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Production of Roof Board Insulation Using Agricultural Wastes Towards Sustainable Building Material

Rafikullah Deraman[1,*], Mohd Nasrun Mohd Nawi[2], Md Azree Othuman Mydin[3], Mohd Hanif Ismail[1], Nur Diyana Mohd Nordin[1], Marti Widya Sari[4], Mohd Suhaimi Mohd-Danuri[5]

[1] Faculty of Civil Engineering and Built Environment, Universiti Tun Hussein Onn Malaysia, 86400, Batu Pahat, Malaysia
[2] Institute for Management & Business Research (IMBRe), School of Technology Management and Logistics, Universiti Utara Malaysia, 06010 Sintok, Kedah, Malaysia
[3] Building Surveying Department, School of Housing, Building and Planning, Universiti Sains Malaysia, Penang 11800, Malaysia
[4] Department of Management Information System, Faculty of Science and Technology, Universitas PGRI Yogyakarta, Indonesia
[5] Center for Building, Construction & Tropical Architecture, Faculty of Built Environment, Universiti Malaya, Kuala Lumpur, Malaysia

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ABSTRACT

Malaysia, like most other developing countries, is facing an increase in the generation of waste and accompanying problems with the disposal of this waste. A large number of biomass wastes were generated due to increased activity in the agricultural and agro-industrial sectors, which led to producing environmental hazards and waste management issues. On the other situation, the energy consumption to cool the indoor building environment is high due to the building being exposed directly to solar radiation throughout the daytime, which increases the temperature outside and inside the building. Most of the low-medium cost housing schemes were constructed using metal roof covering without providing a roof insulation layer which causes a rising in indoor temperature and creates uncomfortable surroundings. Moreover, existing materials for roof insulation in the market use inorganic synthetic materials that could harm human health. The study aims to investigate the potential use of agricultural wastes for the production of roof board insulation material that can provide economic value added to agricultural waste, reduce the environmental issue and provide eco-friendly, sustainable building material. In this study, these agricultural wastes are combined in different proportions of 50% individual fibres, such as sugarcane bagasse with coconut husk, empty fruit bunch with mesocarp fibre, coconut husk with empty fruit bunch, and sugarcane bagasse with mesocarp fibre. The sample was fabricated using the hot-press machine and went through various physical and mechanical testing, which involved thickness of swelling, modulus of rupture, and thermal conductivity. The finding showed that the mixed fibre of empty fruit bunch and mesocarp fibre achieved all the criteria such as density (427 <500kg/m^3); thickness of swelling (19< 20%); modulus of rupture (514<800psi), thermal conductivity (0.0856<0.25 W/m.K) met with the standard requirement in every laboratory test conducted. The outcome of this study suggests that empty fruit bunch and mesocarp fibre are the potential materials for the production of roof board thermal insulation. However, modification of physical and mechanical properties of waste fibre is required to achieve superior performance and is ready to be provided in the market. This study is aligned with the government

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[*] *Corresponding author.*
E-mail address: rafikullah@uthm.edu.my

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initiative for the growth of green building materials for sustainable development in the construction industry.

1. Introduction

The roof is a structural component built at the top of the building structure. The primary function of a roof is to enclose the space and to protect buildings from weather elements, e.g., rain, wind, sun, heat, and snow. According to Malaysia Standard 2680 [1], the roof is the most exposed building component to the outdoor environment, i.e., the proportion of heat gain through the roof is 80% through radiation, and the remaining is through conduction and convection. Based on the climate condition, the duration of roof exposure to solar radiation is longer compared to walls. High transmission of solar creates an uncomfortable environment inside the building. Moreover, the absorption of heat by the roof through conduction transfers heat into interior spaces and increases the temperature inside buildings, causing significant discomfort.

Previously, in the Seventh Malaysia Plan (1996-2000), the government introduced low-medium cost housing schemes to meet the demand for homeownership, especially for middle and low-income groups, e.g., Program Bantuan Rumah (PBR) and Program Perumahan Rakyat (PPR) [2]. However, to reduce construction costs for that scheme, most houses are built using metal deck roofing that can cause the temperature to rise, making it hot and uncomfortable to live in [3-5]. By using metal roofing as roof covering, it can absorb heat quickly, especially in hot weather. These may give a sense of discomfort to the residents [6,7]; thus, residential buildings tend to use the air conditioner [8-10] to achieve a comfortable level, which can cause a high energy consumption [9-11].

Research shows that the energy consumed to cool the indoor environment is as high as 70% [12-14]. However, cooling energy consumption may be reduced by decreasing the amount of heat transfer through the building envelope, i.e., the roof [15,16]. The energy demand of buildings can be reduced by thermally insulating the buildings. Recently, the demand for energy-efficient buildings and better indoor air quality has been increasing in the construction industry. It is reported that if no action is taken to improve the energy efficiency of buildings, energy demand is expected to increase by 50% by 2050 [17,18]. It is essential to ensure that the indoor spaces have acceptable indoor temperatures to meet that demand, which encounter indoor comfort temperature and minimise heat gain [19]. Patnaik *et al.,* [20] and Aditya *et al.,* [21] reported that insulation material used in the roof structure could help to limit the flow of heat between the exterior and the interior of the building. As a result, the temperature became lower and increased the comfort of the occupants inside. Studies showed that energy efficiency could be achieved by designing suitable roof insulation material, which depends on the local climate [22,23].

Thermal insulation is an important factor in minimising the effect of heat absorbed and transmitted, especially from the covering materials of the metal roof. When the roof surfaces reach a high temperature, the ceiling radiates heat to the room below and increases the physiological heat stress [24]. The roof thermal insulation is one of the most effective energy-saving methods that can decrease energy consumption [25,26] thus, reducing the annual energy cost of the building [27,28]. Besides, roof thermal insulation can minimise the heat absorbed and transmitted by metal roofing materials [26,29]. Thermal insulation materials are chosen based on their physical, mechanical, and thermal properties.

Concerning this study, thermal conductivity is the most crucial characteristic of thermal insulation since it directly affects the resistance to the transmission of heat that a material offers. The lower the thermal conductivity value, the lower the overall heat transfer. This study aims to produce low thermal conductivity of a low-density roof fibreboard insulator with a combination of sugar bagasse (SB), coconut husk (CH), empty fruit bunch (EFB), and mesocarp fibre (MF). A better understanding will help to develop productive uses for biomass wastes, mitigating environmental problems from biomass waste while also developing an alternative material to replace synthetic solutions. Therefore, it is crucial to determine the effect of adding these combination fibres in the roof fibreboard insulator manufacturing. Due to the current insulation materials in the market, typically using synthetic materials that have adverse side effects from the production stage to their useful lifetime, it is vital to search for an alternative solution which can satisfy the standard. Additionally, the utilisation of these fibres was very satisfying by promoting passive design through the improvement of material properties, specifically with the production of low thermal conductivity roof fibreboard insulators that can help humankind in the future to reduce energy consumption.

It is concluded that roofs are the building elements affected by the greatest thermal flows between the environment and the building's interior. To limit the amount of heat that flows through roofs, one can either increase the roof's thermal resistance or reduce the quantity of solar radiation that is absorbed by the roof surface. In this research context, to increase the roof's thermal resistance, thermally insulating materials are extremely important to use. However, construction practices normally use synthetic materials, which may lead to adverse side effects on the health of building occupants. The utilisation of biomass waste as the main source in the production of roof insulation boards is a potential solution to reduce the amount of waste generated from the production factory, which, if not taken seriously, can lead to environmental problems. The following section explains the production scale of agricultural and agro-industrial wastes considered in this work.

1.1 Agricultural and Agro-Industrial Wastes

Malaysia, like most other developing countries, is facing an increase in the generation of waste and accompanying problems with the disposal of this waste [30]. A large number of biomass wastes were generated due to increased activity in the agricultural sector, which contributed 168 million tonnes annually, including wood and oil palm waste, rice husks, coconut fibres, municipal waste, and sugarcane bagasse [31]. Malaysia is the world's second-largest palm oil producer after Indonesia, producing 19,900 million tons or 26% of the world's palm oil production in 2020 [32], where the waste produced from the oil palm industry may lead to significant environmental concerns. The waste from the mill consists of pressed fruit fibres (PFF), empty fruit bunch (EFB), oil palm shell (OPS), palm oil mill effluent (POME), oil palm trunks (OPT) and oil palm fronds (OPF). Approximately 89 million tons of residues are generated from oil palm trees every year [33]. The palm oil processing activities yield only 10% palm oil and palm kernel oil, while the remaining 90% remain in the form of biomass or waste that is still not used for the industry. The palm oil biomass waste is projected at 85-110 million tons per year by 2020 [34]. As reported by MPOB in 2016, a total of 86.3 million tonnes of fresh fruit bunches were processed by oil palm mills in Malaysia, generating more than 6 million tonnes (dried weight) of empty fruit bunches [35]. Abdul Wahab *et al.,* [36] reported that, in the year 2016, 453 palm oil mills in Malaysia generated approximately 6.95 million tonnes (dry weight) of mesocarp fibre (MF).

Sugarcane bagasse is reported as the primary and massive agro-industrial waste being produced by the agricultural industry in Malaysia [37-38]. Sugarcane production on a large scale is concentrated in the states of Perlis and Kedah on the northwest tip of peninsular Malaysia. In 2019, approximately 1.56 million metric tons of refined sugar were produced in Malaysia [39]. About 32% of bagasse is produced from every ton of sugarcane [40], and the fibrous waste remains after sugar extraction from sugarcane [37, 41]. Unfortunately, large amounts of these wastes are still unused or unburned, causing greenhouse gases in the environment and harming the ecosystem. On the side, Malaysia has a total coconut plantation land area of 85,630 hectares and producing approximately 541,972 metric tons of coconut in 2020 [42]. With these large quantities, the coconut husk is produced as residue from these coconut products.

All the agricultural and agro-industrial mentioned above produce waste products that can produce an environmental hazard and require disposal costs every year. Moreover, many wastes produced from oil palm mills were left on the land and burned to be disposed of in the fields, causing environmental problems. For coconut, the negative impact of the husk and shell by-products on the environment would be alarming if proper disposal and treatment systems were not in place [43]. Alwani *et al.,* [44] and Sadh *et al.,* [45] have reported that the utilisation of agricultural and agro-industrial wastes could contribute to decreasing the considerable measure of raw waste materials and would preserve and sustain the environment with little destruction. Moreover, concerning waste management issues, it is recommended that eco-friendly solutions should be considered before sending the organic waste for disposal.

The agricultural and agro-industrial residues generated have gained much attention as reinforcement of various materials due to their inherited properties (i.e., biodegradability and renewability, etc.) and low-cost production [41]. Several agricultural and agro-industrial residues, such as rice husks, maise stalks, and sugarcane bagasse, were successfully incorporated to improve their mechanical and physical properties. These sources can be used for the development of biocomposites, power generation, paper production, construction board fillers, solid wood, mulching, and soil conditioning, as well as many other uses [46]. Table 1 summarises agricultural waste and its uses.

Table 1
Agricultural waste and its uses

Agricultural waste	Uses	Functions	References
Hemp Shivs & Corn Starch	Biocomposite boards	Reinforcement for composite.	[47]
Oil palm fibres	Biocomposites products	Reinforcement for composite.	[46]
Oil palm fibres	Biocomposites, hybrid composites, pulp, and paper industries	Reinforcement for composite.	[48]
Oil palm trunk (OPT) & oil palm empty fruit bunches	Hybrid plywood panel product	Reinforcement for composite.	[48]
Empty fruit bunch (EFB) & rubberwood	Hybrid medium density fibreboard (MDF)	Reinforcement for composite.	[48]
Rubberwood, Empty Fruit Bunches (EFB) & rubberwood-EFB blend	Particleboard	Reinforcement for composite.	[49]
Oil palm trunk (OPT)	Particleboard	Reinforcement for composite.	[50]
Oil palm biomass	Composite panel products	Reinforcemeboardnt for composite.	[51]
Empty Fruit Bunches (EFB) and rice husk (RH)	Hybrid composite panelboard	Reinforcement for composite.	[52]
Empty Fruit Bunches (EFB)	Particleboards	Reinforcement for composite.	[53]
Rice Husk (RH)	Particleboards	Reinforcement for composite.	[54]
Lemongrass plant	Cosmetics, food preservation, pharmacology, agriculture, silica production, bigas, paper making, biosorption	Reinforcement for biocomposites	[55]
Sugarcane bagasse	Particleboard panel	Reinforcement for composite.	[56]
Coconut fibre & sugarcane bagasse fibre	Particleboards	Reinforcement for composite.	[57]
Banana trunk waste	Particleboards.	Reinforcement for composite.	[58]
Empty fruit bunch (EFB) & sugarcane bagasse fibres	Thermal insulation materials	Reinforcement for composite.	[59]
Sugarcane bagasse	Semi-structural and structural, food packaging, ballistic resistant	Reinforcement for composite.	[60]

Due to the growing demand for green building materials and the concern over energy consumption, agricultural waste fibre-based thermal insulations are gaining popularity in the construction industry. Materials for thermal insulation can effectively lower heat conductivity and provide a comfortable indoor environment. According to studies by Asdrubali *et al.,* [61] and Panyakaew *et al.,* [8], thermal insulation materials applied to walls and roofs can minimise annual energy usage. Nowadays, research communities are looking at the high lignocellulose content in biomass, where various types of biomass fibres can be used in the market as thermal insulation materials on roofs and walls. The following section goes into detail about the need for roof insulation materials made from biomass fibre waste that appears to have a low environmental impact, are biodegradable, low cost, sustainable, and have good thermal-physical properties.

1.2 Roof Insulation Materials

The roof surface of a building is exposed directly to solar radiation throughout the daytime. This element contributes enormously to building heat gain as compared to walls, mainly because the roofs exhibit straight to the tropical sun between sunrise and dusk. The roofs would absorb the heat from solar radiation, and it is transmitted through and trapped in the attic, which then leads to the hot ceiling. The hot ceiling would radiate heat to the occupants inside a building. Most of the low-medium cost housing schemes were constructed without a ceiling where heat was directly exposed to the occupants inside the building. Thus, the thermal insulation of the roof is crucial as it reduces the energy demand of buildings and saves carbon emissions [62,63].

Nowadays, designers can choose from many different types of thermal insulations [61,62,64] to fulfil the energy performance requirements. In the building materials market for insulation materials, it is clear that the most popular products are artificial materials and mineral wool products represent about 50–55% and plastic foams about 40–45% of the total production [62,65]. These kinds of materials which have high thermal conductivity, cannot compose naturally and is it will cause environmental hazards. On top of that, inappropriate insulating materials can be harmful to human health by polluting the indoor environment, such as emissions of toxic gas and particles. Moreover, synthetic insulation materials like expanded polystyrene, mineral wool, and polyurethane foam are energy-intensive materials and expensive [66,67]. The inorganic materials take hundreds of years to decompose and also bring a long-term impact on the environment and human health [22,68].

Besides, there are reports that the production of synthetic glass fibre-filled has endangered humans and can cause irritation to the skin [69, 70] and lung fibrosis during the production and the construction phase [71, 72]. The application of Styrofoam and urethane is hazardous if a fire happens, it can generate toxic gases during combustion, such as formaldehyde, ethylene cyanide, hydrochloric acid gas, and cyanide gas, which a very critical to the human body [73].

Saad and Kamal [74] and Chiradeja and Ngaopitakkul [23] have demonstrated that the usage of agricultural waste fibres as roof insulation could reduce heat transfer into the building and maintain a comfortable temperature inside the building space. Thus, it can help to overcome the discomfort of homes and reduce indoor electricity consumption, which enables cost savings and reduces gas production that directly pollutes the environment [20]. Organic fibres offer various advantages, such as low density, low cost, biodegradability, and low energy consumption during the processing of the material [75,76]. In the case of organic insulation, it has excellent thermal performance, absorption, and workability [77].

A significant advantage of the insulation based on organic fibres is not only a low value of thermal conductivity [76,78] but also the natural character of input fibres. Organic fibres also have lower carbon footprints [79]. Another advantage is that it is a renewable material that does not place any significant strain on the environment. Several studies attempt to use agricultural waste for insulation board, e.g., using date palm wood fibre [80-82], sunflower stalk [83,84], palm fibre [57,85], coconut husk [86-88], and sugarcane bagasse [57,86,89]. However, most of the studies were conducted not specifically for roof insulation boards and had different densities than this study. Hence, to overcome the highlighted problems, this study was performed to examine the use of SB, CH, EFB, and MF waste material for the potential production of roof board insulation that can improve thermal properties value.

1.3 The Hydrophilic Behaviour and Surface Modifications of Fibre-Based Composite

The selection of potential waste for future application, which in this study refers to the sugarcane bagasse, coconut husk, empty fruits bunch, mesocarp, and its combination, should emphasise certain properties. This is true when the addition of the waste can radically change the properties of the polymer and, consequentially, the composite. The properties of the final composite obtained would depend upon several factors that are crucial to the properties of the composite, which in this study refers to the mechanical and physical characterisation. The focus of most of the studies has been the mechanical and physical characterisation, specifically on the hydrophilic behaviour and surface modifications of the composites obtained to justify their probable use in the future as an alternative material.

All the polymers absorb water in a moist atmosphere. The amount of water absorbed in bio-composites containing fibres mainly depends on the nature of the wastes. Agricultural fibres have an undesirable affinity toward water because of their hydrophilic nature. The moisture absorption by composites containing natural fibres has an adverse impact on their properties, thus affecting their long-term performance. Most of the agricultural waste, for example, rice husk [90, 91]; sugarcane bagasse [58,92]; coconut husk [93]; EFB [57] have increased the rate of water absorption when the increment of waste content since all agricultural fibres are hydrophilic in nature which leads to the barrier in adhesivity between fibre and matrix. The rice husk, sugarcane bagasse, and coconut husk are lignocellulosic materials with hygroscopic OH, which attracts water via hydrogen bond formation. This phenomenon becomes more pronounced as the proportion of RH increases. The water absorption rate of the larger-sized fibre material is higher. This occurs because smaller fibres have more OH groups to interact with the matrix. This prevents water from reaching the OH groups of the filler.

The incorporation of natural lignocellulosic materials into polymers resulted in a lack of good interfacial adhesion between the two components, resulting in poor composite properties [94-97]. Since hydrogen bonds tend to prevent wetting of the composite surfaces, the polar hydroxyl groups on the surface of lignocellulosic materials cannot form a well-bonded interface with a non-polar matrix. Furthermore, lignocellulosic materials tend to clump together. If the matrix is hydrophilic, this incompatibility results in poor mechanical properties and high water absorption. Thus, the interface between the matrix and the lignocellulosic material must be improved to improve its properties. There are several methods for promoting interfacial adhesion in lingo-cellulosic systems, which can be done by chemical, biological and physical treatment methods [52,58]. The methods play a very significant role in improving the surface characteristics of fibres.

Physical treatment methods are basic methods for the chemical-assisted surface modification technique. In this treatment, the steam explosion was commonly used for biomass treatment to separate the fibre into its constituents, such as celluloses, hemicelluloses, and lignin. The explosive steam effect on polyester composite production resulted in a decrease in hemicellulose and lignin fibre and an improvement in water absorption density and thermal stability. Chemical treatment methods are more advantageous because they result in better compatibility between fibre and matrix. The fibre can be chemically treated with alkali, which is the most useful and cost-effective method [98]. Lignin content decreases after alkali treatment with 2% weight volume (w/v) NaOH solution for sugarcane bagasse [99]. However, Mulinari *et al.,* [100] treated coconut fibre with a 1% (w/v) of alkaline solution and revealed increased surface roughness through SEM images as a result of the effective removal of wax, pectin, lignin, hemicellulose, and debris from the surface. Marwardi *et al.,* [101] treated coconut coir fibre in a 5% NaOH solution at a temperature and time of 80°C and 600 seconds, respectively, revealing changes in the morphology of the fibre with a reduction in fibre diameter up to 40%, which causes improvement in the matrix-fibre relationship, increased flexural strengths due to improving the aspect ratio of the fibre in addition to a good interface between the composite constituents [102]. However, Oladele *et al.,* [103] reported that optimum mechanical properties were observed in fibre treated with 20% NaOH, and it was concluded that alkaline treatment greatly improves the hydrophobicity of coir fibres. It can also be treated with Maleic anhydride silane, acetylation (esterification), benzoylation, and other methods [58, 103, 104]. Furthermore, fibre treated with alkaline Xylanase at 4% NaOH followed by 20 weight grams (V/g) of xylanase increased cellulosic content [58]. After alkaline treatment, a smooth surface can be observed, as can a heterogeneous rough surface seen with alkaline Xylanase pretreatment, as well as an increase in the value of the crystallinity index [58].

In other studies, however, small amounts of another component, such as compatibiliser [105, 106], may promote adhesion promoters between polymer matrix and cellulosic fibres by forming chemical bonds. Using the compatibiliser, the composites increased in tensile and flexural strength [107]. The compatibilisers formed a bond with the hydrophilic RH, thus decreasing water absorption [108]. Biological treatment methods, on the other hand, make use of naturally occurring microorganisms such as bacteria and fungi. The aqueous environment is ideal for this treatment, and biological treatment is relatively inexpensive and simple to carry out, but it takes time. The retting process is a common biological fibre treatment. Retting is the controlled degradation of agricultural plant stems to separate and segregate the bast fibres from their respective fibre bundles, as well as to detach them from the woody core and epidermis. Bacteria (mostly Clostridia species) and fungi participate in this process, releasing enzymes that aid in the degradation of pectic and hemicellulosic components in the inside lamella of each fibre cell [58].

2. Materials

The raw materials used in this study are EFB, MF, SB, and CH. For EFB and MF, these wastes were obtained from the Ladang Tereh Mill Kulim Plantation (M) Sdn Bhd, Kluang, Johore. Meanwhile, the SB was collected at the drink stall surrounding Parit Raja, Johore. The CH was obtained from a coconut factory in Senggarang, Johore. All the wastes undergo pretreatment before starting the sample fabrication, as indicated in Figure 1. The pretreatment phase is significant in revealing the scarification (a process of breaking a complex) of cellulase enzymes and fractionation of the major components of raw materials. These pretreatment processes were conducted at the Timber Fabrication Laboratory, Faculty of Civil Engineering and Built Environment, UTHM.

Fig. 1. Pretreatment of Fibres

Pretreatment methods are soaking with alkaline agents such as sodium, potassium, calcium, and ammonium hydroxides [109]. This study used sodium hydroxide (NaOH) for the process of pretreatment of the fibres to remove their residual oil. The alkaline solution was used to remove lignin and a portion of the hemicelluloses, following Sun *et al.,* [110]. The usage of the alkaline solution depended on the lignin content from biomass material. The alkaline solution is more effective for agricultural biomass. Figure 2 shows the use of NaOH in the pretreatment process. The use of NaOH was 2% of the weight of water. Zheng *et al.,* [111] recommended using NaOH between 2% — 4% as acceptable to remove lignin from waste material. After finishing soaking, the fibres were washed using clean water to reduce excess oil and sodium content.

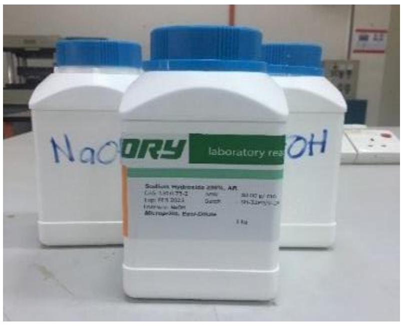

Fig. 2. Sodium hydroxide (NaOH)

The washed fibres were dried out with sun radiation within 3 days or, depending on the weather condition to reduce their moisture until completely dried. This process is a simple step to ensure dried fibre condition and contains less moisture. Moreover, doing this process can reduce the energy consumption of electric ovens [112]. After completing this process, the fibres were undergone oven-dried to ensure that the fibre is less than 10% moisture with a temperature of 110 °C ± 5 °C in an electric oven.

2.1 Fabrication of Sample

The next processes of this study are involved in fabrication works. Several processes are involved in the fabrication, starting with grinding raw fibre materials until the final sample formation in conformity with the size, thickness, and mould set. The fibres are cut to a specific length of about 10 cm manually except MF due to the original size obtained from the mill in an irregular shape and then fiberised using a wood grinder machine to cut into approximately 4-5 cm long pieces. The fibres obtained were sorted into nine sieves from 5mm to 63µm.

In this study, the fibre wastes are combined in different proportion of 50% individual fibres such as 50% SB + 50% CH, 50% EFB + 50% MF, 50% CH + 50% EFB and 50% SB+ 50% MF. The selection of proportion was based on the result of the trail mix that was conducted at early stage. Table 2 lists the mixture composition of the samples. The sample was designed as a low-density board as it possesses better thermal insulation properties [21,76,113,114]. As such, the target density design for this was 400 kg/m³. Lower densities are between 50 kg/m³ to 500 kg/m³ [115]. Other than that, this study also used Urea Formaldehyde (UF) resins. The purpose of the UF is to act as a binder to the fibres in mixed specimens. Ammonium chloride (NH_4Cl) was also used during the mix, which acts as a hardener to accelerate the hardening time of specimens.

Table 2
Mixture Proportions (quantity/ sample)

Size sample	Target Density	Materials (Fibres)	Resin (Fibres: Resin) (100: 18)	Ammonium Chloride (1% of resin)
250mm x 250mm x 25mm thick	400 kg/m^3	50% SB + 50% CH = 625g	112.5g	1.125g
250mm x 250mm x 25mm thick	400 kg/m^3	50% EFB + 50%MF = 625g	112.5g	1.125g
250mm x 250mm x 25mm thick	400 kg/m^3	50% CH + 50% EFB = 625g	112.5g	1.125g
250mm x 250mm x 25mm thick	400 kg/m^3	50% SB + 50% MF = 625g	112.5g	1.125g

The percentage of UF resin used, as shown in Table 2, followed the recommendation made by the manufacturer and Luamkanchanaphan *et al.,* [69], is based on the target density value, which is between 12% to 18%. A schematic of the production process is given in Figure 3. There are different types of sample sizes prepared in this study, which were based on the standard requirement for particular testing. However, this study prepared three samples for each design mix.

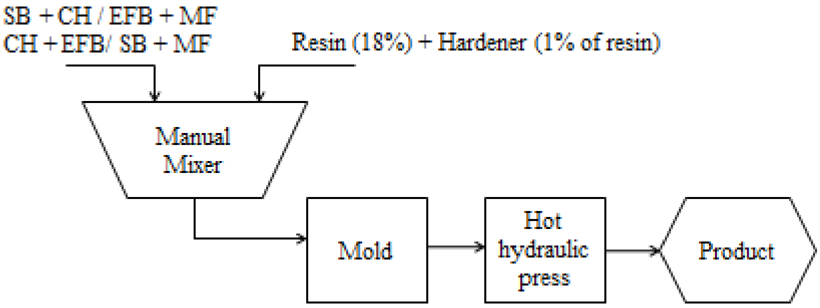

Fig. 3. Schematic of the process involved in the production of roof insulation fibreboard

For the modulus of rupture (MOR) testing, the sample size required is 350 mm × 50 mm × 25 mm, and for water absorption testing, the size was 50 mm × 50 mm × 25mm. The sample was put into the mould, respectively, and the sample was pressed using the hot press machine. The sample needs to be compressed with the temperature of the hot-press machine at 180 °C for 5 to 15 minutes under a 1000 psi pressing load as recommended by Akinlabi *et al.,* [116]. After the compression process was finished, the sample was left at room temperature to cool down the sample before it was removed from the mould, e.g., as shown in Figure 4.

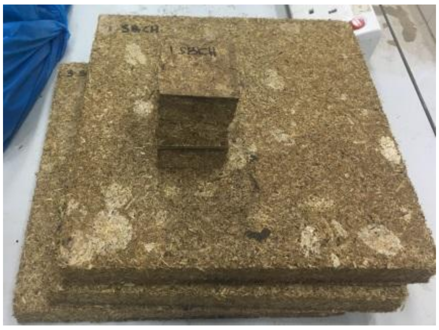

Fig. 4. Samples of 50% SB with 50% CH roof insulation fibreboard

3. Results and Discussion

The results of the test conducted were discussed in this section. The determination of whether the fibre exceeds its suitability depends on the physical, mechanical, and thermal performance of the samples through various laboratory testing, as mentioned in the following sub-sections.

3.1 Specific Gravity

The determination of specific gravity concerning the classification was referred to the British Standard EN 622-1:2003. The result of the specific gravity of different samples is shown in Figure 5.

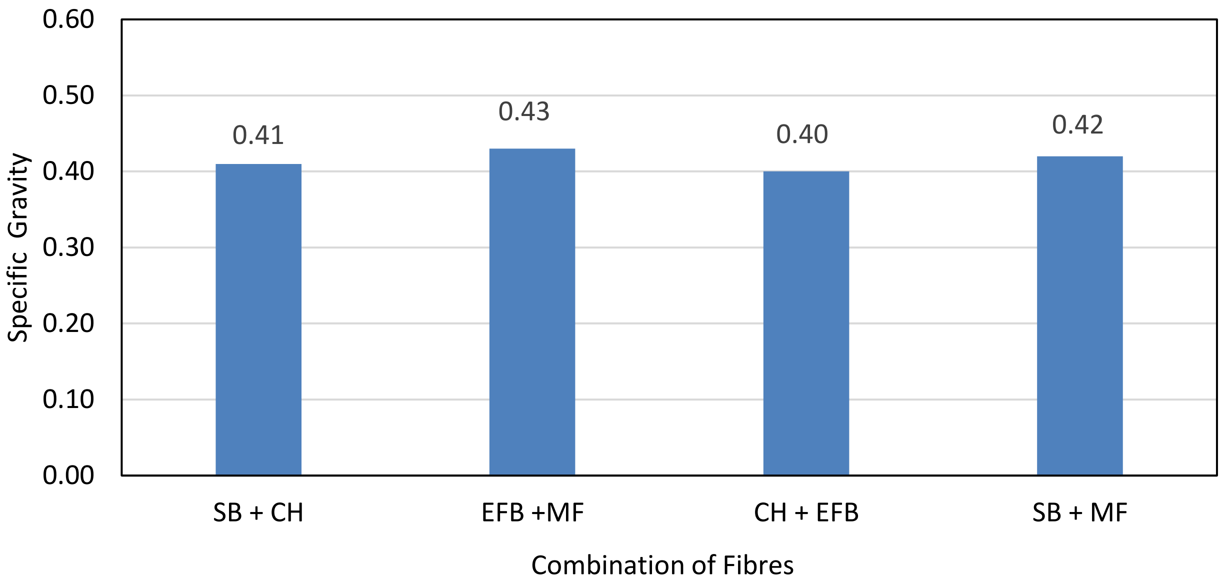

Fig. 5. Result-specific gravity test of different samples

The result shows that the samples were categorised as low-density fibreboard because the specific gravity value was between 0.16 – 0.50 [117]. Kawasaki *et al.,* [115] highlighted that this low-density fibreboard has suitable stability dimensions, better mechanical properties, and superior thermal insulation characteristics. Moreover, low-density fibreboards are mainly used as thermal insulation materials in civil engineering [118].

3.2 Bulk Density

The bulk density is vital in the physical properties of the fibreboard insulator. Bulk density is useful in predicting thermal insulation behaviour [119,120]. Bulk density is influenced by the type of fibre, the thickness of the board, the pressure imposed, and the ratio of resin [121,122]. The results of the bulk density of different samples are shown in Figure 6.

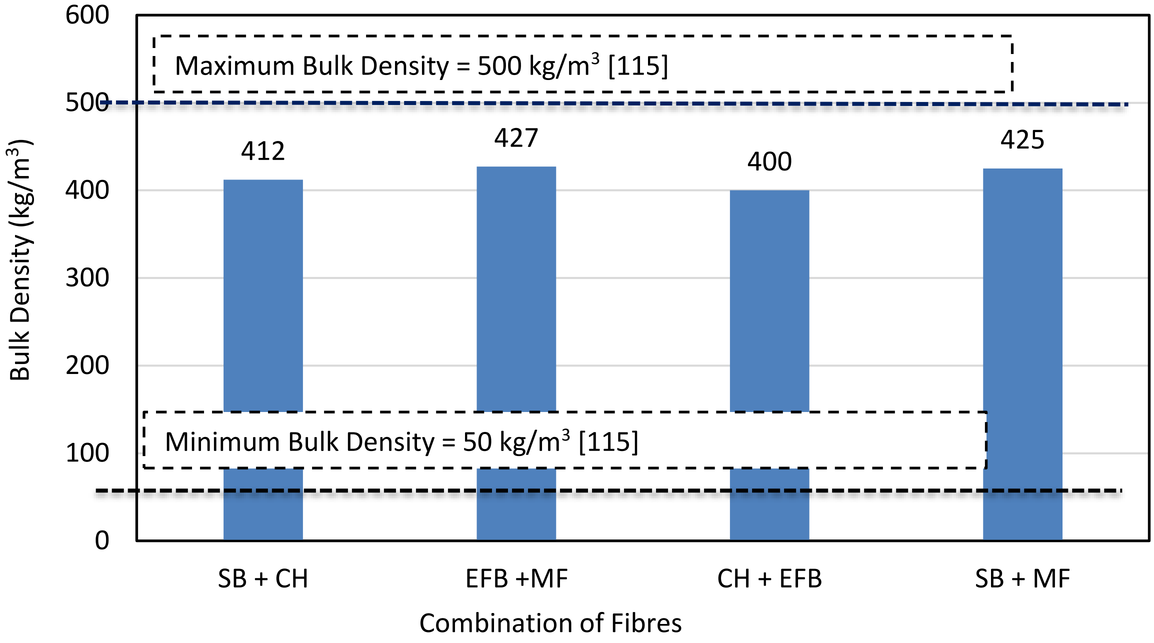

Fig. 6. Result bulk density test of different samples

The result shows that all the bulk densities of roof insulation fibreboard samples are not more than 500 kg/m^3. Kawasaki *et al.,* [115] have reported that the density of LDF ranges between 50 – 500 kg/m^3. Thus, the finding from Figure 6 shows that all the bulk density values of fibreboard met the standard of low-density fibreboard. Low bulk density fibreboard possesses better thermal insulation properties.

3.3 Thickness of Swelling (TS)

This test was performed to measure the amount of water absorbed by the roof insulation fibreboard samples after 24 hours of soaking. The test was carried up and followed the British Standard EN 317-1993. The results of the TS test are shown in Figure 7. The result shows that the samples were categorised as good performance because the TS value obtained was between the ranges of 12% – 20% [123]. The standard requirement for TS is not more than 20% [124]. Lower thickness swelling values represent higher consistency between fibres which provides better dimensional stability and generally presents higher internal bonding values.

Monteiro *et al.,* [125] reported that TS followed the same trend as bulk density. The lower the mass of material per unit volume, the lower the amount of water absorbed and thus the lower the swelling. Many physical properties of composites are affected by the amount of moisture present in the composites. TS is independent of composite size and thickness, as stated by Kelly [126]. Previous studies reported that the oil palms composite was the highest TS among different types of composites [97,127]. The value obtained by the samples (EFB+MF) indicated that the high porosity or the presence of voids on the surface of the samples affected its swelling. Saad and Kamal [74] have mentioned that for the low-density board, the highly porous structure could allow water to penetrate the board surface and increase water intake, resulting in the board swelling and thus causing an increase in the thickness of the swelling. The type of resin used may also affect the thickness swelling of the composite boards. This can be related to the poor dimensional stability of urea formaldehyde [128]. The fibres used are hydrophilic in nature because of an abundance of hydroxyl groups that are not compatible with the hydrophobic matrices of urea formaldehyde. This incompatibility leads to low fibre–matrix interfacial bond strength, poor wetting of the fibres by the matrix resin, and a reduction of mechanical performance when exposed to moisture, thereby increased in thickness swelling [128]. The TS could easily be controlled by adding water-repellent chemicals as a surface treatment in the production of composite fibreboards.

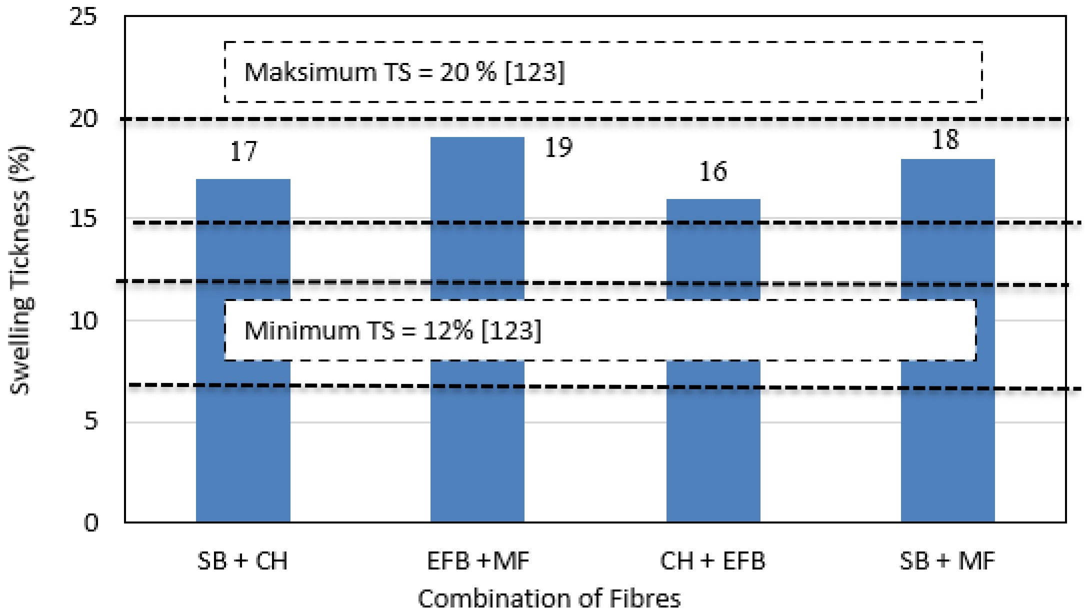

Fig. 7. Result swelling thickness of different samples

3.4 Modulus of Rupture (MOR)

The MOR test was performed to determine the strength against bending using the Universal Testing Machine (UTM). The test was carried up following the BS EN 310:1993. The reading obtained from the UTM determined the load capacity of the board. The results of the MOR are shown in Figure 8.

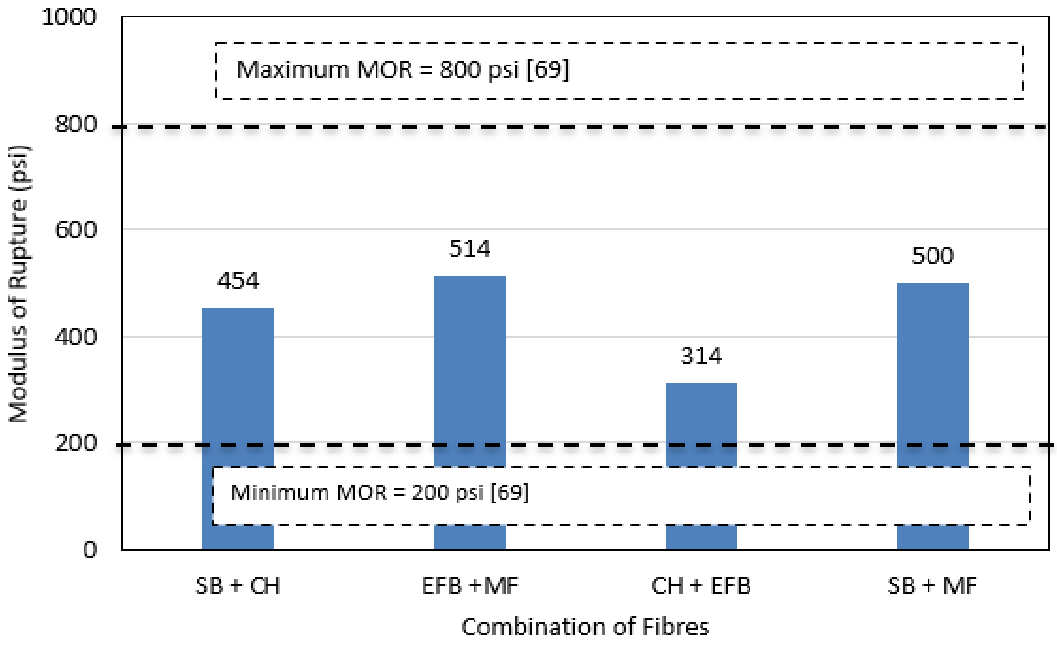

Fig. 8. Result MOR test of different samples

The average MOR of the samples with a density of 400, 412, 425, and 427 kg/m^3 are 314, 454, 500, and 514 psi, respectively. According to Luamkanchanaphan *et al.,* [69], the average MOR values range from 200 to 800 psi. Thus, based on the results obtained, all the samples met the standard for insulation fibreboard requirements. From this experiment, the MOR showed a significant increase when the sample density increased from 400 kg/m^3 to 427 kg/m^3 (see Figure 6), and this result is consistent with other studies using natural fibres [129]. The MOR increased with increasing board density [130, 131]. The sample of EFB+MF shows the highest MOR value because the particles and the matrix of the board have better bonding compared to others. The bending properties, such as MOR, are adversely influenced by the absence of any adhesive to bind the reinforcement fibres [56]. Pandey *et al.,* [132] suggested that the surface and heat treatment processes result in improved surface adhesion properties of the composites. The excellent compression ratio and better particle bonding within boards led to a better contact area between the resin and wastes of EFB+MF particles, which resulted in high strength properties. Conversely, the lowest MOR value referred to the sample (i.e., CH+EFB) due to the porous structure applied to the sample and the reduction in inter particles' contact area, which resulted in the formation of weaker bonds [129].

3.5 Thermal Conductivity

This test was conducted to measure the ability of samples to conduct heat using a heat flow meter HFM 436/3/1 Lambda. The test was carried out at Advanced Oleochemical Technology Division (AOTD), Malaysian Palm Oil Berhad (MPOB), following the ASTM C518 [133] and ISO 8301 [134]. The results of the thermal conductivity are shown in Figure 9.

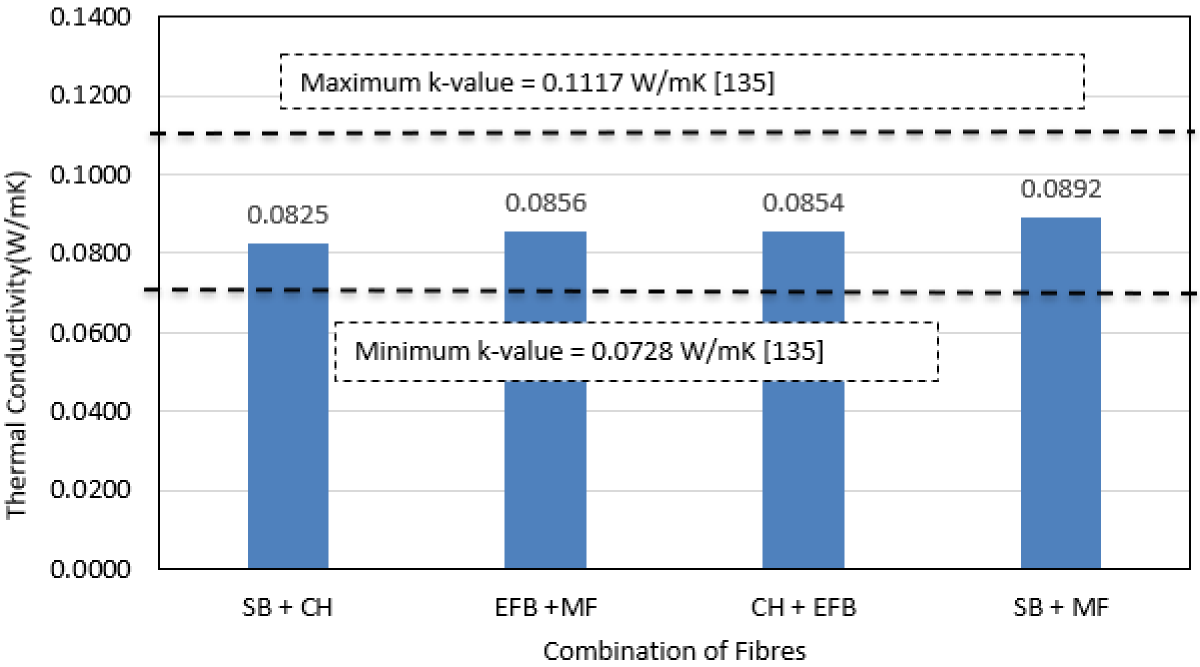

Fig. 9. Result of thermal conductivity value of different samples

This study revealed that the samples with a density of 400 – 427 kg/m^3 had thermal conductivity values ranging from 0.0825- 0.0892 W/mK, which is less than other fibrous materials such as durian peel and coconut coir (0.0728 – 0.1117 W/mK) [135]; sugarcane bagasse (0.079 – 0.09796 W/mK) [68]; corn cob (0.096 W/mK) [136]. All the samples have met the requirement of the standard, which is between 0.05 to 0.10 W/mK [137]. Moreover, materials with thermal conductivity of less than 0.25 W/mK are generally seen as good thermal insulations [57, 138-141].

Therefore, it revealed that the sample with a density of 400 kg/m^3, i.e., a combination of the fibre of CH+EFB, had thermal conductivity values of 0.0825 W/mK, which was less than SB+MF, SB+CH, and EFB+MF, with K-value 0.0856 (425 kg/m^3), 0.0854 (412 kg/m^3) and 0.0892 W/mK (427 kg/m^3), respectively. This low thermal conductivity recorded in the samples is probably caused due to the use of larger fibres, leading to voids filled with air, which is one of the poorest conductors [142]. Luamkanchanaphan *et al.,* [69] and Asfaw [122] have pointed out that the main factors that affect thermal conductivity are the density and the porosity of the materials. Increasing the density intensifies the thermal conductivity [68, 143]. Meanwhile, lower-density boards could achieve better thermal performance, which could be explained by the greater air content inside the board [143].

3.6 Summary of Findings

Based on the findings, this study found that the composite sample (EFB+MF) met all required settings as shown in Table 3.

Table 3
The summary of the results obtained

Parameter	Samples (EFB+MF)	Criteria
Bulk density (kg/m^3)	427	50 – 500 [115]
Thickness of swelling (TS) (%)	19%	12 – 20 % [123]
Modulus of rupture (MOR) (psi)	514	200 – 800 [69]
Thermal conductivity (W/mK)	0.0856	0.0728 – 0.1117 [135]

Based on the results in Table 3, however, they need several modifications of agricultural waste on the following.

3.6.1 Pretreatment of agricultural waste

The problem is the usage of EFB and MF waste in the composite is the high content of grease, oil, and minerals in the fibres. Oil consists of ester components that may disturb the bonding proficiency between fibres and the matrix during composite production [144]. Oily constituents and impurities stick on the surface of EB and MF, causing poor surface wetting and decreasing coupling efficiency between fibre and matrix. Moreover, all waste used in the composite, including EFB and MF, are hydrophilic in nature and contains strongly polarised hydroxyl groups, which are characteristically incompatible with hydrophobic matrices. Utilising agricultural waste as reinforcements in such matrices will cause poor interfacial adhesion between polar-hydrophilic fibre and the nonpolar-hydrophobic matrix [53] and high moisture absorption between fibres and matrix in composites [97] which can be seen in all the samples tested obtained in this study have a close value between samples in the swelling thickness test. Thus, in order for the oil palm fibre (EFB+MF) to be potential for replacement of synthetic polymeric composites, the oil palm fibre needs to be pretreated before being applied as a reinforcing material in composite panels production [53,55,97,145-147]. As mentioned by Fiore *et al.,* [148] that the pretreatment will alter the oil palm fibre physically or chemically to reinforce the poor characteristics of the fibre through the removal of contaminations, altering the chemistry and crystallinity formation, refining the interface of fibre and matrix, achieving good bonding between fibre and matrix. In this study, pretreatment was done using 2% sodium hydroxide (NaOH), as suggested by Zheng *et al.,* [111] and Liu *et al.,* [99], to remove its residual oil.

However, based on the result obtained for future improvement, the amount of NaOH needs to increase by more than 2% to improve cellulose structure and increase crystallinity index, which will follow the suggestion of Latip *et al.,* [149] and Kamal *et al.,* [150].

3.6.2 Resin matrix

The interfacial adhesion between the reinforcement and matrix in a composite material plays an important role in the composite performance. The formaldehyde-based adhesive is a synthetic polymeric material, also known as resin, chemically prepared using formaldehyde as one of its active ingredients. Among formaldehyde-based adhesives used in the wood industry is urea-formaldehyde (UF) which was used in this study. However, the problem with UF resin is a lack of resistance to moisture which leads to a decrease in bonding strength, an important characteristic of composite materials. This weakness of UF resin was shown through the result of TS and MOR samples obtained which are critical physical properties of biomass composite materials and reflected in interfacial adhesion bonds between composite and resin matrix. Moreover, due to the environmental requirement and need for eco-friendly green materials, therefore, the modification of the resin matrix from synthetic to natural materials in future products that meet satisfactory physical and mechanical properties is important. Harmful formaldehyde emissions can be reduced by adding various inorganic, organic, and mineral compounds as formaldehyde scavengers to conventional wood adhesives using formaldehyde-free adhesive formulations [151]. Based on the study by Antov *et al.,* [152] and Hong *et al.,* [153], a formaldehyde-free adhesive is a potential resin to be utilised as an eco-friendly additive to UF adhesive formulations as it can increase MOE and TS value compared to UH resin.

4. Conclusion

This paper presents the research outcome that highlights the potential of using agricultural waste as polymeric reinforcement composites for thermal roof board insulation by considering current environmental issues, and green, environmentally friendly, and sustainable products. Overall, the selection for potential samples as thermal roof board insulation refers to the samples mixed with EFB + MF, which achieved all the criteria such as density (427 <500kg/m^3); TS (19< 20%); MOR (514<800psi), thermal conductivity (0.0856<0.25 W/m.K). However, to be a potential agricultural waste to be applied as a composite material to roof board insulators, this study found that a major modification to the waste preparation involved surface treatment of the waste fibre and the application of formaldehyde-free adhesive as resin matrix of the composite. Doing this can achieve the desired mechanical properties of the composites. This study directs the next research where the combination of fibres EFB +MF would be selected for the physical and mechanical properties improvement considering the modification suggested in this study.

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References

[1] Malaysia Standard 2680. "Malaysian Standard: Energy efficiency and use of renewable energy for residential buildings- Code of practice." *Department of Standards Malaysia* (2017): 1-56.

[2] Abd Shatar, S., Othman, N., Mohd Yusof, N.A. and Mohamed, Z. "Preliminary review on housing policy and its implementation in Malaysia." *Journal of Science, Technology and Innovation Policy* 3, no. 1 (2017):2013–2016.

[3] SUHAKAM. “Laporan mesyuarat bersama agensi kerajaan mengenai hak perumahan wajar dan mencukupi.” Kuala Lumpur. (2012): 1–12.

[4] Yew, M. C., NH Ramli Sulong, W. T. Chong, S. C. Poh, B. C. Ang, and K. H. Tan. "Integration of thermal insulation coating and moving-air-cavity in a cool roof system for attic temperature reduction." *Energy conversion and management* 75 (2013): 241-248. https://doi.org/10.1016/j.enconman.2013.06.024

[5] Roslan, Qairuniza, Siti Halipah Ibrahim, Rohaida Affandi, Mohd Nasrun Mohd Nawi, and Azhaili Baharun. "A literature review on the improvement strategies of passive design for the roofing system of the modern house in a hot and humid climate region." *Frontiers of Architectural Research* 5, no. 1 (2016): 126-133. https://doi.org/10.1016/j.foar.2015.10.002

[6] Kaamin, M., Rahman, R. A., Suwandi, A. K., Kesot, M. J. and Razzaq, A. R. A. "Kajian alternatif mengurangkan suhu rumah beratap zink di waktu tengahari." *Proceeding of the International Conference on Social Science Research (ICSSR)*, (2013):357–368.

[7] Bhikhoo, Nafisa, Arman Hashemi, and Heather Cruickshank. "Improving thermal comfort of low-income housing in Thailand through passive design strategies." *Sustainability* 9, no. 8 (2017): 1440. https://doi.org/10.3390/su9081440

[8] Panyakaew, S. and Fotios, S. "Agricultural waste materials as thermal insulation for dwellings in Thailand: preliminary results." In *25th Conference on Passive and Low Energy Architecture*, (2008): 1-6.

[9] Al-Yacouby, A. M., Khamidi, M. F., Teo, Y. W., Nuruddin, M. F., Farhan, S. A., Sulaiman, S. A. and Razali, A. E. "Housing developers and home owners awareness on implementation of building insulation in Malaysia." *WIT Transactions on Ecology and the Environment* 148, (2011): 219–230. https://doi.org/10.2495/RAV110211

[10] Gonzalez-Longo, Cristina, and Mohd Firrdhaus Mohd Sahabuddin. "High-rise social housing in hot-humid climates: towards an ‘airhouse’standard for comfort." *Applied Sciences* 9, no. 23 (2019): 4985. https://doi.org/10.3390/app9234985

[11] Ali, S.B.M., Hasanuzzaman, M., Rahim, N.A., Mamun, M.A.A. and Obaidellah, U.H. "Analysis of energy consumption and potential energy savings of an institutional building in Malaysia." *Alexandria Engineering Journal*, (2020):1-16.

[12] Qahtan, A. M., Nila IM Keumala, and S. P. Rao. "Occupant satisfaction in respect to indoor environmental quality in energy efficient certified buildings in Malaysia." In *16th international conference of the CIB W104 open building implementation on “open and sustainable building*. 2010.

[13] Hassan, A. S. and Al-Ashwal, N. T. "Impact of building envelope modification on energy performance of high-rise apartments in Kuala Lumpur, Malaysia." *International Transaction Journal of Engineering, Management, & Applied Sciences & Technologies* 6, no.3 (2015): 91 – 105.

[14] Chen-Yi, Z., Xiao, Z., Song, L., Shuai, H. and Peng, L. "Study on the relationship between thermal comfort and air-conditioning energy consumption in different cities." *Journal of Computers* 28, no. 2 (2017): 135-143.

[15] Mirrahimi, Seyedehzahra, Mohd Farid Mohamed, Lim Chin Haw, Nik Lukman Nik Ibrahim, Wardah Fatimah Mohammad Yusoff, and Ardalan Aflaki. "The effect of building envelope on the thermal comfort and energy saving for high-rise buildings in hot–humid climate." *Renewable and Sustainable Energy Reviews* 53 (2016): 1508-1519. https://doi.org/10.1016/j.rser.2015.09.055.

[16] Jannat, Nusrat, Aseel Hussien, Badr Abdullah, and Alison Cotgrave. "A comparative simulation study of the thermal performances of the building envelope wall materials in the tropics." *Sustainability* 12, no. 12 (2020): 4892. https://doi.org/10.3390/su12124892

[17] International Energy Agency. Transition to Sustainable Buildings, (2013).

[18] Irfan, Muhammad, and Faizir Ramlie. "Analysis of Parameters which Affects Prediction of Energy Consumption in Buildings using Partial Least Square (PLS) Approach." *Journal of Advanced Research in Applied Sciences and Engineering Technology* 25, no. 1 (2021): 61-68. https://doi.org/10.37934/araset.25.1.6168

[19] Magar, N. M. "Hygrothermal performance of sarking roof structure." Metropolia University of Applied Sciences, Helsinki, Sweden, Undergraduate Thesis. (2017): 1-70.

[20] Patnaik, A., Mvubu, M., Muniyasamy, S., Botha, A. and Anandjiwala, R. D. "Thermal and sound insulation materials from waste wool and recycled polyester fibers and their biodegradation studies." *Energy and Buildings* 92 (2015): 161–169. https://doi.org/10.1016/j.enbuild.2015.01.056

[21] Aditya, L., Mahlia, T.M.I., Rismanchi, B., Ng, H.M., Hasan, M.H., Metselaar, H.S.C., Muraza, D. and Aditiya, H.B. "A review on insulation materials for energy conservation in buildings." *Renewable and Sustainable Energy Review* 73 (2017): 1352-1365. https://doi.org/10.1016/j.rser.2017.02.034

[22] Ibrahim, S. H., Sia, W. K., Baharun, A., Nawi, M. N. M. and Affandi, R. "Thermal performance of oil palm fibre and paper pulp as the insulation materials." *Journal of Civil Engineering, Science and Technology* 5, no.2 (2014): 22-28. https://doi.org/10.33736/jcest.135.2014

[23] Chiradeja, Pathomthat, and Atthapol Ngaopitakkul. "Energy and economic analysis of tropical building envelope material in compliance with thailand's building energy code." *Sustainability* 11, no. 23 (2019): 6872. https://doi.org/10.3390/su11236872

[24] Vecchia, F. and Givoni, B. "Analysing thermal performance of occupied houses in Descalvado." *PLEA 2001 - The 18th Conference on Passive and Low Energy Architecture* (2001): 1–7.

[25] Nikolaidis, Y., Pilavachi, P.A. and Chletsis, A. "Economic evaluation of energy saving measures in a common type of Greek building." *Applied Energy* 86 (2009): 2550–2559. https://doi.org/10.1016/j.apenergy.2009.04.029

[26] Lucerno-Alvarez, J., Rodriguez-Munoz, N.A. and Martin-Dominguez, I.E. "The effects of roof and wall insulation on the energy costs of low-income housing in Mexico." *Sustainability* 8, 590 (2016): 1-19. https://doi.org/10.3390/su8070590

[27] Al-Homoud, M. S. "The effectiveness of thermal insulation in different types of buildings in hot climates." *Journal of Thermal Envelope and Building Science* 27, no. 3 (2004): 235–247. https://doi.org/10.1177/1097196304038368

[28] Shehadi, Maher. "Energy consumption optimization measures for buildings in the Midwest regions of USA." *Buildings* 8, no. 12 (2018): 170. https://doi.org/10.3390/buildings8120170

[29] Harimi, M., Harimi, D., Kurian, V. J. and Nurmin, B. "Evaluation of the thermal performance of metal roofing." *The World Sustainable Building Conference*, (2005): 27–29.

[30] Zainu, Z. and Songip, A. "Policies, challenges and strategies for Municipal waste management in Malaysia." *Journal of Science, Technology and Innovation* 3, no. 1 (2017): 18–22.

[31] Roda, J.M., Goralski, M., Benoist, A. and Tahir, P. "Sustainability of bio-jetfuel in Malaysia." *Centre of International Cooperation in Agronomy Research for Development (CIRAD)*, (2015): 1-115. https://doi.org/10.19182/agritrop/00001

[32] Yacob, N.S., Mohamed, H. and Shamsuddin, A.H. "Investigation of palm oil wastes characteristics for co-firing with coal." *Journal of Advanced Research in Applied Sciences and Engineering Technology* 23, no. 1 (2021): 34-42. https://doi.org/10.37934/araset.23.1.3442

[33] Singh, R. P., Ibrahim, M. H., Esa, N. and Iliyana, M. S. "Composting of waste from palm oil mill: A sustainable waste management practice." *Reviews in Environmental Science and Biotechnology* 9, no. 4 (2010): 331–344. https://doi.org/10.1007/s11157-010-9199-2

[34] Dalton, O.S., Mohamed, A.F. and Chikere, A.O. "Status evaluation of palm oil waste management sustainability in Malaysia." *International Journal of Sustainable Development* 10, no. 12 (2017): 41-48.

[35] Ibrahim, Z., Aziz, A. A., Ramli, R., Hassan, K. and Mamat, R. "Production of high density fibreboard (HDF) from empty fruit bunch fibres." *MPOB Information Series*, July, No. 616 (2017).

[36] Abdul Wahab, N., Ali Othman, N.E., Ismail, F. and Abdul Aziz, A. "A review on extraction processes of lignocellulosic chemicals from oil palm biomass." *Journal of Oil Palm Research* 29 (2017): 512-527. https://doi.org/10.21894/jopr.2017.00016

[37] Nik Malek, N.A.N., Yusof, M.H. and Kamaru, A.A. "Simultaneous action of surfactant modified sugarcane bagasse: Adsorbent and antibacterial agent." *Malaysian Journal of Fundamental and Applied Sciences* 15, no. 1 (2019): 32-37. https://doi.org/10.11113/mjfas.v15n2019.1203

[38] Ministry of Agriculture and Agro-Based Industry, Malaysia. "Agrofood statistics 2013." (2014).

[39] Hirschmann, R. "Production of refine sugar in Malaysia 2013-2019." *Statisca.com*. Feb 19 (2020).

[40] Sahiron, N., Rahmat, N. and Hamzah, F. "Characterization ofsodium silicate derived from sugarcane bagasse ash." *Malaysian Journal of Analytical Science* 21, no. 2 (2017): 512–517. https://doi.org/10.17576/mjas-2017-2102-26

[41] Mokhena, Teboho C., Mokgaotsa J. Mochane, Tshwafo E. Motaung, Linda Z. Linganiso, Oriel M. Thekisoe, and Sandile P. Songca. "Sugarcane bagasse and cellulose polymer composites." *Sugarcane-technology and research* (2018): 225-40. https://doi.org/10.5772/intechopen.71497

[42] Abu Dardak, R. and Mohd Yon, R. "Strengthening the coconut industry in Malaysia." *FFTC Agricultural Policy Platform,* (2021).

[43] Man, H.C.B., Akinbile, C.O. and Jun, C.X. "Coconut husk adsorbent for the removal of methylene blue dye from wastewater." *BioResources* 10, no. 2 (2015): 2859-2872. https://doi.org/10.15376/biores.10.2.2859-2872

[44] Alwani, M. S., Abdul Khalil, H. P. S., Sulaiman, O., Islam, M. N. and Dungani, R. "An approach to using agricultural waste fibres in biocomposites application: Thermogravimetric analysis and activation energy study." *BioResources* 9, no. 1 (2014): 218–230. https://doi.org/10.15376/biores.9.1.218-230

[45] Sadh, P.K., Duhan, S. and Duhan, J.S. "Agro-industrial wastes and their utilization using solid state fermentation: a review." *Bioresources and Bioprocess* 5, no.1 (2018): 1-15. https://doi.org/10.1186/s40643-017-0187-z

[46] Dungani, Rudi, Pingkan Aditiawati, Sri Aprilia, Karnita Yuniarti, Tati Karliati, Ichsan Suwandhi, and Ihak Sumardi. "Biomaterial from oil palm waste: properties, characterization and applications." *Palm Oil* 31 (2018): 1-6. https://doi.org/10.5772/intechopen.76412

[47] Kremensas, A., 1, Kairyt˙e, A., Vaitkus, S., V˙ejelis, S. and Balˇci, G. "Mechanical performance of biodegradable thermoplastic polymer-based biocomposite boards from hemp shivs and corn starch for the building industry." *Materials* 12 (2019): 845, 1-14. https://doi.org/10.3390/ma12060845

[48] Abdul Khalil, H.P.S., Fazita, N., Bhat, A.H. and Nik Fuad, N.A. "Development and material properties of new hybrid plywood from oil palm biomass." *Materials and Design* 31 (2010): 417-427. https://doi.org/10.1016/j.matdes.2009.05.040

[49] Zaidon, A., Nizam, A.M.N., Noor, M.Y.M., Abood, F., Paridah, M.T., Yuziah, M.Y.N. and Jalaludin, H. "Properties of particleboard made from pretreated particles of rubberwood, EFB and rubberwood-EFB blend." *Journal of Applied Science* 7, no. 8 (2007): 1145-1151. https://doi.org/10.3923/jas.2007.1145.1151

[50] SaifulAzry, S.O.A., Lee, S.H. and Lum, W.C. "Oil palm biomass for composite panels." *Fundamentals, Processing, and Applications* (2022): 153-174.

[51] Ilyas, R.A., Sapuan, S.M., Ibrahim, M.S., Wondi, M.H., Norrahim, M.N.F., Harussani, M.M., Aisyah, H.A., Jeno, M.A., Hayawin, Z.N., Atikah, M.S.N., Ibrahim, R., SaifulAzry, S.O.H., Hassan, C.S. and Haris, N.I.N. "Classification and application of composite panel products from oil palm biomass, Oil palm biomass for composite panels." *Fundamentals, Processing, and Applications* (2022): 217-240. https://doi.org/10.1016/B978-0-12-823852-3.00012-X

[52] Abdul Karim, M.H., Mohd Shah, M.K., Jundam, M.F. and Abdullah, S. "Investigation of tensile properties of the eco-board of hybrid composite that consist of oil palm empty fruit bunch (OPEFB) fiber added with rice husk." *IOP Conference Series: Materials Science and Engineering* 834 (2020):1-14. https://doi.org/10.1088/1757-899X/834/1/012012

[53] Chin, Kit Ling, Chuan Li Lee, Paik San H'ng, Pui San Khoo, and Zuriyati Mohamed Asa'ari Ainun. "Pretreatment of empty fruit bunch fiber: Its effect as a reinforcing material in composite panels." In *Oil Palm Biomass for Composite Panels*, pp. 153-174. Elsevier, 2022.

[54] Battegazzore, D., Alongi, J., Frache, A., Wagberg, L. and Carosio, F. "Layer by layer-functionalized rice husk particles: A novel and sustainable solution for particleboard production." *Materials Today Communications* (2017): 92-101. https://doi.org/10.1016/j.mtcomm.2017.09.006

[55] Fiore, V., Badaglacco, D., Sanfilippo, C., Pierrone, R., Siengchin, S., Rangappo, S.M. and Botto, L. "Lemongrass plant as potential sources of reinforcement for biocomposites: A preliminary experimental comparison between leaf and culm fibers." *Journal of Polymers and the Environment* (2022): 1-12. https://doi.org/10.1007/s10924-022-02545-8

[56] Wan Nadhari, W.N.A., Abdul Karim, N., Boon, J.G., Mohd Salleh, K., Mustapha, A., Hashim, R., Sulaiman, O. and Azni, M. "ESugarcane (Saccharum officinarium L.) bagasse binderless particleboard: Effect of hot-pressing time study." *Materials Today: Proceedings* 31 (2020): 313–317. https://doi.org/10.1016/j.matpr.2020.06.016

[57] Fiorelli, J., Bueno, S.B. and Cabal, M.R. "Assessment of multilayer particleboards produced with green coconut and sugarcane bagasse fibers." *Construction and Building Materials* 205 (2019): 1-9. https://doi.org/10.1016/j.conbuildmat.2019.02.024

[58] Wan Nadhari, W.N.A., Danish,M., Mohd Nasi, M. S. R. and Boon, J.G. "Mechanical properties and dimensional stability of particleboard fabricated from steam pre-treated banana trunk waste particles." *Journal of Building Engineering* 26 (2019): 1-4. https://doi.org/10.1016/j.jobe.2019.100848.

[59] Ramlee, N.A., Naveen, J. and Jawaid, M. "Potential of oil palm empty fruit bunch (OPEFB) and sugarcane bagasse fibers for thermal insulation application – A review." *Construction and Building Materials* 271 (2021):1-16. https://doi.org/10.1016/j.conbuildmat.2020.121519

[60] Jaiswal, Deeksha, and G. L. Devnani. "Bagasse fibers, their composites and applications." In *Plant Fibers, their Composites, and Applications*, pp. 111-130. Woodhead Publishing, 2022. https://doi.org/10.1016/B978-0-12-824528-6.00005-9

[61] Asdrubali, F., D'alessandro, F. and D'alessandro, S. "A review of unconventional sustainable building insulation materials." *Sustainable Materials and Technologies* 4 (2015): 1–17. https://doi.org/10.1016/j.susmat.2015.05.002

[62] Nagy, B., Simon, T.K. and Nemes, R. "Effect of built-in mineral wool insulations durability on its thermal and mechanical performance." *Journal of Thermal Analysis and Calorimetry* 139 (2020): 169–181. https://doi.org/10.1007/s10973-019-08384-5

[63] MacKay, J.C.D. "Sustainable Energy—without the hot air." *Cambridge, United Kingdom* (2009).

[64] Schiavoni, S., D'alessandro, F., Bianchi, F. and Asdrubali, F. "Insulation materials for the building sector: a review and comparative analysis." *Renewable Sustainable Energy Review* 62 (2016): 988–1011. https://doi.org/10.1016/j.rser.2016.05.045

[65] Bozsaky, D. "The historical development of thermal insulation materials." *Periodica Polytechnica Architecture* 41, no. 2 (2010): 49–56. https://doi.org/10.3311/pp.ar.2010-2.02

[66] Monahan J. and Powell, J.C. "An embodied carbon and energy analysis of modern methods of construction in housing: A case study using a lifecycle assessment framework." *Energy and Buildings* 43, no. 1 (2011): 179-188. https://doi.org/10.1016/j.enbuild.2010.09.005

[67] D'Alessandro, F., Schiavoni, S. and Bianchi, F. "Insulation materials for the building sector: A review and comparative analysis." *Renewable and Sustainable Energy Reviews* 62 (2016): 988-1011. https://doi.org/10.1016/j.rser.2016.05.045

[68] Liao, R., Xu, J. and Umemura, K. "Low density sugarcane bagasse particleboard bonded with citric acid and sucrose: Effect of board density and additive content." *BioResources* 11 (2016): 2174–2185. https://doi.org/10.15376/biores.11.1.2174-2185

[69] Luamkanchanaphan, T., Chotikaprakhan, S. and Jarusombati, S. "A study of physical, mechanical and thermal properties for thermal insulation from narrow-leaved cattail fibers." *APCBEE Procedia* 1 (2012): 46–52. https://doi.org/10.1016/j.apcbee.2012.03.009

[70] Worksafe New Zealand. "Workplace exposure standard (WES) review- synthetic mineral fibres (SMF)." *New Zealand Government, Wellington, New Zealand, Mac* (2019): 1-44.

[71] Lipworth, L, La Vecchia, C., Bosetti, C. and McLaughlin, J.K. "Occupational exposure to rock wool and glass wool and risk of cancers of the lung and the head and neck: A systematic review and meta-analysis." *Journal of Occupational and Environmental Medicine* 51, no. 9 (2009):1075-1087. https://doi.org/10.1097/JOM.0b013e3181b35125

[72] Velichko, Evgeny, Edward Tskhovrebov, and Andrew Shevchenko. "Environmental safety providing during heat insulation works and using thermal insulation materials." In *MATEC Web of Conferences*, vol. 106, p. 03009. EDP Sciences, 2017. https://doi.org/10.1051/matecconf/201710603009

[73] Farhan, Shameel, Rumin Wang, Hao Jiang, and Kezhi Li. "Use of waste rigid polyurethane for making carbon foam with fireproofing and anti-ablation properties." *Materials & Design* 101 (2016): 332-339. https://doi.org/10.1016/j.matdes.2016.04.008

[74] Saad, Mohamad Jani, and Izran Kamal. "Mechanical and physical properties of low density kenaf core particleboards bonded with different resins." *Journal of Science and Technology* 4, no. 1 (2012): 7-32.

[75] Rozman, H. D., Ahmadhilmi, K. R. and Abubakar, A. "Polyurethane (PU) - oil palm empty fruit bunch (EFB) composites: The effect of EFB reinforcement in mat form and isocyanate treatment on the mechanical properties." *Polymer Testing* 23, no. 5 (2004): 559–565. https://doi.org/10.1016/j.polymertesting.2003.11.004

[76] Ramlee, N.A., Naveen, J. and Jawaid, M. "Potential of oil palm empty fruit bunch (OPEFB) and sugarcane bagasse fibers for thermal insulation application – A review." *Construction and Building Materials* (2020): 121519. https://doi.org/10.1016/j.conbuildmat.2020.121519

[77] Jeon, C. K., Lee, J.S., Chung, H., Kim, J.H, and Park, J.P. "A study on insulation characteristics of glass wool and mineral wool coated with a polysiloxane agent." *Advances in Materials Science and Engineering* (2017): 1-6. https://doi.org/10.1155/2017/3938965

[78] Zach, J., Hroudová, J., Brožovský, J., Krejza, Z. and Gailius, A. "Development of thermal insulating materials on natural base for thermal insulation systems." *Procedia Engineering* 57 (2013): 1288-1294. https://doi.org/10.1016/j.proeng.2013.04.162

[79] Parlato, M.C.M. and Porto, S.M.C. "Organized framework of main possible applications of sheep wool fibers in building components." *Sustainability* 12, no. 761 (2020): 1-17. https://doi.org/10.3390/su12030761

[80] Agoudjil, B., Benchabane, A., Boudenne, A., Ibos, L. and Fois, M. "Renewable materials to reduce building heat loss: characterisation of date palm wood." *Energy and Buildings* 43, no. 2–3 (2011): 491–49. https://doi.org/10.1016/j.enbuild.2010.10.014

[81] Hegazy, S., Ahmed, K. and Hiziroglu, S. "Oriented strand board production from water-treated date palm fronds." *BioResources* 10 (2015): 448–456. https://doi.org/10.15376/biores.10.1.448-456

[82] Lahouioui, M., Arfi, R.B., Fois, M., Ibos, L. and Ghorbal, A. "Investigation of fiber surface treatment effect on thermal, mechanical and acoustical properties of date palm fiber-reinforced cementitious composites." *Waste and Biomass Valorization* 11 (2020): 4441–4455. https://doi.org/10.1007/s12649-019-00745-3

[83] Binici, Hanifi, Mustafa Eken, M. Kara, and M. Dolaz. "An environment-friendly thermal insulation material from sunflower stalk, textile waste and stubble fibers." In *2013 International Conference on Renewable Energy Research and Applications (ICRERA)*, pp. 833-846. IEEE, 2013. https://doi.org/10.1109/ICRERA.2013.6749868

[84] Eschenhagen, A., Raj, M., Rodrigo, N., Zamora, A., Labonne, L., Evon, P. and Welemane, H. "Investigation of miscanthus and sunflower stalk fiber-reinforced composites for insulation applications." *Advances in Civil Engineering* (2019): 1-7. https://doi.org/10.1155/2019/9328087

[85] Ferrández-García, C. C., Ferrández-García, C. E., Ferrández-Villena, M., Ferrández-García, M. T. and García-Ortuño, T. "Acoustic and thermal evaluation of palm panels as building material." *BioResources* 12, no. 4 (2017): 8047–8057. https://doi.org/10.15376/biores.12.3.6698-6712

[86] Panyakaew, S. and Fotios, S. "New thermal insulation boards made from coconut husk and bagasse." *Energy and Buildings* 43, no. 7 (2011): 1732–1739. https://doi.org/10.1016/j.enbuild.2011.03.015

[87] Iwaro, J. and Mwasha, A. "Effects of using coconut fiber–Insulated masonry walls to achieve energy efficiency and thermal comfort in residential dwellings." *Journal of Architecture Engineering* 25, no. 1 (2019): 1-12. https://doi.org/10.1061/(ASCE)AE.1943-5568.0000341

[88] Narciso, C. R. P., A. H. S. Reis, J. F. Mendes, N. D. Nogueira, and R. F. Mendes. "Potential for the use of coconut husk in the production of medium density particleboard." *Waste and Biomass Valorization* 12, no. 3 (2021): 1647-1658. https://doi.org/10.1007/s12649-020-01099-x

[89] Abdulkareem, S., Ogunmodede, S., Aweda, J.O., Abdulrahim, A.T., Ajiboye, T.K., Ahmed, I.I. and Adebisi, J.A. "Investigation of thermal insulation properties of biomass composites." *International Journal of Technology* 6 (2016): 989-999. https://doi.org/10.14716/ijtech.v7i6.3317

[90] Nouri, M., Jafarzadeh-Dogouri, F., Oromiehie, A. and Langroudi, A.E. "Mechanical properties and water absorption behaviour of chopped rice husk filled polypropylene composites." *Iranian Polymer Journal* 15, no. 9 (2006): 757–766.

[91] Bisht, N., Gope, P.C. and Rani, N. "Rice husk as a fibre in composites: A review." *Journal of the Mechanical Behavior of Materials* 29 (2020): 147–162. https://doi.org/10.1515/jmbm-2020-0015

[92] Onésippe-Potiron, C., Bilba, K., Zaknoune, A. and Arsène, M.A. "Auto-coherent homogenization applied to the assessment of thermal conductivity: Case of sugar cane bagasse fibers and moisture content effect." *Journal of Building Engineering* 33, (2021): 101537. https://doi.org/10.1016/j.jobe.2020.101537

[93] Oladele, Isiaka Oluwole, Samson Oluwagbengea Adelani, Baraka Abiodun Makinde-Isola, and Taiwo Fisayo Omotosho. "Coconut/coir fibers, their composites and applications." In *Plant Fibers, their Composites, and Applications*, pp. 181-208. Woodhead Publishing, 2022. https://doi.org/10.1016/B978-0-12-824528-6.00004-7

[94] Frisoni, G., Baiardo, M., Scandola, M., Lednická, D., Cnockaert, M.C, Mergaert, J. and Swings, J. "Natural cellulose fibers: heterogeneous acetylation kinetics and biodegradation behavior." *Biomacromolecules* 2, no. 2 (2001): 476–482. https://doi.org/10.1021/bm0056409

[95] Bisht, N., Gope, P.C. and Rani, N. "Rice husk as a fibre in composites: A review." *Journal of the Mechanical Behavior of Materials* 29 (2020): 147–162. https://doi.org/10.1515/jmbm-2020-0015

[96] Oladele, I.O., Makinde-Isola, B.A., Adeniran, A., Oladejo, M.O., Owa, F.A. and Olayanju, T.M.A. "Mechanical and wear behaviour of pulverised poultry eggshell/sisal fiber hybrid reinforced epoxy composites." *Materials Research Express* 7 (2020): 045304. https://doi.org/10.1088/2053-1591/ab8585

[97] Ramlee, N.A., Jawaid, M., Yamani, S. A. K., Zainudin, E. S. and Alamery, S. "Effect of surface treatment on mechanical, physical and morphological properties of oil palm/bagasse fiber reinforced phenolic hybrid composites for wall thermal insulation application." *Construction and Building Materials* 276, (2021): 1-10. https://doi.org/10.1016/j.conbuildmat.2020.122239

[98] Bartos, A., Anggono, J., Farkas, Á.E., Kun, D., Soetaredjo, F.E., Móczó, J., Antoni, H.P. and Pukánszky, B. "Alkali treatment of lignocellulosic fibers extracted from sugarcane bagasse: composition, structure, properties." *Polymer Testing* 88 (2020): 106549. https://doi.org/10.1016/j.polymertesting.2020.106549

[99] Liu, Y., Yu, Q., Xu, J. and Yuan, Z. "Evaluation of structural factors affecting high solids enzymatic saccharification of alkali-pretreated sugarcane bagasse." *Cellulose* 27, no. 3 (2020): 1441–1450. https://doi.org/10.1007/s10570-019-02890-3

[100] Mulinari, D.R., Baptista, C.A.R.P., Souza, J.V.C. and Voorwald, H.J.C. "Mechanical properties of coconut fibers reinforced polyester composites." *Procedia Engineering* 10 (2011): 2074–2079. https://doi.org/10.1016/j.proeng.2011.04.343

[101] Mawardi, Indra. "Microfibrillation of Coir Using High Speed Blender to Improvement of Tensile Behavior of Coir Reinforced Epoxy Composites." *KnE Engineering* (2019): 157-170. https://doi.org/10.18502/keg.v1i2.4441

[102] Ahmad, R., Hamid, R. and Osman, S.A. "Physical and chemical modifications of plant fibres for reinforcement in cementitious composites." *Advances in Civil Engineering* (2019): 1-18. https://doi.org/10.1155/2019/5185806

[103] Oladele, Isiaka Oluwole, Samson Oluwagbengea Adelani, Baraka Abiodun Makinde-Isola, and Taiwo Fisayo Omotosho. "Coconut/coir fibers, their composites and applications." In *Plant Fibers, their Composites, and Applications*, (2022): 181-208. https://doi.org/10.1016/B978-0-12-824528-6.00004-7

[104] Verma, V. and Gope, P. "The use of coir/coconut fibers as reinforcements in composites." *Biofiber Reinforcement in Composite Materials*, (2015): 285-319. https://doi.org/10.1533/9781782421276.3.285

[105] Yang, H.S., Kim, H.J., Son, J., Park, H.J., Lee, B.J. and Hwang, T.S. "Rice husk flour filled polypropylene composites, mechanical and morphological studies." *Composite Structure* 63, no. 3-4 (2004): 305–312. https://doi.org/10.1016/S0263-8223(03)00179-X

[106] Simone, M.L., Santos, E.F., Ferreira, C.A. and Sonia, M.B. "Studies on the properties of rice husk filled PP composites-effect of maleated PP." *Material Research* 12, no. 3 (2009): 333–338. https://doi.org/10.1590/S1516-14392009000300014

[107] Petchwattana, N., Covavisaruch, S. and Chanakul, S. "Mechanical properties, thermal degradation and natural weathering of high-density polyethylene/ rice hull composites compatibilized with maleic anhydride grafted polyethylene." *Journal of Polymer Research* 19, no. 7 (2012): 9921. https://doi.org/10.1007/s10965-012-9921-6

[108] Chand, N., Fahim, M., Sharma, P. and Bapat, M.N. "Influence of foaming agent on wear and mechanical properties of surface modified rice husk filled polyvinylchloride." *Wear* 278 (2012): 83–86. https://doi.org/10.1016/j.wear.2012.01.002

[109] Park, Y. C. and Kim, J. S. "Comparison of various alkaline pre-treatment methods of lignocellulosic biomass." *Energy* 47, no. 1 (2012): 31–35. https://doi.org/10.1016/j.energy.2012.08.010

[110] Sun, S. L., Wen, J. L., Ma, M. G. and Sun, R. C. "Enhanced enzymatic digestibility of bamboo by a combined system of multiple steam explosion and alkaline treatments." *Applied Energy* 136, (2014): 519-526. https://doi.org/10.1016/j.apenergy.2014.09.068

[111] Zheng, Y., Zhao, J., Xu, F. and Li, Y. "Pre-treatment of lignocellulosic biomass for enhanced biogas production." *Progress in Energy and Combustion Science* 42, (2014): 35-53. https://doi.org/10.1016/j.pecs.2014.01.001

[112] Kiharason, J. W., Isutsa, D. K. and Ngoda, P. N. "Effect of drying method on nutrient integrity of selected components of pumpkin (Cucurbita Moschata Duch)." *Fruit Flour* 12, no. 3 (2017): 110–116.

[113] Xu, J., Sugawara, R., Widyorini, R., Han, G. and Kawai, S. "Manufacture and properties of low-density binderless particleboard from kenaf core." *Journal of Wood Science* 50, (2004): 62-67. https://doi.org/10.1007/s10086-003-0522-1

[114] Johnson, A.C. & Yunus, N. "Particleboards from rice husk: a brief introduction to renewable materials at construction." *Jurutera*, (2009): 12-15.

[115] Kawasaki, T., Zhang, M. and Kawai, S. "Manufacture and properties of ultra-low-density fiberboard." *Journal of Wood Science* 44, no. 5 (1998): 354–360. https://doi.org/10.1007/BF01130447

[116] Akinlabi, O., Adeiza, B. A. and Emmanuel, O. O. "Development of laboratory hot compression mounting press machine." *Journal of Scientific Research & Reports* 18, no. 1 (2018): 1–12. https://doi.org/10.9734/JSRR/2018/39372

[117] Rowell, R., Kawai, S. and Inoue, M. "Dimensionally stabilized, very low density fiberboard, wood and fiber." *Science* 27, no. 4 (1995): 428–436.

[118] Troppova´, E., Sˇvehlı´k, M., Tippner, J. and Wimmer, R. "Influence of temperature and moisture content on the thermal conductivity of wood-based fibreboards." *Materials and Structures* 48 (2015): 4077–4083. https://doi.org/10.1617/s11527-014-0467-4

[119] Volf, M., Diviš, J. and Havlík, F. "Thermal, moisture and biological behaviour of natural insulating materials." *Energy Procedia* 2, no. 78 (2015): 1599–1604. https://doi.org/10.1016/j.egypro.2015.11.219

[120] Liuzzi, S., Sanarica, S. and Stefanizzi, P. "Use of agro-wastes in building materials in the Mediterranean area: A review." *Energy Procedia* 126 (2017): 242–249. https://doi.org/10.1016/j.egypro.2017.08.147

[121] Hunt, J. F., O'Dell, J. and Turk, C. "Fiberboard bending properties as a function of density, thickness, resin, and moisture content." *Holzforschung* 62, no. 5 (2008): 569–576. https://doi.org/10.1515/HF.2008.083

[122] Asfaw, B.T., Shabu, H.G. and Gari, M.T. "Case study for the construction of particleboard using sugarcane bagasse: A review." *Journal of Catalyst and Catalysis* 6, no. 3 (2019): 14-24.

[123] Berglund, L. and Rowell, R. M. "Wood Composites." In *Handbook of Wood Chemistry and Wood Composites* (2012): 279–302.

[124] Macatangay, P.M., Magundayao, E.C. and Rosales, C.A.M. "Utilisation of agricultural wastes in the manufacture of composite boards." *ASEAN Journal on Science and Technology for Development* 29, no.2 (2012): 129-140. https://doi.org/10.29037/ajstd.59

[125] Monteiro, S., Martins, J., Magalhaes, F.D. and Carvalho, L. "Low density wood particleboards bonded with starch foam—Study of production process conditions." *Materials* 12 (2019): 1-14. https://doi.org/10.3390/ma12121975

[126] Kelly A. *Concise encyclopedia of composite materials. Revised*, England, Pergamon (1994). https://doi.org/10.1016/B978-0-08-042300-5.50011-X

[127] Jawaid, M., Khalil Abdul, H.P.S., Khanam, P.N. and Bakar, A.A. "Hybrid composites made from oil palm empty fruit bunches/jute fibres: Water absorption, thickness swelling and density behaviours." *Journal of Polymers Environment* 19, no. 1 (2011): 106–109. https://doi.org/10.1007/s10924-010-0203-2

[128] Abdul Khalil, H. P. S., and A. H. Bhat. "Oil palm biomass: Fibre cultivation, production and its varied applications." *Oil Palm: Cultivation, Production and Dietary Components* (2010): 21-34.

[129] Chiang, T.C., Hamdan, S. and Osman, M.S. "Effects of density of sago/urea formaldehyde particles board towards its thermal stability, mechanical and physical properties." *Journal Teknologi* 78, no. 10 (2016): 187-197. https://doi.org/10.11113/jt.v78.8174

[130] Aljayi, B. and Badejo, S.O.O. "Effects of board density on bending strength and internal bond of cement-bonded flakeboards." *Journal of Tropical Forest Science* 17, no. 2 (2005): 228–234.

[131] Hussein, Zakia, Taha Ashour, Mervat Khalil, Adel Bahnasawy, Samir Ali, Jutta Hollands, and Azra Korjenic. "Rice straw and flax fiber particleboards as a product of agricultural waste: An evaluation of technical properties." *Applied Sciences* 9, no. 18 (2019): 3878. https://doi.org/10.3390/app9183878

[132] Pandey, A., A. Telang, and R. Rana. "Mechanical characterization of bio-char made hybrid composite." *Int J Eng Res Appl* 6 (2016): 26-31.

[133] ASTM C518 Standard test method for steady-state thermal transmission properties by means of the heat flow meter apparatus, ASTM International, West Conshohocken, PA, USA (2017).

[134] ISO 8301. "Thermal insulation- determination of steady-state thermal resistance and related properties -Heat flow meter apparatus." *International Organization for Standardization (ISO)* (1991): 1-54.

[135] Khedari, J., Nankongnab, N., Hirunlabh, J. and Teekasap, S. "New low-cost insulation particleboards from mixture of durian peel and coconut coir." *Building and Environment* 39, no. 1 (2004): 59–65. https://doi.org/10.1016/j.buildenv.2003.08.001

[136] Sampathrajan, A., Vijayaraghavan, N.C. and Swaminathan, K.R. "Mechanical and thermal properties of particle boards made from farm residues." *Bioresources and Bioprocessing* 40, (1992): 49-251. https://doi.org/10.1016/0960-8524(92)90151-M

[137] Chinese National Forestry Industry. "Standard Low-density fiberboard." *Standards Press of China*, Beijing (2007): 1718-2007.

[138] Wang, S.H. "Construction materials science." *China Construction Industry Publisher*, (1988).

[139] Al-Homoud, M.S. "Performance characteristics and practical applications of common building thermal insulation materials." *Building and Environment* 40, no. 3 (2005): 353-366. https://doi.org/10.1016/j.buildenv.2004.05.013

[140] Karwa, Rajendra. "One-Dimensional Steady-State Heat Conduction." In *Heat and Mass Transfer*, (2020): 7–112.

[141] Ahmad Saffian, Harmaen, Mohd Aizam Talib, Seng Hua Lee, Paridah Md Tahir, Ching Hao Lee, Hidayah Ariffin, and Ainun Zuriyati Mohamed Asa'ari. "Mechanical strength, thermal conductivity and electrical breakdown of kenaf core fiber/lignin/polypropylene biocomposite." *Polymers* 12, no. 8 (2020): 1833. https://doi.org/10.3390/polym12081833

[142] Tangjuank, S. and Kumfu, S. "Particle boards from papyrus fibers as thermal insulation." *Journal of Applied Sciences* 11 (2011): 2640–2645. https://doi.org/10.3923/jas.2011.2640.2645

[143] Ferrandez-Garcia, Maria Teresa, Antonio Ferrandez-Garcia, Teresa Garcia-Ortuño, Clara Eugenia Ferrandez-Garcia, and Manuel Ferrandez-Villena. "Influence of particle size on the properties of boards made from Washingtonia palm rachis with citric acid." *Sustainability* 12, no. 12 (2020): 4841. https://doi.org/10.3390/su12124841

[144] Rozman, H.D., Tay, G.S., Kumar, R.N., Abusamah, A., Ismail, H. and Mohd Ishak, Z.A. "The effect of oil extraction of the oil palm empty fruit bunch on the mechanical properties of polypropylene-oil palmempty fruit bunch-glass fibre hybrid composites." *Polymer-Plastics Technology and Engineering* 40 (2001): 103–115. https://doi.org/10.1081/PPT-100000058.

[145] Nadhari, Wan Noor Aidawati Wan, Mohammed Danish, Muhammad Syafiq Ridhwan Mohd Nasir, and Boon Jia Geng. "Mechanical properties and dimensional stability of particleboard fabricated from steam pre-treated banana trunk waste particles." *Journal of Building Engineering* 26 (2019): 100848. https://doi.org/10.1016/j.jobe.2019.100848

[146] Ferrandez-Villena, Manuel, Clara Eugenia Ferrandez-Garcia, Teresa Garcia-Ortuño, Antonio Ferrandez-Garcia, and Maria Teresa Ferrandez-Garcia. "Analysis of the thermal insulation and fire-resistance capacity of particleboards made from vine (Vitis vinifera L.) prunings." *Polymers* 12, no. 5 (2020): 1147. https://doi.org/10.1016/j.jobe.2019.100848.

[147] Ismail, Fatiha, Nur Eliyanti Ali Othman, Noorshamsiana Abdul Wahab, and Astimar Abdul Aziz. "The Effect of Chemical and High Pressure Homogenization Treatment Conditions on the Morphology of Nanocellulose." *Journal of Advanced Research in Applied Mechanics* 93, no. 1 (2022): 1-7.

[148] Fiore, V., Bella, G.D. and Valenza, A. "The effect of alkaline treatment on mechanical properties of kenaf fibers and their epoxy composites." *Composites, Part B- Engineering* 68, (2015): 14-21. https://doi.org/10.1016/j.compositesb.2014.08.025

[149] Latip, N.A., Sofian, A.H., Ali, M.F., Ismail, S.N. and Idris, D.M.N.D. "Structural and morphological studies on alkaline pretreatment of oil palm empty fruit bunch (OPEFB) fiber for composite production." *Materials Today Proceedings* 17 (2019): 1105–1111. https://doorg/10.1016/j.matpr.2019.06.529

[150] Kamal, A. S. M., M. I. Misnon, and F. Fadil. "The effect of sodium hydroxide concentration on yield and properties of bacterial cellulose membranes." In *IOP Conference Series: Materials Science and Engineering* 732, no. 1, (2020). https://doi.org/10.1088/1757-899X/732/1/012064

[151] Kawalerczyk, Jakub, Joanna Siuda, Radosław Mirski, and Dorota Dziurka. "Hemp flour as a formaldehyde scavenger for melamine-urea-formaldehyde adhesive in plywood production." *BioResources* 15, no. 2 (2020): 4052-4064. https://doi.org/10.15376/biores.15.2.4052-4064

[152] Antov, Petar, Viktor Savov, Ľuboš Krišťák, Roman Réh, and George I. Mantanis. "Eco-friendly, high-density fiberboards bonded with urea-formaldehyde and ammonium lignosulfonate." *Polymers* 13, no. 2 (2021): 220. https://doi.org/10.3390/polym13020220

[153] Hong, M.K., Lubis, M.A.R., Park, B.D., Sohn, C.H. and Roh, J. "Effects of surface laminate type and recycled fiber content on properties of three-layer medium density fiberboard." *Wood Materials and Science Engineering* 15, (2020): 163–171. https://doi.org/10.1080/17480272.2018.1528479