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MEDIUM DENSITY FIBREBOARD (MDF) FROM OIL PALM FIBRE: A REVIEW

(Papan Gentian Kepadatan Sederhana daripada Fibre Kelapa Sawit: Satu Ulasan)

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Abstract

Rubberwood was favored for the production of medium density fibreboard (MDF). However, with the increasing demand for MDF, the limited supply of rubberwood and the need for biomass conservation, fibre boards made from agricultural residue are under investigation, though their dimensional stability is a challenge. Several researchers have used various methods and techniques for the improvement of MDF mechanical and physical properties. This article reviews the current process of MDF manufacturing and performance indexes that help find the optimum criteria for board fabrication. It was discovered that oil palm fibre has its own chemical composition and thus impacts the properties of board when used as an alternative raw material for MDF production. Thus, the mechanical and physical properties of fibreboard made from oil palm-based fibre were discussed in various hybridization ratios with different types of fibre and compared with rubberwood board. Furthermore, chemical treatments, such as alkaline treatment, acetylation or soaking, and washing with boiling water or removing parenchyma cells were also studied. It was found that the dimensions of the fibre affected the mechanical properties, such as modulus of rupture (MOR), modulus of elasticity (MOE) and internal bonding (IB). The chemical changes in fibre that occur when oil palm fibre is chemically modified were also discussed and summarized.

Keywords: chemical composition, oil palm fibre, medium density fibreboard

Abstrak

Kayu getah digemari bagi pembuatan papan gentian kepadatan sederhana (MDF). Walau bagaimanapun, peningkatan permintaan bagi penghasilan MDF, bekalan kayu getah yang terhad, dan keperluan untuk pemuliharaan biojisim, papan gentian yang diperbuat daripada sisa pertanian sedang dikaji, walaupun terdapat cabaran terhadap kestabilan dimensinya. Beberapa penyelidik telah menggunakan pelbagai kaedah dan teknik bagi penambahbaikan sifat mekanikal dan fizikal MDF. Artikel ini mengkaji proses semasa dalam penghasilan MDF dan indeks prestasinya bagi membantu mengetahui kriteria optimum dalam pembuatan fabrikasi papan. Hasil kajian mendapati gentian kelapa sawit mempunyai komposisi kimianya sendiri dan seterusnya mempengaruhi sifat papan apabila digunakan sebagai bahan mentah alternatif bagi pembuatan MDF. Oleh itu, sifat mekanikal dan fizikal papan gentian yang diperbuat daripada gentian berasaskan kelapa sawit dalam pelbagai nisbah penghibridan bersama gentian yang berbeza jenis telah dibincangkan dan dibandingkan dengan papan kayu getah. Selain itu, rawatan kimia seperti rawatan alkali, asetilasi atau rendaman, dan mencuci dengan air mendidih atau mengeluarkan sel parenchyma juga turut dikaji. Kajian mendapati bahawa dimensi gentian mempengaruhi sifat mekanikal seperti modulus kepecahan (MOR), modulus kekenyalan (MOE), dan ikatan dalaman (IB). Perubahan kimia yang berlaku dalam gentian apabila gentian kelapa sawit diubah suai secara kimia turut dibincangkan dan diringkaskan.

Kata kunci: komposisi kimia, fibre kelapa sawit, papan gentian kepadatan sederhana

Introduction

Medium density fibreboard (MDF) is a composite wood product that is traditionally made by breaking down softwood into wood fibre in a defibrator. Then, it is mixed with wax and a synthetic resin binder, such as urea formaldehyde (UF) resin and forming board by using high temperature and pressure. Additives may be added during the manufacturing process to impart additional qualities. However, not all MDF are identical, such as texture, density, color and other characteristics that vary depending on the material used.

MDF has several characteristics that make it a good substitute for plywood or particle board. The material is dense, flat, sturdy, free of knots and machine-friendly. It is made up of small particles and gives dimensional stability without the presence of a noticeable grain, as wood does. MDF, unlike most plywood, has no gaps and produces sharp edges with no tear-out. Besides, MDF panels are available in a wide range of physical properties and dimensions, allowing to construct a finished product with the exact MDF features and density required. It is also an environmentally friendly product that uses renewable resources, such as kenaf, wheat straw, radiata pine, bamboo and non-wood fibres.

Rubberwood is also one of the most preferred raw materials for MDF production as compared to other renewable resources. According to Md. Rowson et al. [1], rubberwood possesses all of the necessary characteristics and its abundance makes it successful in the wood-panel industry. However, at present, rubber plantations are cultivated for the production of latex rather than wood manufacturing [1]. Therefore, rubberwood supply has recently become limited in the wood processing industry because of climatic (extended wet periods) circumstances that made rubberwood harvesting inefficient, especially on higher slopes. In addition, the resource is not available in larger, more desirable blocks, which has an impact on economies of scale. Finally, the demand outstrips supply, making rubberwood a finite (at least in short to medium term) resource.

Oil palm plantations, which are progressively replacing rubber plantations in Southeast Asia, have lately been introduced as popular fibres for new materials in MDF production. It is an under-utilized material, similar to rubber, with potential applications in a variety of industries. Oil palm fibres are now being researched for usage in various wood-based boards, pulp and paper, mushroom cultivation, and animal feed. Empty fruit bunches (EFB) are used as mulch, boiler fuel, fertilizer and for the manufacture of automobile cushions and mattresses [2]. Oil palm trunk (OPT) and oil palm frond (OPF) fibrous threads can be used to produce pulp, paper and chipboard [3]. Fruit bunch fibres can be used to make laminated isotropic fibreboard, cement board and pulp. Therefore, in addition to the research as previously mentioned, oil palm fibre also has a significant potential for converting low-value raw materials into high-quality wood panels that may be utilized as raw materials for the production of MDF.

This study aimed to review and summarize the current process of MDF production by using various agricultural biomasses. In this review, developments in MDF production from various oil palm-based fibres and factors influencing the properties of MDF will be discussed. These studies also identified the properties of MDF made from oil palm-based fibre with the greatest potential, considering their availability and the quality of boards they produce.

Medium density fibreboard raw materials

In general, the wood processing industry is undergoing significant structural changes, with a steady shift away from large-diameter trees and towards smaller-diameter second-cut trees, as well as a shift towards plantations and the estate sector. The latest developments in the MDF sector are strikingly comparable to those in the plywood industry. The main difference is that the latter arose as a result of government policies promoting domestic wood-based industries. However, MDF manufacturing plants arose as a result of raw material shortages that have become increasingly apparent in recent years, as well as the opportunity to use previously untapped resources.

Mixed tropical species, bagasse, radiant pine, rubberwood and cotton stalks, wheat straw, bamboo and rice straw are all important raw materials for MDF [4]. In Malaysia, rubberwood is the only raw material used, as opposed to particleboard or cement-bonded products, which rely on a mix of species and wood waste. Rubberwood has a light color and consistent texture; thus, making it an attractive fibre source for MDF manufacture [1].

Debarking and chipping are the first processes in the MDF manufacturing process. In a digester, cleaned chips are boiled and refined into wood fibres, which are then combined with resin and wax. Before being formed into a continuous mat, the wet fibre, resin and wax combination are dried and delivered to the mat forming. It is trimmed, sanded and cut to desired specifications in the final processing stage.

Current process for manufacturing MDF

MDF is a nonstructural fibre-based panel made out of wood fibres that have been glued together with resin under heat and pressure. Before being mixed with resin and wax, the fibres are refined in a defibrator or refiner. The surface of the fibres is coated with a bonding agent or resin. The resonant fibres are dried, then molded into mats, which are subsequently hot pressed to make a uniform board. The density ranges between 660 kg/m^3 and 850 kg/m^3 [5].

The utilization of various wood or fibrous materials in the production of MDF is shown in Table 1. Table 1 compares the mechanical and physical characteristics of various fibres with those of rubberwood. The qualities of the board were affected by both the manufacturing process and the chemical composition of the fibre. The mechanical and physical characteristics of the board are affected by the resin type, resin level, pressing time, pressing temperature, and refining parameters. Most materials use UF as a resin as compared to PF resin. In addition, it can be seen that, regardless of the type of fibre employed, higher resin content will increase MOR and MOE. However, higher pressing temperatures increase the internal bonding (IB) and lead to decrease WA and TS. Nevertheless, the mechanical (MOR and MOE) and IB of the board improve after increase refining parameters thus low WA and TS were obtained.

Figure 1 depicts the entire manufacturing process, including material preparation (chipping), fibre formation, fibre treatment, mat forming and hot pressing and board treatment. First, the wood is chipped using a chipper machine. After that, the chips are screened to separate the fibre different sizes [6]. A belt conveyor with an iron remover built over it transports the confirming chips to the chip's washer. The chips are then washed to increase their quality. After that, the chips are moved to the fibre separation section. To soften the chips, they are heated at 160°C–180°C or 6–8 bar pressure for 3 min–5 min.

To make the softened chips less prone to swelling, around 1 wt.%-2 wt.% paraffin wax is applied [7]. After that, the softened chips are transferred to the grinding chamber. The materials are mechanically decomposed in the grinding chamber with the help of water and heat. UF resin is added to pulp as it passes through the blow valve. The pulp, in the form of fibre, is placed in the dryer [8]. Moisture vaporizes in fibre and is controlled within the appropriate range. The fibre final moisture content is kept within 8%–13% (wt.). The fibre is evenly distributed into the matting conveyor belt and the preset thickness is made by using the air blow function. Hot pressing is used to get the desired thickness.

The prepress removes the air from the mat and strengthens it [18]. Fibreboard is typically categorized by density and can be produced using either the dry or wet methods. Dry method can be used on both high-density (hardboard) and medium-density (medium-density) boards (MDF). Both high-density hardboard and low-density insulation boards can be processed by using the wet method.

Table 1. Studies on the production of MDF from various wood or fibrous materials

Material	Panel Density (kg/m^3)	Resin Type	Resin Level (%)	Refining Parameter (bar, min)	Pressing Temp. (°C)	Pressing Time (min)	MOR (mpa)	MOE (mpa)	IB (mpa)	TS (%)	WA (%)	Ref.
Kenaf core	700	UF	12	7,3	175	5	28.0	3379	0.67	15.4	68	[9]
				7,5			30.3	3619	0.66	14.6	62	
Kenaf bast	700	UF	12	7,3	175	5	20.6	1921	0.24	28.8	77.9	[10]
				7,5			22.9	2113	0.17	27.1	73.9	
Bagasse	900	UF	20	NA	125	60	45.0	3532	NA	16.9	64.8	[11]
Wheat straw	750	UF	12	NA	138	7	23-14	3200-3400	0.6-0.7	10-11	NA	[5]
Canola straw	700	UF	11	NA	NA	4	21-22	2300-2400	0.53-0.55	26-29	NA	[12]
						6	20-21	2200-2300	0.52-0.54	26-29	NA	
Bamboo	734	UF	8	NA	NA	NA	26.1	2760	1.16	25	72	[13]
Rubberwood	680	UF	11	NA	170	5	30.7	2412	0.50	16.5	46.3	[14]
	751	UF	11	NA	160	6	33.7	3285	1.16	23.8	72.1	[15]
Coir	808	PF	20	NA	145	8	29.1	3143	2.1	NA	NA	[16]
Banana stem	780	UF	20	NA	170	8	50.91	3939	NA	15.70	38.5	[17]

UF: urea formaldehyde; PF: phenol formaldehyde: MOR: modulus of rupture; MOE: modulus of elasticity; IB: internal bonding; TS: thickness swelling; WA: water absorption
NA: not available

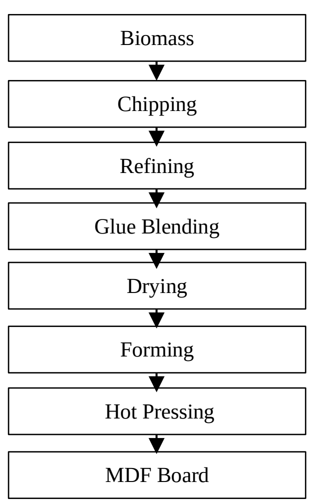

Figure 1. Flow chart for the production of MDF

Dry process fibreboard

Particleboards and dry process fibreboards are created in the same way. Resins such as UF and phenol formaldehyde (PF), as well as other additives can be sprayed on the fibres or added as the wet fibres are fed from the refiner into a blow line drier. On the other hand, some fibreboard plants add the resin to the refiner. The adhesive-coated fibres are then air-laid into a mat for pressing, similar to how particleboard mats are formed. Dry-process fibreboard pressing differs from particleboard pressing in a few ways. The fibre mat is normally pre-pressed in a band press once it is created. Next, the densified mat is trimmed with disc cutters and transferred to caul plates for hardboard pressing; in the case of MDF, the trimmed mat is directly transported to the press. All dry-formed boards are pressed in multi-opening presses at temperatures ranging from 140°C to 165°C for UF-bonded goods and 190°C for PF-bonded products [19].

Wet process hardboard

Hardboards made with a wet process differ from fibreboards made with a dry process in various ways. The fibres are first formed into a mat by using water as the distribution medium. Secondly, some wet process boards are manufactured without the use of extra binders. If there is sufficient lignin in the lignocellulosic material and it is kept after the refining process, lignin can be used as a binder. Lignin will flow and act as a thermosetting adhesive when exposed to heat and pressure, increasing the naturally occurring hydrogen bonds. In wet process hardboards, refining is a critical stage in creating strength. The refining process must also produce fibre with a high freeness or the ability to remove water from the fibrous mat easily. The soupy pulp runs quickly and easily onto a continually moving mesh screen in the wet process. Water is drained through the screen and then through a series of press rolls that wring out any remaining moisture. Wet process hardboards are pressed in steam-heated multi-opening presses. The press cycle is divided into three sections and lasts between 6 min and 15 min. The first phase, which is carried out under high pressure, eliminates the majority of the water while getting the board to the necessary thickness. The second phase major goal is to eliminate water vapor. The third phase is relatively brief and leads to the completion of the cure. The maximum pressure employed is at 5 MPa. To induce fibre-to-fibre bonding, heat is required while pressing [19].

MDF Performance Index

MDF performance index is divided into three categories: physical, mechanical and biological performance [20]. The most important physical properties are density, moisture content (MC), water absorption (WA) and thickness swelling (TS). Internal bonding (IB), modulus of elasticity (MOE), modulus of rupture (MOR) and screw holding force (face and side) are the primary mechanical characteristics, whereas the emission of formaldehyde is a major part of biological performance [20].

Physical performance

The swelling that can occur in a board is known as TS, which is inversely proportional to IB values. When the IB value is high, the TS value is usually low. This property is determined by how well the interparticle connection resists moisture absorption. The TS is affected by the MC of the mixture, pressing duration, board moisture, testing conditions and density of board. When the board is exposed to water, the amount of water absorbed into the wood substance is known as WA. It is very dependent on the structure of the wood cell [14]. However, by applying thermal treatment to the fibre, some changes are found, such as degradation of hemicellulose and reduction of hydroxyl group; thus, it reduces the TS value [15].

The drawback of MDF over plywood is that it swells more than plywood when exposed to water and a greater proportion of that expansion may not be recoverable after drying. High internal strains can be caused by in-plane movements as a result of increased or decreased moisture content in the board. These forces may be severe enough to result in buckling board, pushed-out nails and board detachment from the structure. As a result, the fibreboard must be able to swell and expand to control the destructive effect.

Heat treatment enhances the stability of wood, but it can also alter its surface features, hence its wetting properties [21]. Surface inactivation can occur when a wood surface is exposed to a high-temperature environment [22]. When exposed to high temperatures, the wood surface undergoes a few known changes, including oxidation. Inactivation of wood surfaces, which causes poor bond quality, is a time-dependent process that can be expedited by raising the temperature [23]. Due to interference with adhesive wetting, flow and penetration, as well as the cure and resulting cohesive strength of the adhesive, an inactivated wood surface might produce adhesion issues.

Wood drying at temperatures between 160°C and 180°C causes surface composition changes, as reported by Li et al. [24]. In wood bonding, wettability is critical for good adhesion. To make close contact between wood molecules and adhesive, the adhesive must moisten, flow and penetrate the cellular structure of the wood. There is evidence that wood wettability and adhesion have a favorable relationship. Many tests have demonstrated that high drying temperatures lower the bonding strength of wood adhesives or that high temperatures reduce wood hygroscopicity and impede wettability [25]. Heat treatment causes wood fibres to become hydrophobic; thus, reduces their wetting ability [24]. Contact angle analysis can be used to determine the wettability of wood. The adhesive and coating qualities of wood and wood-based composite surfaces are vital to be determined [26]. Perfect wetting of a surface happens when the contact angle is zero.

The volume of fibre used in MDF has been shown to alter the density of the MDF produced in previous studies. Shorter fibres were well blended with longer fibres by filling the gaps between and amongst the fibres, resulting in a more uniform board with a low density. According to a study [13], the lower-density board had less swelling because it had less wood per unit volume and a low degree of hygroscopic response. Besides, to maintain homogeneous density across the length and width of the board, the fibres are required to be distributed uniformly [14].

Mechanical performance

The MOR is the maximum fibre stress computed in the upper and lower surfaces of the board. It is the material unique breaking stress, given in stress unit per unit area. MOE, on the other hand, is a measure of material stiffness that may be used to calculate the deflection of a product under stress, whereas internal bond measures the fibreboard efficiency and indicates the compatibility of resin adhesive with fibre [27]. Therefore, various factors may contribute to changes in mechanical properties, with some having better mechanical properties, as investigated by researchers. However, it was found that the main factor that affected mechanical properties of board was fibre length [28]. Fibres with a greater length and thickness provided a larger surface area for adhesive contact. According to Wan Daud & Law [29], fibre length had a bigger impact on board dimensional stability than mechanical qualities.

Oil palm biomass *vs* rubberwood

Rubberwood is an environmentally beneficial wood due to its unique characteristics and value that are not found in other materials. According to previous studies, the demand for sawn timber in furniture applications has increased yearly because consumers prefer the unique wood grain and light color of rubberwood, which is easy to work with and furnish with other materials and is durable. Rubberwood has a light-straw to light-brown color and a density of 550 kg/m^3 to 650 kg/m^3. The trunk diameter is usually between 30 cm and 35 cm, while the length is usually between 3 m and 5 m [30].

Oil palm EFB pulp fibres and rubberwood have been identified as two key sources for MDF production. Previous research has shown that oil palm EFB pulp fibres are superior to rubberwood pulp fibres because they contain fibres with higher pH values and buffering capacities. This buffering effect is caused by an acidic reaction agent that converts to a less reactive molecule and obstructs resin flow [31]. MDF made from EFB can be used instead of sawdust MDF, which is known to be less durable.

Most researchers prefer EFB to the currently available resources for manufacturing MDF as the primary raw material. As a result, the qualities of MDF will be affected by changes in the raw material. As previously stated, MDF mechanical properties and stability are greatly influenced by the technique and materials used in MDF manufacturing [32].

Properties of oil palm fibre vs rubberwood

The three main chemical components of a cellulosic fibre of wood are cellulose, hemicellulose and lignin. Cellulose is semi-crystalline polysaccharide with a large amount of hydroxyl group. This hydrophilic nature causes poor resistance to moisture absorption and poor interfacial bond. On the other hand, the physical properties of fibre used affect the mechanical properties of the board produced, such as fibre diameter, length, density, moisture gain, and cell wall. Table 2 compares chemical composition and physical properties of rubberwood and oil palm-based fibre. As listed in Table 2, the chemical composition of oil palm fibre and rubberwood vary in contents.

Generally, MDF manufactured from long fibre length, high density, thick cell wall and small lumen width produces MDF with greater MOR, MOE and IB. However, long fibre increase hydrophilicity; thus, increases their moisture absorption and board swelling. Besides, hydrophilic fibre characteristics can cause poor fibre and resin adhesion because of hydroxyl and polar group present in the component. As aforementioned, a large amount of hydroxyl group present in the fibre reduces their compatibility with resin adhesive because resin is hydrophobic. Therefore, improving adhesion between fibre and resin by reducing hydroxyl group would increase their compatibility by increase the wettability of the fibre surface [33].

EFB fibres are multicellular fibres with a central lacuna that are rigid and strong. The porous surface of EFB provides better mechanical links with resin. However, EFB fibres are coated with residual oil produced during the processing of palm oil. OPF fibre, on the other hand, consists of various sizes of vascular bundles. Vascular files are widely found in thin-walled parenchyma tissues. Each bundle consists of round gloves, vessels, fibres, phloem and parenchyma tissue. Unlike OPF, OPT is filled with relatively smooth and dense parenchyma ground tissues that comprised mainly hemicellulose and cellulose. Parenchyma ground tissues have high hydroxyl bonds which increased water uptake to retain more water as a water-transporting organ in plant trunks [34]. However, only the outer part of oil palm trunk is suitable for use because soft parenchyma tissue is high in the central region [35].

As shown in Table 2, EFB is rich in cellulose as compared to rubberwood, OPT and OPF. However, lignin and hemicellulose content of EFB is smaller if compared to rubberwood. Based on chemical composition, rubberwood is more similar to OPT except for its length, which shows rubberwood has a longest fibre than oil palm-based fibre. However, the biggest drawback of oil palm fibre is its low resistance to fungal attack because of the high carbohydrate (e.g., sugar and starch) deposited in the parenchyma.

Effect of hybridization

Many studies have been reported for enhancing the mechanical properties of MDF produced from oil palm-based fibre. This is because the properties of oil palm-based fibre affect the structural strength of the MDF produced. However, to meet the demand for environmentally friendly MDF, oil palm-based fibre is considered attractive because of their low cost, biodegradability and recyclability. Apart from these benefits, oil palm-based fibre imparts some drawbacks, including short fibre length, thin cell wall and low fibre density. Therefore, hybridization of oil palm-based fibre which is low modulus fibre with high modulus fibre like rubberwood is needed to overcome these disadvantages. This technique aims to produce MDF with better physical and mechanical properties by combining the strengths of both fibres to compensate for the weaknesses of the other. However, there are limited findings on the various blending ratios utilized and the changes of new hybrid on the properties of MDF produced. Table 3 shows the properties of MDF made from oil palm fibre (EFB, OPT and OPF), as well as rubberwood, mix tropical hardwood (MTH) and fibre mixing.

Abdul Khalil et al. [32] studied the effects of hybridization of EFB and rubberwood and discovered that MDF made from a 20:80 blend of EFB: rubberwood had better mechanical and physical qualities than MDF made from a 50:50 blend. In a separate study, Mustapha et al. [43] used EFB and kenaf fibre and found that a

50:50 EFB: kenaf resulted in lower mechanical properties as compared to 70:30 EFB:kenaf. This finding occurred because the addition of EFB fibre altered the pH value and buffering capacity; thus, affected UF resin flow which was suitable to be used with rubberwood and kenaf fibre [33]. Moreover, poor distribution of UF resin and EFB fibre resulted in the formation of lumps which released during exposure to water; thus increased the swelling thickness [33].

Table 2. Chemical composition and physical properties of oil palm fibre and rubberwood

Fibre	Density (g/cm^3)	Cellulose (%)	Lignin (%)	Hemi-cellulose (%)	Length (mm)	Diameter (µm)	Cell Wall Thickness (µm)	Lumen Width (µm)	Ref.
OPT	-	41	24.5	-	0.66	16.6	8.0	-	[36]
	-	29–37	-	12–17	-	-	-	-	[37]
	-	-	-	-	0.96	29.6	4.8	-	[29]
	0.27-0.44	-	-	-	-	-	-	-	[35]
OPF	-	49.8-56.0	20.5	-	-	-	-	-	[36]
		-	-	-	1.59	19.7	3.95	-	[29]
	-	-	-	32	-	-	-	-	[38]
EFB	0.18-1.32	50.5-62.9	17.8	-	-	19.1	3.38	-	[39]
	-	-	-	-	0.99	-	-	-	[40]
RW	0.6	44	23	-	1.34	27	6	14	[41]
	-	-	-	30.4-31.5	-	-	-	-	[42]

In another study, the capabilities of EFB fibre and its effect on mechanical qualities of MDF were demonstrated by Harmaen et al. [14]. Table 3 shows that the MDF panel made entirely of rubberwood fibres had significantly better mechanical properties (MOR, MOE, and IB) than the other ratios of rubberwood: EFB. Generally, boards having less than 50% of oil palm EFB fibre had better strength properties. Therefore, weak mechanical properties were expected, but replacing 50% rubberwood is already considerable in the industry. MDF contains 70% EFB and 30% of rubberwood surpassing the minimum requirements of MOR and MOE based on EN standards, which are 11 N/mm^2 and 1800 N/mm^2, respectively [44].

On the other hand, physical performance (TS and WA) of the panel made from rubberwood mixture decreased, indicating that lack of hydroxyl group from rubberwood fibre made it less able to absorb water. However, the density of MDF was not affected by the mixture ratio. This was because 100% rubberwood board had a higher board density. In comparison to lower density boards, Wan Daud & Law [29] mentioned that high density boards had more intimate particle contact; thus contained more wood to withstand mechanical loads.

In addition, the strength of MDF also contributed by the fibre length. As mentioned in previous study, EFB fibres are shorter than rubberwood fibres, resulting in a lower IB value. Shorter EFB fibres contributed to a higher resin-covered surface area. Based on the study, 9%-12% resin was used to cover all surfaces of rubberwood fibres; however, it was insufficient to cover the larger surface area of EFB fibres. As a result, inadequate bonding between fibres would occur throughout the board, as seen on EFB-fibreboard.

The similar trend was also recorded when blending rubberwood with OPF and MTH. However, blending OPF with rubberwood and MTH recorded a better IB value as compared to other blending ratio reported by other researchers [45]. Another study demonstrated the use of 100% OPF at different refining parameters was performed [46], however the resin level required to achieve optimum performance much higher as compared to other reported study. As reported by Zawawi et al. [46], unlike OPT and EFB, OPF had better characteristics. OPT had higher amount of parenchyma cell, whereas EFB contained residual oil. Therefore, increment of fine fibre of nonfibrous plant material from OPT such as parenchyma tissue during refining process or fine fibre coated with residual oil from EFB reduced wettability which led to a poor bonding between fibre and resin.

MDF from 100% OPT has also been produced at different refining parameters. The pressing temperature was heated at 200°C and 10% resin level was used [47]. These MDF provided an improved IB and TS behavior. In another study reported by Zawawi et al. [48], the board from OPT offered a good surface appearance, good strength and a light color. In comparison to MDF produced from rubberwood and OPT, MDF from EFB has a darker color because of residual oil presence on the surface of EFB. Other than that, Zawawi et al. [48] also conducted research by removing parenchyma cell from OPT fibre. As expected, removing parenchyma tissue enhanced the properties of MDF by increasing the ratio of fibre; thus, facilitated mechanical interlocking with resin.

Treatment of cellulosic fibre of oil palm

The main problem of cellulosic fibre and resin is their compatibility. The hydrophilic characteristics of the cellulose fibres lead to high moisture uptake which can seriously lower the mechanical properties of board produced. In addition, pectin and waxy substance present on the fibre covers the reactive functional groups of cellulose fibre and act as barrier to interlocking with the resin. The wax in cellulosic fibre act as barrier by reducing wettability; thus, adhesion of resin into the fibre. Based on several researches, studies of the chemical treatment were conducted to enhance the properties of fibres such as improvement of wettability, surface modification, chemical groups and tensile strength of oil palm fibre, as well to improve interfacial bonding of fibre and resin [49].

Asyraf et al. [3] also reported a similar finding on chemical modification to improve mechanical properties of oil palm fibre. Their survey found that chemical modification approaches have been widely reported to overcome oil palm fibre limitation; thus, improved compatibility, hydrophobicity and interfacial bonding. This can be achieved by eliminating the fibre hydrophilic characteristics, which raise hydrophobicity and interfacial bonding between the fibre and resin, thus resulting in a greater compatibility. The reactive functional group on fibre, such as the hydroxyl group, is modified during this process by the interaction with chemical treatment. Therefore, surface impurities such as pectin, wax and hemicellulose can be removed effectively. Chemical treatment approaches that are widely used for natural fibres include alkaline, acidity, silane, acetylation and coupling agents [3, 49].

The most widely used method to treat cellulose fibre of oil palm is alkaline treatment. In this treatment, fibre is immersed in alkali solution with different temperatures for different periods and then the fibre is washed with water and oven dried. This treatment improves fibre wetting by removing of wax, hemicellulose, lignin, pectin and oil substance; thus, fibre and resin compatibility [3]. Removing this substance increased the ratio of cellulose in the material and allowed good penetration of resin into the fibre. It also reduced the fibre diameter and produced rougher surface [50]. Studies of EFB fibre by Norul Izani et al. [51] showed that the surface fibre after treatment with NaOH became smoother compared with that of untreated fibre as proven by SEM analysis. Therefore, that fibre treated with NaOH displayed improvement in mechanical and physical properties [52]. However, amongst the properties mentioned, only TS and IB value recorded the lowest and highest values from other treated fibre.

Besides, esterification of fibre also can be done to improve the fibre surface. Esterification or acetylation causing plasticization of cellulosic fibre. The reaction involves generation of acetic acid as by product. Chemical modification of acetic anhydride substitutes hydroxyl group with acetyl group; thus, allowing the fibre to become hydrophobic. A study by Zawawi et al. [53] found that acetylation processes of EFB contributed to a reduction of TS value; thus increased the dimensional stability of MDF produce.

A comparative evaluation of MDF mechanical properties produced from EFB treated with alkaline and acetylation treatment also was reported [54]. In contrast with their earlier finding [53], the property of MDF from acetylation treatment revealed that MOR, MOE and IB values were higher as compared to alkaline treatment. Zawawi et al. [55] mentioned that alkaline treatment had successfully removed higher oil from EFB surface as compared to acetylation treatment, unfortunately, higher oil removal was not the major factor of the improvement in mechanical properties of MDF board. Similar findings were reported by Bam et al. [56] using bagasse fibre and David Chukwudi [57] using raffia fibre, whereby the acetylation treatment showed a better compatibility with UF resin than that of alkaline treatment.

As mentioned by Zhang et al. [58], adhesive penetration could be a factor to the adhesion strength of the bonded wood. Therefore, research on adhesion properties, such as wettability and pH values are necessary for a strong bond to improve mechanical properties of board. A study performed by Zawawi et al. [53] reported that adhesives used, such as UF performed a better dimensional stability at an acidic condition was because treatment using acetic acid increased resin curing times during hot pressing [54], thus reducing hydrogen bonding sites for water molecule to attach. The surface modification increased bonding strength by understanding the behavior of adhesives and fibre properties. However, reducing wettability of adhesive allowed over penetration into the fibre, resulting in small portion of adhesive remained at fibre interface. Therefore, provided inefficient mechanical property of adhesive [58].

Problems and research needs

The use of oil palm fibre (EFB/OPT/OPF) to replace rubberwood as a material for producing MDF panels has showed promise as a long-term sustainable resource for the MDF industry. However, this only applies to blending oil palm fibre with rubberwood in a ratio of less than 50%, as opposed to the existing industry technique, which allows 100% rubberwood fibre to be exposed to the MDF process and achieve good quality results. Furthermore, past research has shown that using 100% EFB induces a color shift even after the fibre has been treated. Studies to increase the strength of MDF produced, especially its mechanical properties by using 100% biomass from oil palm without increasing the resin content should also be carried out. Below are potential barriers which occur with the use of palm fibre and possible solutions.

Table 4. Potential barriers with the use of oil palm fibres and possible solutions

Barriers	Solutions
High ash and silica content	• Avoid soil contamination • Thorough separation and washing
High moisture content and bulkiness	• On site processing • Seasoning
Heterogeneity of material	• Improvement in fibre extraction technique
Short fibre length	• Optimization of pulp yield • Blending with softwood fibre
Fibre efficiency	• Process development for the mixed raw material (stems, fronds, bunches & mesocarp)
Dark colour	• Improvement in fibre washing/treatment
High resin use	• Blending with other fibre

Table 3. Mechanical and physical properties of oil palm based MDF

Ratio (%)	Panel Density (kg/m^3)	Resin Type	Resin Level (%)	Refining Parameter (bar, min)	Pressing Temp. (°C)	Pressing Time (min)	MC (%)	MOR (mpa)	MOE (mpa)	IB (mpa)	TS (%)	WA (%)	Ref.
RW:EFB (50:50)	650	UF	12	2-8	200	-	-	-	-	0.69	13.5	29.86	[35]
RW:EFB (80:20)										0.73	11.0	27.36	
RW (100)	680	UF	11	5	170	5-6	6.75	30.7	2412	0.50	16.5	46.27	[13]
RW:EFB (70:30)	678						6.70	29.5	2264	0.53	15.6	48.98	
RW:EFB (50:50)	672						7.07	26.3	1951	0.45	14.2	54.50	
RW:EFB (30:70)	667						7.18	26.2	1849	0.44	14.3	59.17	
EFB (100)	662						7.28	21.0	1313	0.45	14.8	44.42	
OPF (100)	-	UF	9	6, 5	200	5	-	32.4	2870	1.12	14.3	-	[41]
OPF:RW,MTH (95: 5)								32.9	2694	1.17	13.6		
OPF:RW,MTH (90:10)								43.9	3515	1.05	13.5		
OPF:RW,MTH (85:15)								44.4	3862	1.26	13.8		
OPF:RW,MTH (80:20)								45.4	3953	1.28	13.4		
OPF (100)	720	UF	12	6,5	180	5	4-5	23.7	2829	0.66	13.9		[42]
OPT (100)	720	UF	10	6, 1.7	200	5	4-5	38.3	3444	0.68	15.7	-	[43]
				6, 3.3			4-5	39.9	3538	0.72	14.6		
				6, 5.0			4-5	38.3	3597	0.73	14.6		
				6, 6.6			4-5	35.1	3421	0.73	14.4		
Parenchyma content of OPT (10)	650-750	UF	8-10	6, 5	200	5	4-5	39.6	3235	1.19	14.8	-	[44]
Parenchyma content of OPT (20)	650-750						4-5	35.0	3010	1.11	15.0		
Parenchyma content of OPT (30)	650-750						4-5	31.7	2687	0.97	15.7		

MDF: medium density fibreboard; RW: rubberwood; EFB: empty fruit bunch; OPT: oil palm trunk; OPF: oil palm frond; MTH: mix tropical hardwood; MC: moisture content; MOR: modulus of rupture; MOE: modulus of elasticity; IB: internal bonding; TS: thickness swelling; and WA: water absorption.

Conclusion

MDF produced from oil palm biomass are an important part in developing new strategies and policies that aid in reducing the dependence on rubberwood and other wood sources. Oil palm fibre has their own chemical composition and hence their properties differ from those of rubberwood. By chemically modifying oil palm-based fibre through chemical treatments, such as alkaline treatment, acetylation or soaking and washing with boil water or remove parenchyma cell, their mechanical properties such as MOR, MOE and IB could be improved. Chemically modified oil palm-based fibre exhibits better wettability, surface morphology, acidity and buffering capacity because of removed wax, lignin, pectin and oil from fibre surface. Nonetheless, identifying a MDF that has high dimensional stability would be a challenge. Poor dimensional stability of MDF can be remedied by hybridization with rubberwood or other wood source with a ratio of oil palm based less than 50%.

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