this finding. When compared to Figure 8 (b), the SEM micrograph in Figure 9 (a) exhibited fewer voids and agglomerations (Zailuddin and Husseinsyah 2016).

The untreated OPEFB fiber in Figure 8 had a relatively smooth surface covered with wax, lignin, and hemicellulose that stopped the fiber from rupturing. After processing, the surface fiber significantly changed due to removing particular inter-fiber material (Latip et al. 2018).

Mechanical properties

Thermoplast (TPS)-based plastics must have similar mechanical and barrier qualities as traditional plastic to compete with it. However, this is particularly challenging due to the hydrophilic rates that

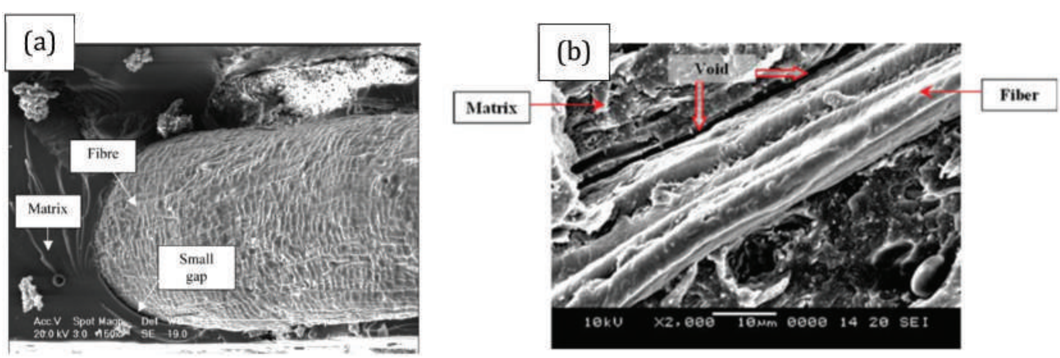

Figure 8. SEM micrograph of composite fiber with different matrix (a, left) matrix epoxy (b, right) matrix PVC. Reproduced under common creative lisence from (a) Arif et al. (2010) and (b) Hassan et al. (2010).

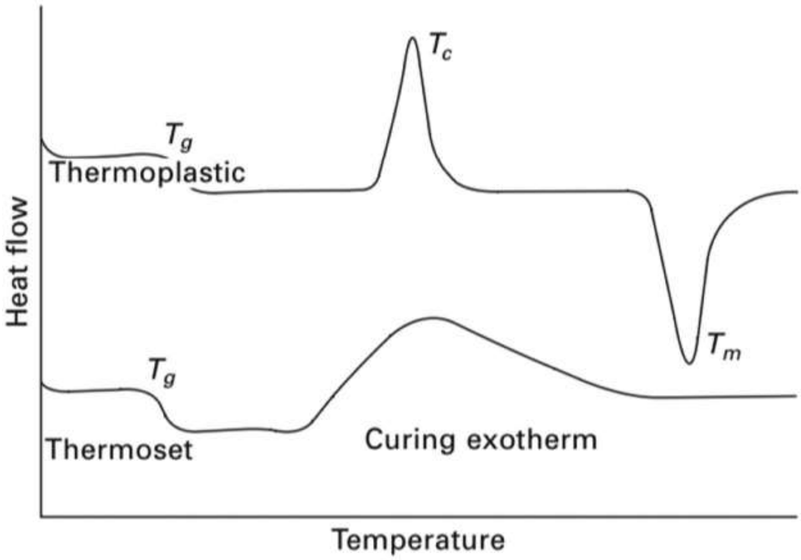

Figure 9. Curve DSC for thermoplastic and thermoset. Reused with permission from elsevier citing (Ratna 2012).

thermoplastic starch inherited and its high susceptibility to environmental moisture absorption. With rising humidity, thermoplastic starch's mechanical characteristics degrade exponentially (Lai et al. 2021). Adding inorganic or organic fillers enhances mechanical strength and barrier qualities (Osman et al. 2021). The tensile toughness value will increase as the area under the curve increases, indicating that the polymer exhibits better tensile strength and elongation at the break due to a more effective energy absorption mechanism (Miles, Ball, and Matthew 2016). Bakar et al. (2005) conducted a study examining the impact of incorporating OPEFB on the mechanical and thermal characteristics of unplasticized poly(vinyl chloride) (PVC) composites. The inclusion of OPEFB fibers in the PVC-U matrix resulted in an enhancement of the flexural modulus. This improvement can be attributed to the restriction of segmental mobility of the polymer chains in close proximity to the fibers. The introduction of OPEFB at a concentration of 10 wt.% within PBS/starch/glycerol led to an increase in flexural properties, yielding a value of 85 MPa. However, an inverse relationship was observed between the impact strength of the composites and the OPEFB fiber content. This decline can be attributed to factors such as fiber agglomeration, inadequate dispersion, and moisture absorption. The effect of various weight percentages of kenaf and OPEFB hybrid compositions, as well as fiber fractions (wt.%), on the mechanical and thermal properties of unsaturated polyester (UPE)/epoxidized palm oil (EPO) composites, was investigated by Mustapha et al. (2022). The study focused on three different kenaf/OPEFB hybridization compositions: 100/0, 90/10, 70/30, and 50/50 (wt.%), at three different fiber weight fractions (9, 12, and 15%) reinforced in UPE/EPO resin. The alkali treatment effectively eliminated a significant portion of the moisture, cellulose, and hemicellulose in both kenaf and OPEFB fibers. The mechanical analysis demonstrated that a higher proportion of OPEFB in the kenaf/OPEFB hybrid fiber composition enhanced Young's modulus, tensile strength, elongation at break, and impact strength of the resulting composite, particularly at 9 and 12% fiber fractions. Table 7. Shows the thermoset and thermoplastic polymer mechanical properties.

Thermal properties of OPEFB composites

Figure 9. shows DSC curves illustrating melting, crystallization, and glass transition. The first derivative of the free energy (enthalpy) versus temperature graphs constantly during melting is a first-order thermodynamic change. Melting is a characteristic of crystalline materials characterized by

Table 7. Thermoset and thermoplastic polymer mechanical properties.

Thermoplastic

Fiber Type	Matrix	Treatments	Flexural Strength (MPa)	Flexural Modulus (GPa)	Tensile Strength (MPa)	Tensile Modulus (GPa)	Impact Strength (kJ/m^2)	References
Oil palm mesocarp 5–25 wt.% (300 mesh)	ILDPE	– OPMF/LLDPE was created using the hand lay-up technique. The mixture was then heat for 20 minutes at 150°C in an aluminum mold with 295 × 210× 6 mm dimensions.	-	-	7.3–9.0	0.2–0.3	97–160	(Olusunmade, Adetan, and Ogunnigbo 2016)
OPEFB 8–25 wt.% (300–600 µm)	PBS/starch/glycerol	– Using an industrial extruder, the hybrid composites were created at a temperature between 115 and 145°C and an 80 rpm rotating speed. – After melting the compound, it uses a calendaring machine to create a sheet.	55–69	2.8–3.3	-	-	7–11	(Bakar, Hassan, and Yusof 2005)
OPEFB 30–49 wt.% (75µm)	Unplasticized PVC	– A high-speed mixer was used to combine PVC and OPEFB for 10 minutes. The two roll mill was used to sheet – The dry-blended PVC material for 10 minutes at 165°C. – The mill sheet underwent a 5-minute hot pressing process at 180 C and 120 kg/m^2 of pressure.	55–69	2.8–3.3	-	-	7–11	(Bakar, Hassan, and Yusof 2005)
OPEFB 5 vol.% (10–20 mm)	Epoxy	– Hand lay-up techniques were used to create epoxy/OPEFB composites, which were then pressed to a 3 mm.	40.9	3.2	29.9	1.4	-	(M. Y. M. Zuhri et al. 2010)
Oil palm shell 30% (1.0–2.8 mm)	Unsaturated polyester (UPE)	– 1% methylethylketone peroxide (MKEP) was added to the compression mold technique used to create OPS-reinforced UPE, which was then given 24 hours to cure.	-	-	20	8.5	-	(Sahari and Maleque 2016)
OPEFB 12 wt.% (2 cm)	Unsaturated polyester (UPE)/ epoxidized oil palm (EPO)	– Blended UPE/EPO made by combining 15% EPO and 85% UPE. On the hot plate, the mixture was stirred at a temperature of 55 C. At 1.5 phr, benzoyl peroxide (hardener) was added to the mix. – 6% NaOH solution was applied to kenaf and OPEFB fiber for 3 hours at room temperature. – Mats made of hybridized kenaf/OPEFB fiber were put within an aluminum mold. UPE/EPO was poured until the resin wholly coated and drenched the fibers. The composite was allowed to cure for two hours at 100°C in the oven.	-	-	1.3	1.5	1.8	(Mustapha et al. 2022)

a sharp peak in the DSC, which is the heat flow versus temperature plot. Thermosets can not melt, but some crystal segments can experience melting, polyurethane being one example. In comparison, thermoplastic is easy to melt. A steep peak in the DSC, or heat flow versus temperature, indicates softening, a property of crystalline materials. Although thermosets cannot melt, specific crystal segments, like polyurethane, can. In contrast, thermoplastic dissolves easily (Ratna 2012).

Application of OPEFB composite

The potential for OPEFB composites as materials for high-performance applications is enormous. The qualities of OPEFB can be improved with much work, specifically through fiber alterations, hybridization with other natural fibers in a synergistic way, the use of additives and enhancers in composites, and the implementation of appropriate manufacturing processes for different purposes. Creating OPEFB composites for high-performance applications across various industries is possible. Due to its comparable mechanical properties to synthetic fibers, low manufacturing cost, acceptable thermal and acoustic characteristics, and environmentally friendly processing, oil palm lignocellulosic fiber is an attractive replacement material for polymer composite (Asyraf et al. 2022). Figure 10 shows the application OPEFB composite.

Natural fiber-reinforced polymer composites have been widely used in numerous industries to produce various items, including biorefinery OPEFB vis-a-vis composites. This progress has been recorded during the previous few decades (Norizan et al. 2019; Panigrahi 2010) for biodegradable packaging materials (A. Khalil et al. 2017) and structural and construction materials. Furthermore, biomass from oil palm is used to make high-performance polymers for use in ballistic and bulletproof applications (Nurazzi, Asyraf, Khalina, et al. 2021), thermal

Figure 10. Application OPEFB composite.

Table 8. Potential application of OPEFB fibers reinforced composites for building and construction materials.

Title	Parametric study	Remarks	Ref.
Potential of Oil Palm (Elaeisguineensis) Empty Fruit Bunch Fibres Cement Composites for Building Applications	- Pre-treatment of fibers with water at varying temperatures - Chemical additive (NaOH) concentrations at different levels	- Pre-treatment of fibers enhanced sorption resistance and mechanical properties. – NaOH concentration and fiber content influenced composite properties.	(Omoniyi 2019)
A preliminary study on the oil palm empty fruit bunch-polyurethane (EFB-PU) composites	– Reacting EFB and PEG with MDI – Determining OH content by reacting EFB with phthalic anhydride	– Flexural and impact properties influenced by EFB percentage and reinforcing effect – PU matrix crucial for stress transfer to filler	(Rozman et al. 2010)
Empty Fruit Bunches as a Reinforcement in Laminated Bio-composites	- Laminate configuration (Five-ply veneer laminated bio-composites) – Alternately arranging oil palm trunk veneer and EFB mat	- Improvement in mechanical, physical, and thermal properties - better water absorption, thickness swelling, bending strength, bending modulus, screw withdrawal, and thermal stability	(A. H. P. S. Khalil et al. 2010)
Tensile, physical and morphological properties of oil palm empty fruit bunch/sugarcane bagasse fiber reinforced phenolic hybrid composites	– Effect of hybridized	– Hybrid composites show better performance and properties – 7OPEFB:3SCB hybrid composites have highest tensile strength and modulus	(Ramlee et al. 2019)
Characterization of Polymeric Foam Composite Reinforced with Empty Fruit Bunch	Effect of nano EFB as a filler in foam composite	- loading with 15% wt. of EFB showed the best tensile strength. - increased EFB loading, increasing the thermal stability.	(Adlie et al. 2019)
Morphology and properties of EVA/empty fruit bunch composites	Effects of the fiber and vinyl acetate (VA) contents of the ethylene vinyl acetate	- SEM micrographs show fiber pull-outs and voids in EUO18/EFB composites. – No intimate contact between EUO18 and EFB.	(Sefadi and Luyt 2012)
Simultaneous effects of coupling agent and flame retardant on empty fruit bunch fiber/polypropylene composites	Effect of coupling agent	- Tensile strength and flexural modulus of treated empty fruit bunch fibers-composite with malic anhydride grafted polypropylene and flame retardant increased by 23% and 133% more than the corresponding composite without these additives.	(Beg et al. 2013)
Effects of Chemical Treatment on Oil Palm Empty Fruit Bunch Reinforced High Density Polyethylene Composites	- Effect of chemical treatment such as silane treatment (MTS and VTS)	– Chemical treatments enhanced tensile strength and modulus - Composites treated with 3% silane treatment (MTS) showed highest reduction in water absorption and increase in tensile strength and modulus.	(Arif, Yusoff, and Ahmad 2010)
Oil palm empty fruit bunch filled polypropylene composites	– Effect of fiber loading	– Tensile strength of composites increases with increasing EFB loading up to 20% in the presence of acrylic acid and dicumyl peroxide. – Elongation at break shows a decreasing trend with increasing filler loading.	(Wirjosentono and Ismail 2004)

(Continued)

Table 8. (Continued).

Title	Parametric study	Remarks	Ref.
The Physical Properties of Oil Palm Empty Fruit Bunch (EFB) Composites Made from Various Thermoplastics	- Properties of EFB reinforced PE, PP, PS and PVC	- Flexural modulus increased for EFB-PE and EFB-PP composites. - Flexural modulus decreased for EFB-PS and EFB-PVC composites.	(Rozman et al. 1999)
Properties of Empty Fruit Bunches Eco-Composite Boards from Elaeis guineesis	– Effect of density and resin content of fiber board	-increased density of fiber board up to 700 kg/m^3 increasing the maximum modulus of rupture and modulus of elasticity	(Wahab, Rasat, and Don 2017)
Mechanical performance of oil palm empty fruit bunches fiber reinforced polyester resin	Effect of volume fraction.	- loading with 50%wt. of EFB offers a highest tensile strength (22.31 N/mm^2). – Water absorption increased with increasing percentage of EFB.	(Adam and Asik 2019)
Preparation and characterization of polyvinyl alcohol/oil palm empty fruit bunch fiber composite	Effect of fiber loading	– Tensile strength of composite increases with EFB fiber – filler plays important role in determining mechanical properties	(Ching et al. 2014)

insulators, concrete building material, water treatment using carbon activation, and automotive disk brake pads (Sahari and Maleque 2016). Additionally, oil palm biomass waste has been used to create a variety of products with additional value, such as pulp and paper production, nanocomposites, thermoset and thermoplastic composites, oriented strand board, blockboard, and laminated veneer lumber, as well as particle, polywood, chip, and hardboard (Suhaily et al. 2012).

Table 8. shows the potential applications of OPEFB fibers reinforced composites for automotive.

OPEFB has shown potential as a reinforcing material in polymer composites, opening up various applications in different industries. Some potential applications of OPEFB-reinforced polymer composites include construction and building materials, the automotive industry, packaging materials, furniture and consumer goods, and the electrical and electronic industries. OPEFB-reinforced polymer composites can be used in the construction industry for structural components, wall panels, roofing sheets, and insulation boards. The enhanced mechanical properties of these composites, such as improved strength and stiffness, make them suitable for load-bearing applications. Empty fruit bunch (OPEFB) composites have been studied for their potential use in building materials. Various studies have shown that EFB fibers can enhance the physical and mechanical properties of composites. Table 9 shows the potential application of EFB fibers reinforced composites for building and construction materials. Omoniyi (2019) found that pre-treatment of EFB fibers with water at 60°C and a NaOH concentration of 8% improved the performance of cement-bonded composites. Rozman et al. (2010) highlighted the importance of forming a polyurethane matrix in OPEFB-polyurethane composites for good stress transfer and improved flexural and impact properties. Khalil et al. (2010) investigated laminated bio-composites reinforced with OPEFB and observed improvements in mechanical, physical, and thermal properties. Ramlee et al. (2019) studied hybrid composites using OPEFB and sugarcane bagasse fibers and found that the hybridization improved tensile strength, water absorption, and thickness swelling. Adlie et al. (2019) explored the use of OPEFB fibers in polymeric foam composites and observed enhanced tensile strength and thermal stability. These studies have suggested that OPEFB composites have the potential for use in building materials due to their enhanced properties.

OPEFB-reinforced polymer composites can find applications in the automotive sector, particularly in manufacturing interior components, such as door panels, bulletboards, and seat backs. These composites can provide lightweight alternatives to traditional materials while maintaining sufficient strength and durability. OPEFB composites have been investigated for automotive applications. OPEFB fibers have been used to reinforce epoxy resin for bumper beams in cars, replacing epoxy/glass fiber composites (Witayakran et al. 2017). OPEFB-polyurethane (OPEFB-PU) composites were also produced, with the flexural and impact properties influenced by the percentage of OH groups in OPEFB and the reinforcing effect of the filler (Rozman et al. 2010). Composites based on ethylene vinyl acetate (EVA) copolymers and EFB fibers were prepared, but further details were not provided (Sefadi and Luyt 2012). Composites have been prepared from recycled polypropylene (RPP), OPEFB, and/or glass fiber using extrusion and injection molding techniques (Islam et al. 2017). OPEFB fibers have been treated in sodium hydroxide solution and used in composites with polypropylene, resulting in improved mechanical properties with the addition of a coupling agent and flame retardant (Beg et al. 2013). Overall, these studies suggested that OPEFB composites have the potential to be used as green materials in automotive applications.

Table 9. shows the potential applications of OPEFB fibers reinforced composites for building and construction materials.

Conclusions and future outlook

Indonesia, the world's top palm oil producer, has an abundance of palm oil biomass that can be used as a starting point for creating biocomposite materials. One type of solid waste biomass widely used in palm oil mills is OPEFB. OPEFB can be manufactured in quantities of 22 to 23 million tons annually.

Table 9. Potential application of OPEFB fibers reinforced composites for automotive.

Title	Insights	Results	Ref.
Development of Oil Palm Empty Fruit Bunch Fiber Reinforced Epoxy Composites for Bumper Beam in Automobile	Empty fruit bunch (EFB) fibers were used to reinforce epoxy resin for bumper beam in cars, providing an alternative green material for automotive applications.	- Chemical treatment with 30% NaOH provided stronger fibers – EFB fiber reinforced epoxy composite is a green alternative for bumper beam in automobiles.	(Witayakran et al. 2017)
Characterization of microwave-treated oil palm empty fruit bunch/glass fibre/polypropylene composites:	The paper discusses the preparation of composites using oil palm empty fruit bunch and recycled polypropylene for potential automotive applications.	- The density of composites increased due to incorporation of fibers.- The Microwave-treated fiber-based composite showed the maximum density.	(Islam et al. 2017)
Dry Sliding Wear of Oil Palm Empty Fruit Bunch (OPEFB) Epoxy Composite	The paper does not mention the use of empty fruit bunch composites for automotive applications.	- Mass loss values were higher for the smallest fiber size (100Âµm) at 30N load.- Mass loss values were relatively close for other fiber sizes.	(Salmiah, Anizah, and Ali 2011)
Effect of polypropylene, ethylene vinyl acetate and polyamide-6 on properties of recycled polypropylene/empty fruit bunch composites	Empty fruit bunch composites, specifically recycled polypropylene/ empty fruit bunch (rPP/EFB) composites, can be used in automotive applications.	– Mechanical properties improved with incorporation of PP and PA6. – Thermal properties improved with incorporation of EVA.	(Mohsin et al. 2015)
Low velocity impact and compression after impact properties on gamma irradiated Kevlar/oil palm empty fruit bunch hybrid composites	The study investigates the impact and compression properties of Kevlar/oil palm empty fruit bunch hybrid composites, but it does not specifically mention their application in the automotive industry.	- Non-irradiated Kevlar/OPEFB has greater impact resistance. – Gamma radiation improves compressive residual strength.	(Amir et al. 2020)
Empty Fruit Bunches as a Reinforcement in Laminated Bio-composites	Empty fruit bunches were used as reinforcement in laminated bio-composites, resulting in improved mechanical, physical, and thermal properties.	- Improvement in mechanical, physical, and Thermal properties - better water absorption, thickness swelling, bending strength, bending modulus, screw withdrawal, and Thermal stability	(A. H. P. S. Khalil et al. 2010)

But only 10% of it is used; the rest is wasted (Padzil et al. 2020). OPEFB is an excellent raw material to be extracted into cellulose or modified on its surface. The use of cellulose obtained from OPEFB has yet to be thoroughly studied, especially in biocomposites. However, nanocellulose has very bright prospects.

To the best of our knowledge, Almeida-Naranjo et al. (2022) who investigated the water absorption behavior of OPEFB for fillers in acrylic thermoplastic composites presented their findings on the water absorption behavior for composites. According to the scientists, the morphology of the composite, the presence of functional groups, and the reinforcement's properties all impacted the adsorption capacity. Identifying polysaccharides, functional groups (mostly carboxyl and hydroxyl), porosity, and voids in the reinforcement and composites revealed their presence. The morphology/size of the reinforcement and the production temperature have the most impact on the composite's ability to absorb water. Notably, water absorption rises as processing temperature and particle size are reduced. According to this study, to produce biomaterial composites with high water absorption, paying attention to these aspects is required while creating composites.

Highlights

- Cellulose content in the OPEFB fibers increases the mechanical properties of the composite.
- OPEFB can potentially be used for thermoplastic and thermoset composites
- OPEFB can be produced for high-performance applications. Given that it has mechanical properties that are comparable to those of synthetic fibers, acceptable thermal properties, and processing that is ecologically friendly.

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Author contributions

Melbi Mahardika conceived and designed the manuscript review. Aminatuz Zakiyah and Melbi Mahardika wrote the manuscript. Siti Mariyah Ulfa, Rushdan Ahmad, Mohamad Zaki Hassan, and Devita Amelia approved the manuscript. Victor Feizal Knight and Mohd Nor Faiz Norrrahim collaborated, institutional support, and responsibility for the publication fees.

Ethics approval and consent to participate

There is no need for any ethical approval in this study given here in this manuscript.

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