MECHANICAL PROPERTIES AND THERMAL CHARACTERISTICS OF SANDWICH COMPOSITE PANEL FROM SPENT MUSHROOM SUBSTRATE AND EMPTY FRUIT BUNCH FIBERS TOWARDS HEAT INSULATION APPLICATION

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by

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LIST OF SYMBOLS

kg	Kilogram
cm	Centimeter
g	Gram
rpm	Revolution per minute
R_t	Thermal resistance, m^2K/W
k	Thermal conductivity, W/m.K
L	Thickness, mm
A	Surface area, m^2
α	Thermal diffusivity, mm^2/s
ρ	Composite density, g/cm^3
Cp	Specific heat capacity, J/kg. ℃
Q	Heat flux, W/m^2
T1	Temperature of hot region, ℃
T2	Temperature of cold region, ℃
m/s	Meter per second
µm	Micrometer
m^2/g	Square meter per gram
MPa	Megapascal
kJ/m^2	Kilo Joule per square meter
W/m.k	Watt per meter kelvin
kg/m^3	Kilogram per cubic meter

K/W	Kelvin per watt
mm^2/s	Square millimeter per second
W/m^2	Watt per square meter

LIST OF ABBREVIATIONS

ASTM	American standard test method
ANOVA	Analysis of variance
ASTM	American Society for Testing and Materials
AD	Air dried
DTG	Derivative Thermo-Gravimetric Analysis
EFB	Empty fruit bunch
EOD	Expected oven dried
FRS	Fresh rubber wood sawdust
FTIR	Fourier Transform Infrared
SEM	Scanning electron microscope
SMS	Spent mushroom substrate
TGA	Thermo-Gravimetric Analysis
JIS-A	Japanese Industrial Standard – Civil Engineering and Architecture
OD	Oven dried

SIFAT MEKANIKAL DAN CIRI TERMAL PANEL KOMPOSIT TERAPIT DARI SISA SUBSTRAT CENDAWAN DAN SERAT TANDAN BUAH KOSONG KE ARAH APLIKASI PENEBATAN HABA

ABSTRAK

Permintaan yang semakin meningkat untuk produk dan bahan mesra alam mendorong beberapa kajian mengenai potensi serat sisa semula jadi seperti sekam kelapa dan hampas tebu sebagai panel penebat komposit. Walau bagaimanapun, penyelidikan mengenai panel komposit yang dibuat daripada sisa substrat cendawan (SMS) dan serat tandan buah kosong (EFB) untuk tujuan penebat adalah terhad. Kecekapan panel ini sangat bergantung pada sifat dan prestasi haba, dikawal oleh pelbagai parameter. Hanya beberapa kajian yang melihat kepada kesan nisbah serat dan tahap fibrilasi. Hanya sebilangan kecil penyelidikan yang wujud ini bertumpu kepada proses fabrikasi menggunakan teknik komposit terapit. Oleh itu, kajian ini bertujuan untuk mencirikan sifat fizik-kimia serat SMS dan EFB berdasarkan proses fabrikasi panel komposit berkapit; untuk menilai sifat mekanikal dan prestasi terma panel komposit berkapit pada nisbah serat yang berbeza dan; untuk menilai kesan darjah fibrilasi serat EFB terhadap sifat mekanikal dan prestasi haba. Untuk mencapai objektif ini, sifat fizik-kimia serat SMS dan EFB dari segi komposisi kimia, analisis ukuran zarah dan analisis termogravimetrik (TGA) dicirikan dan dibandingkan dengan keadaan asalnya iaitu serat serbuk gergaji kayu getah segar (FRS). Untuk menilai kesan nisbah serat dan tahap fibrilasi EFB terhadap sifat mekanikal dan prestasi terma, sampel panel komposit terapit dibuat. Sampel dibuat berdasarkan tiga nisbah serat iaitu 80 SMS: 20 EFB, 60 SMS: 40 EFB, 40 SMS: 60 EFB dan, tiga keadaan darjah fibrilasi 191.40%, 211.70% dan 271.68%. Sampel yang difabrikasi ini diuji dan dianalisis untuk mengkaji sifat mekanikal dan prestasi termalnya. Selain EFB, hasil kajian ini menunjukkan bahawa sifat fizik-kimia serat SMS telah merosot sedikit berbanding dengan serat FRS. Serat SMS dan EFB didapati sesuai dan relevan untuk digunakan sebagai bahan mentah dalam pembuatan panel komposit terapit untuk aplikasi penebat. Dengan meningkatkan nisbah serat dan darjah fibrilasi serat EFB, sifat mekanikal and prestasi terma menjadi meningkat. Berdasarkan analisis ini, ditentukan bahawa sampel panel komposit terapit dengan nisbah serat 60 SMS: 40 EFB dan tahap fibrilasi 211.70% mempunyai keadaan komposit terbaik, dengan analisis fluks haba antara 164 W/m^2 dan 1435 W/m^2. Oleh itu, penemuan menunjukkan bahawa panel komposit berkapit yang dihasilkan berpotensi tinggi untuk digunakan dalam aplikasi penebat kerana sifat mekanikalnya yang baik dan prestasi terma yang dapat diterima, yang dapat menambah daya tahannya. Penyelidikan lebih lanjut dicadangkan agar dilakukan untuk memperluas ruang lingkup kajian ini mengenai prestasi dan pemindahan haba panel komposit terapit yang difabrikasi ini untuk aplikasi penebat bangunan.

MECHANICAL PROPERTIES AND THERMAL CHARACTERISTICS OF SANDWICH COMPOSITE PANEL FROM SPENT MUSHROOM SUBSTRATE AND EMPTY FRUIT BUNCH FIBERS TOWARDS HEAT INSULATION APPLICATION

ABSTRACT

The growing demand for eco-friendly products and materials has prompted several studies on the potentials of natural waste fiber such as coconut husk and sugarcane bagasse as composite panels towards heat insulation application. However, research on composite panels fabricated of the spent mushroom substrate (SMS) and empty fruit bunch (EFB) fibers for insulating purposes is limited. These panels' efficiency is heavily reliant on their properties and thermal characteristic, controlled by a range of parameters. Thus, only a few research have looked at the impact parameters of fiber ratio and fibrillation degree. There are less researcher concentrated on the fabrication process using sandwich composite approach. Therefore, this study aimed to characterize the physico-chemical properties of SMS and EFB fibers towards sandwich composite panel fabrication process; to evaluate the properties and thermal characteristic of the sandwich composite panel at different SMS and EFB fibers ratios and; to assess the effect of EFB fiber fibrillation degree on its properties and thermal characteristic. To achieve these objectives, the SMS and EFB fibers physico-chemical properties in terms of chemical composition, particle size and thermal degradation temperature were characterized and compared with fresh rubberwood sawdust (FRS) fiber. To assess the effects of fibers ratio, and EFB fibrillation degree on the properties and thermal characteristic, sandwich composite panel samples were fabricated. The samples were fabricated based on three different ratios of 80 SMS: 20 EFB, 60 SMS: 40 EFB, 40 SMS: 60 EFB and, three fibrillation degree conditions of 191.40 %, 211.70 % and 271.68 %. These fabricated samples were tested and analyzed to study their mechanical properties and thermal characteristic. For the physico-chemical properties, except for EFB fiber, results indicated that the chemical composition, particle size and thermal degradation of SMS fiber recorded a very minimal reduction compare to FRS fiber. Therefore, it makes the SMS and EFB fibers to be suitable and relevant for use as a raw material in the fabrication of sandwich composite panel for heat insulation application. Next, by increasing the EFB fiber ratio and increasing fibrillation degree respectively, the mechanical properties and thermal characteristic of the sandwich composite panel were considerably increased significantly. Based on these analyses, it was determined that the sandwich composite panel sample with a fiber ratio of 60 SMS: 40 EFB and a fibrillation degree of 211.70 % had the best composite condition, with heat flux analysis ranging between 164 W/m^2 and 1435 W/m^2. Thus, the findings indicated that the fabricated sandwich composite panel had a high potential for use in heat insulation application owing to its good properties and acceptable thermal characteristic, which may add to its durability. It is recommended that further research be conducted to broaden the scope of this study concerning the performance and heat transfer of the fabricated sandwich composite panel for building heat insulation application.

CHAPTER 1

INTRODUCTION

1.1 Research Background

Agricultural industry generates a large amount of natural waste fibers, including spent mushroom substrate (SMS) and empty fruit bunch (EFB) fibers. A high generation rate and improper disposal management might result in these massive quantities of valuable natural waste fibers having a detrimental effect on our ecosystem contributing to various environmental pollutions. Commonly, most of the valuable SMS fiber and EFB fiber were dumped and burned, resulting in an increase in stockpiles, water/river contamination, and open burning area, respectively (Faizi et al., 2017; Owodunni et al., 2020).

According to 2017 data, the mushroom industries generated around 50 million tonnes of SMS fiber per year, while the oil palm sector generated approximately 51.19 million tonnes of EFB fiber per year globally (Hamzah et al., 2019; Rajavat et al., 2020). From the environmental perspective, it appears that the EFB fiber holds similar issues as SMS fiber, where both natural waste fibers have high quantity generation with low commercial value, resulting in significant environmental pollution. This issue has gained considerable attention from researchers, scientists, and engineers to develop appropriate technologies for utilizing the SMS and EFB fibers based on waste-to-resource approach (Faizi et al., 2017; Thyavihalli et al., 2019). Concerning this, a few developed methods have been implemented in utilizing the SMS and EFB fibers in various applications, such as animal feed, plant fertilizer, and composite insulation panels (Grimm & Wosten, 2018; Khoo et al., 2020). In the development process towards these applications, the utilization of SMS and EFB fibers should be capable of meeting the application requirements in terms of properties and performance. In general, properties in science definition refer to a feature or attribute that may be used to characterize matters or materials by observation, measurement, or a combination of these. Based on the performance of materials, Ramlee et al (2021) revealed that one of the most effective approaches is by utilizing the fibers in the fabrication process into composite panel towards heat insulation application. The composite panel is a combination of two or more different types of material, fabricated together based on various material processing, followed by a cold or hot press process to form into a panel which later could be used in the heat insulation application (Fleischer et al., 2018).

Generally, the insulation panel can be defined as a product that is capable to resist and reduce heat. The insulation panel has a wide range of applications, where in tropical climate countries it is commonly used as part of building materials to provide better thermal comfort of an indoor space (Hysek et al., 2019). The use of adequate insulation panel in the building envelope is one of the most efficient techniques to minimize the rate of heat transmission and energy consumption to cool and heat buildings (Nematchoua et al., 2017). The most common insulation panels used in the tropical climate countries are polystyrene panel (Cetiner & Shea, 2018; Wong et al., 2020) and gypsum panel (Aghaee et al., 2015). This is because they have a high load-bearing capacity at a low weight, water resistance, and vapor barrier, are airtight in controlled settings, have a long shelf life, require little maintenance, and economical to manufacture (Capasso et al., 2021; Ramli et al., 2019). Recently, with the growing significance of climate change, the building industry is under increasing pressure to minimize its environmental effect, including the use of building materials and insulation panels. Keeping this in mind, efforts are being undertaken to produce eco-friendly insulating panels that reduce the environmental impact of buildings over their life cycle by decreasing waste and greenhouse gas emissions. This include the development of alternative materials such as natural waste fiber panel (Muthuraj et al., 2019; Robert et al., 2019; Rojas et al., 2019). These increasing amount of natural waste fiber has contribute to the generation of mountain size dumping area similar as current landfill area which giving negative impacts such as air, water and environmental pollution. Amongst the natural waste fiber panels, studies indicated that natural waste fibers of SMS and EFB fibers have an excellent insulation behavior in terms of properties and thermal characteristic making them suitable to be used as raw material for composite panel towards heat insulation application (Hassanin et al., 2016; Muthuraj et al., 2019). The unique properties of the natural waste fiber insulation panels are due to the formation of air void structure which contributed to enhancing the thermal characteristic effectively (Rebolledo et al., 2018). The existence of the air void structure somehow would reduce the mechanical and physical properties of the composite panel. But according to Tsalagkas et al (2019) the composite panel towards heat insulation application does not require high mechanical and properties as long as it is able to provide appropriate thermal properties for heat transfer mechanism. Based on these factors, most of the existing insulation panels are constructed from low-density materials with air-void structure (Kang et al., 2018; Pasztory et al., 2017). It has been reported that that due to the air void structure and low durability, their use in heat insulation applications that required high durability, curved surfaces, and more susceptible to impact damage are limited (Aghaee et al., 2015).

Despite these conditions, it should be noted that the insulation panel's mechanical and physical properties should be able to withstand the least amount of load possible during their handling, installation, and maintenance processes (Iucolano et al., 2019). Additionally, the thermal characteristic of the insulation panel can be easily deteriorated following damage and impact accidents during the installation process or when utilized in heavy condition applications (Boccarusso et al., 2020). Therefore, both the properties and thermal characteristic of composite panels are critical and should not be compromised in the heat insulation application.

1.2 Problem Statement

Most of the existing insulation panels are composed from synthetic and non-environment friendly materials. As an alternative, insulation panels are then fabricated using natural waste fibers. Throughout the literature, natural waste fibers such as coconut husk (Robert et al., 2019), EFB fiber, sugarcane bagasse (Ramlee et al., 2021), and SMS fiber (Schritt et al., 2021) are frequently utilized in the fabrication of composite panels towards heat insulation application. Numerous researches have reported on the fabrication of composite panels using a single type fiber (Cascone et al., 2019; Sharma et al., 2021), while several studies have concentrated on the fabrication of composite panels using two different types of fibers (Sair et al., 2019). These existing studies involved the fabrication technique using a composite mixing method with addition of a binder (Deraman et al., 2019; Valasek & Ambarita, 2018) but not investigating the binderless sandwich composite method.

The efficiency of these fiber composite panels towards heat insulation application is heavily dependent on their properties and thermal characteristic which are determined by a variety of typical factors such as material's density, porosity and moisture content.

Therefore, the composite insulation panel in previous studies, has limitation to manipulate these factors as it bound by the fabrication method. The mixing method and addition of binder has required the composite to obtain high density and low porosity structure in order to provide a sufficient mechanical strength properties. However, these conditions has result the thermal characteristics of composite towards heat insulation application become decrease. By implementing the sandwich method, the composite fabrication process involves a three-fiber layering process which has significant impact by increasing on both mechanical properties and thermal characteristic of the composite panel towards heat insulation application (Lee et al., 2018; Mohammadabadi et al., 2021). In this context, the physico-chemical properties of fiber, the ratio of two different types of fiber used, and the fiber fibrillation degree during the fabrication process are crucial in enhancing the properties and thermal characteristic of the composite panel (Benthien & Ohlmeyer, 2017, 2020; Iswanto & Ompusunggu, 2019).

Amongst the studies on the composite panel fabrication from two different types of fiber, only a few highlighted on the utilization of wood waste from SMS fiber together with EFB fiber (Hamid et al., 2015; Lusiani et al., 2020). The existing studies only focused on composite fabrication using mixing method with addition of binder based on the amount of SMS and EFB fiber ratio. Also, the studies does not focusing towards fibrillation degree and not using the panel as insulation approaches. Technically, the properties and thermal characteristic of the sandwich composite panels also can be influenced by the fiber ratio and fiber fibrillation degree. In previous studies, composite panel manipulated the fiber ratio through mixing processed and the fiber physical structure was determined based on particle size. For sandwich composite panel, different fiber ratio will be manipulated based on composite layers and the fiber physical structure was determined based on fibrillation. These changes will allow the sandwich composite panel will obtained different properties and thermal characteristics compare to mixing type composite panel. Therefore, to fill the knowledge gap, development and investigation of fiber composite panel towards heat insulation application through a sandwich method fabrication process was conducted. Two types of natural waste fibers in terms of SMS and EFB were selected and studied. The SMS fiber was known as waste fiber that has undergo chemical degradation due to its usage as mushroom substrate. This condition has result the SMS fiber to become less selected to be used as raw material in composite because chemical composition in fiber is crucial to determine the physical and mechanical properties. However, there are only several studies concentrated on characterizing the chemical composition of SMS fiber and less study focused on utilization SMS fiber generated from waste of Oyster mushroom species. Despite that, the SMS fiber was still selected in this due to its physical condition as a readymade ground fiber with higher tendency possessing sufficient chemical composition for fabrication composite. For EFB fiber, it was a well-known natural waste fiber that contained a huge amount of lignocellulose component giving a better mechanical influence on composite compare to other natural waste fiber. Nevertheless, utilization of EFB fiber has limitation due to its physical structure as it required fiber length modification such as fibrillation degree in order to be suit as reinforcement into composite. Another factor making these fiber was selected in this study is because, both fibers has generated tremendously in tropical climate countries. The fibers were characterized, the composite panel properties and thermal characteristic at different fibers ratios and fiber fibrillation degrees were evaluated.

1.3 Research Questions

This study embarks to answer the following specific research questions:

i. What are the physico-chemical properties of SMS fiber as a raw material towards composite panel fabrication process?

ii. How the properties and thermal characteristic of sandwich composite panel will be affected by different SMS and EFB fibers ratios towards heat insulation application?

iii. How the EFB fiber fibrillation degree would affect the sandwich composite panel's properties and thermal characteristic towards heat insulation application?

1.4 Research Objectives

The study aims to achieve the following objectives:

i. To characterize the chemical composition, particle size and thermal degradation of SMS and EFB fibers towards composite panel fabrication process.

ii. To evaluate the mechanical properties and thermal characteristics of sandwich composite panel made of SMS and EFB fibers at different ratios towards heat insulation application.

iii. To assess the effect of SMS fiber with EFB fiber at different fibrillation degree on the sandwich composite panel mechanical properties and thermal characteristics towards heat insulation application.

1.5 Research Scope

In this study, a sandwich composite panel was made from with SMS and EFB fibers using sandwich method. The selected composite mechanical properties and thermal characteristic were investigated based on experimental approach towards heat insulation application. The sample materials of SMS fiber were collected only from Oyster mushroom farm house. While for EFB, the fiber samples were supplied and provided by the mill in shredded and cleaned condition. In this study, the characterization on the physico-chemical properties of SMS and EFB fibers were specified into chemical composition, particle size, and thermal degradation temperature. The incorporation EFB fiber in composite was classified into three SMS: EFB fibers ratios which is 80 SMS: 20 EFB, 60 SMS: 40 EFB, 40 SMS: 60 EFB. For the EFB fiber modification, only refining treatment method was used without including any chemicals. The sandwich composite properties were tested using Japanese Industrial Standard (JIS) A 5908 and American Society for Testing and Materials (ASTM) D3039-17 & ASTM D256. While for the thermal characteristic assessment, the sandwich composite was analyzed based on thermal conductivity, thermal resistance, and thermal diffusivity. The thermal characteristic was also evaluated by performing heat flux (conduction) simulation experimental investigations using computational fluid dynamic software (ANSYS Student). Meanwhile, the experimental investigation was carried out under laboratory conditions using tropical climate approach. To give and overview on the tropical climate and provide a meaningful finding, a discussion on the properties and characteristic analyses with gypsum panel known as common insulation panel used in tropical climate was included.

1.6 Significance of Research

This study contributed significantly to get a better understanding and additional information in the fundamental and applied knowledge of material science specific and technology specifically on the fabrication of sandwich composite panel from the SMS and EFB fibers. The SMS fiber was considered as not suitable natural waste fiber to be used as raw material in composite due to its low physico-chemical properties in terms of chemical composition, particle size and thermal degradation temperature. Meanwhile, the use of EFB fiber as reinforcement material to improve fiber network in composite has limitation in terms of fiber length due to having long and stranded structure causing the fibers to become entangled during fabrication process. The data gathered in this study could be used as baseline and preliminary information towards the expansion of knowledge on the potential of using SMS fiber as a raw material towards sandwich composite panel fabrication process. The capability of EFB fiber as reinforcement material in improving degree of fiber network in the sandwich composite panel was revealed in this study which could benefit various fields and applications concerning the fiber. The findings from this study may serve as a baseline reference and may provide useful information about the properties and thermal characteristic of sandwich composite panel made of SMS and EFB fibers towards insulation panel technology and engineering field particularly in building sector.

1.7 Thesis Structure

The thesis presents a total of six chapters. In Chapter 1, the general idea of the thesis is described, which covered the background, research background, problem statement, research question, research objectives, research scope and limitation, and also included significance of research. In Chapter 2, a detailed review of scientific literature is discussed to ascertain the state of knowledge gathered from prior studies and potential ideas, including the limitations of utilizing natural waste fiber to fabricate sandwich composite panel. It also encompasses discussions on the potential of natural waste fiber as composite raw material, fiber distribution mechanism, selection of insulation material, influence of composite fabrication, and effect of fiber processing towards composite panel. The properties and thermal characteristic of the gypsum panel, which later used as insulation references and benchmark for the sandwich composite panel, was reviewed.

Chapter 3 describes the research methodology used in this study such as fiber collection, fiber preparation, fiber characterization, fiber treatment, composite fabrication process, and composite properties and thermal characteristic testing standard methods. The chapter focuses on two primary parameters involved in the composite fabrication process: i) composite fabrication process using SMS and EFB fibers at different ratios and; ii) process of fabricating composites using treated EFB fibers with different fibrillation degrees.

In Chapter 4, the analyzed data arising from the results and analyses of characterization tests, properties and thermal characteristic of sandwich composite panel made of SMS and EFB fibers at different ratio are presented. The generated data obtained from properties and thermal characteristic test were analyzed statistically using one-way ANOVA. At the end of this chapter, it concludes a discussion on the performance analysis between the sandwich composite panel and gypsum panel based on the existing data from previous literature studies and experimental testing. In Chapter 5, the analyzed data based on the evaluation of fiber morphology, and properties and thermal characteristic of sandwich composite panel at different fibrillation degrees of treated EFB fiber are explained. One-way ANOVA was also used to analyze the generated data based on the properties and thermal characteristic results. This chapter also addresses a discussion of heat flux analysis of the sandwich composite panel using simulation and experimental approach. In addition, in this chapter, heat flux analyses between the sandwich composite panel and gypsum panel are discussed. Finally, Chapter 6 presents the conclusions based on each objective. Recommendations for future research are also highlighted in this chapter.

CHAPTER 2

LITERATURE REVIEW

2.1 Overview of Natural Waste Fibers

The rise of environmental consciousness and a scarcity of natural resources have prompted many manufacturing industries to look for a new potential material derived from renewable resources to replace conventional materials. This urging for 'green' material has led the manufacturing company to utilize natural waste fiber as an alternative material (Antov et al., 2018). Natural waste fiber has been identified as a renewable and biodegradable resource frequently generated by the agriculture and wood industry (Jaafar et al., 2019; Mansor et al., 2019). According to recent studies, Malaysia generates more than 168 million tonnes of natural waste fibers each year (Baharin et al., 2020; Ozturk et al., 2017). Spent mushroom waste fiber (Azahari et al., 2020), oil palm waste fiber (Onoja et al., 2019), banana trunk fiber (Nadhari et al., 2019), coconut husk fiber (Narciso et al., 2021), and sugarcane bagasse fiber(Yano et al., 2020) are some of the most prevalent natural waste fibers that are produced in large quantities and are ineffectively being utilized.

Apart from the numerous advantages on the utilization of the natural waste fibers in terms of abundance, availability, and low cost, they also have high strength and eco-friendly properties that make them suitable for use in a wide variety of applications such as automotive, construction, packaging, furniture, and shipping pallets (Thyavihalli et al., 2019). Each type of natural waste fiber may have its unique capability and behavior characteristics. Thus, during material selection, additional criteria such as processing costs, chemical composition, thermal stability, shelf life behavior, elongation at failure, and fiber adhesion must be considered before being fabricated into particular products (Bharath & Basavarajappa, 2016; Ilyas et al., 2019; Taiwo et al., 2019).

Without proper and inefficient utilization, these wastes would result in a significant negative impact on the environment. Previous research indicated that increasing the stockpile of natural waste fibers in landfills may result in the release of methane gas, thereby contributing to the greenhouse effects (He et al., 2020; Krishnan et al., 2017). Another study stated that a flawed waste fiber management system has resulted in significant environmental and air pollution due to increased dumping areas and open burning (Owodunni et al., 2020). Therefore, these natural waste fibers must be efficiently used and managed to reduce the negative impact on the environment (Zakaria, 2020).

2.1.1 Spent Mushroom Substrate Fiber and Potential of Environmental Impact

Spent mushroom substrates (SMS) fiber is a valuable waste from the mushroom industry. It is a form of lignocellulose substance that contains carbon and is used as a nutrient to enhance mushroom growth, mushroom production, and mushroom fruiting bodies (Mortada et al., 2020). Generally, most SMS fiber is made from rubber wood sawdust due to its high lignocellulose content, including its elemental composition suitability towards mushroom cultivation (Ali et al., 2018; Zakil et al., 2019). Nevertheless, it does not limit to any other lignocellulose materials such as EFB fiber (Marlina et al., 2015), sugarcane bagasse (Karpagavalli et al., 2020), leaves, and including waste paper (Dinssa et al., 2020).

The SMS fiber is obtained and generated tremendously in the mushroom farm after harvesting (Meng et al., 2019). The SMS fiber mainly comprises the remaining mushroom root known as mycelium, and a huge amount of residual nutrients breakdown from lignocellulose components (Economou et al., 2020; Meng et al., 2017). It has been reported that SMS fiber in the range weight about 645 g/kg to 703.6 g/kg usually contained cellulose content (38 to 46.6%), lignin content (25 to 34.5%), hemicellulose content (19 to27.7%), and the remaining percentage are, other organic matters (Rajavat et al., 2020).

Based on the standard formulation of a mushroom substrate in tropical countries, the SMS fiber is commonly manufactured from rubberwood sawdust, wheat bran, hydrated lime and water based on a particular standard amount ratio (Zakil et al., 2019). Then, these mixtures are sterilized in an autoclave or heating chamber to kill the current fungus in the fiber and avoid mushroom contamination from occurring (Marlina et al., 2015). This kind of mushroom substrate can be used to cultivate various types of mushroom species, including white oyster (*Pleuratos ostreatus*), grey oyster (*Pleuratos sajor-caju*), abalone (*Pleuratos cystidiosus*), ganoderma (*Ganoderma lucidium*), and black jelly (*Auricularia polytricha*) (Rasib et al., 2015).

It was reported that mushroom production specifically for oyster species is increasing at a rate of 7% per year, and in 2017, the amount was generated up to 10 million tonnes globally (Rajavat et al., 2020). As one of the tropical climate countries, the oyster mushroom production in Malaysia was reported approximately 65000 tonnes in 2020, and the amount is expected to increase (Wan et al., 2020). Technically, 5 kg of fresh wood fiber is required to be converted into waste fiber (SMS fiber) to produce 1 kg of oyster mushroom (Luo et al., 2018; Meng et al., 2018). Thus, massive mushroom production has significantly has generated a tremendous quantity of SMS fiber, as well led to cause serious environmental pollution.

The SMS fiber is often unutilized and being discarded as waste after mushroom harvesting. With the increasing mushroom demand and a tremendous amount of SMS fiber generated, it has become the biggest challenge to dispose of and manage (Hanafi et al., 2018). Currently, the effective method used to dispose of the SMS fiber, which is commonly practiced in the mushroom industry, is by dumping on the land and incineration (Jasinska, 2018). According to reports, the massive stockpile of SMS fiber has been declared environmentally hazardous after it was discovered to be a new breeding ground for flies and a source of foul odors (Najafi et al., 2019). These environmentally hazardous actions have resulted in environmental pollution such as contamination of water sources, air pollution, and eutrophication (Ariff et al., 2019; Wan et al., 2020). Most importantly, ineffectively utilizing SMS fibers after being classified as agricultural waste is viewed as a significant loss to our industries.

2.1.2 Empty Fruit Bunch (EFB) Fiber and Potential of Environmental Impacts

Since the 14th century, the oil palm industry has grown rapidly in South East Asian countries such as Malaysia, Indonesia, and Thailand, owing to the global demand for oil and fat production (Daneshfozoun et al., 2017; Iskandar et al., 2018). In the production process, the fresh fruit bunch (FFB) is harvested from the oil palm tree, and the fruit is detached from the FFB for oil extraction (Faizi et al., 2017). From the overall process, only 21 % of palm oil can be obtained from each fruit bunch, and the remaining waste produces are include palm kernel shell, fruit fiber, and empty fruit bunch (EFB) fiber (Liew et al., 2018; Triyono et al., 2019).

Among these generated waste, the empty fruit bunch fiber (EFB) is considered the most valuable natural waste fiber generated abundantly during the process, which has many potentials to be used in various applications (Onoja et al., 2019). As a replacement for conventional cellulose-based materials, the chemical properties of EFB fiber have been reported to contain almost similar composition to hardwood material (Yiin et al., 2019). Compared to other natural waste fibers, the EFB fiber has gotten attention as a top natural waste fiber with a high yield of cellulose components ranging from 48 to 65% (Khairul et al., 2017; Palamae et al., 2017). Generally, the cellulose content in fiber is a crucial aspect in determining the performance of the fiber in terms of strength before select and use in particular applications (Ramlee et al., 2019). Therefore, EFB fiber has been widely used as a source of material for cellulosic products such as composite panel, pure cellulose fiber filler, nano cellulose filler, pulp, paper, and bioplastics (Ali et al., 2020; Cifriadi et al., 2017; Hanan et al., 2020).

South-East Asia countries were known as the world's largest oil palm producers, with approximately 5.9 million hectares of plantation land in 2019 (Hisham & Jamil, 2020; Ismail et al., 2020). As the second major exporter of palm oil globally, in the year 2015, Malaysia produced approximately 83 million tonnes of oil palm solid waste, including trunks, fronds, and EFBs. However, a recent study by Hamzah et al (2019) stated that the amount of production was decreased to 51.19 million tonnes in 2017 probably due to the global issue. About 73% of the solid waste from the oil palm industry is composed of EFB fiber, making them the most abundant natural waste fiber (Khairul et al., 2017). Also, the EFB fiber has a low commercial value and constitutes a disposal problem due to its large quantity (Foo et al., 2019).

The increasing demand and growth in the use of palm oil have led to serious environmental issues due to the increasing number of EFB fiber as solid waste (Dullah et al., 2017). Typically, the EFB is sent directly from farmers to private palm oil mills, and later, it is discarded around the premises as waste, contaminating the surrounding environment (Triyono et al., 2019). Due to high moisture content in the range of 55 to 65 % and its bulky structure, the EFB fiber has become harder to be handled and transported (Hisham & Jamil, 2020). This issue becomes the biggest challenge to the operator to manage the EFB fiber disposal system and may escalate the operating cost.

2.1.3 Waste-to Resource Approach as a Sustainable Strategy

The increasing demand for wood products due to high population growth has led to the unavailability of conventional wood-based materials (Owodunni et al., 2020). Thus, utilizing the natural waste fibers and reducing the current usage of natural resources is the key to solving the current problem. Replacing the conventional natural resources with natural waste fibers according to a specific application is one of the most effective ways towards a sustainable approach to the development of cleaner production in the industry sector (Alrshoudi et al., 2020).

In general, reduction of carbon dioxide emissions from the agricultural sector towards sustainability has been included as one of the major strategic thrusts in the Sustainable Development Goals, Agenda of 2030 under the United Nation (Akdag & Yıldırım, 2020; Tambichik et al., 2018; Rashed & Shah, 2021). The aim is to reduce carbon dioxide emissions and waste stockpiles from the agricultural sectors. Recent studies reported that many technologies were developed utilizing natural waste fibers in various applications (Faizi et al., 2017). Considering its advantages such as abundance, availability, eco-friendly, good insulation properties, and low cost, the demand for the commercial use of natural waste fibers in composite production has increased significantly (Thyavihalli et al., 2019). The list of natural waste fiber used in various applications is summarized in Table 2.1.

Table 2.1 Summarize the list of natural waste fiber used in various applications.

Type of fiber	Applications	References
Coconut fiber	• Heat insulator • Concrete panel	(Dungani et al., 2016) (Oliveira et al., 2019)
Sugarcane bagasse	• Bio-sorbent for dye • Animal feed	(Ponce et al., 2021) (Casanova et al., 2017)
Rice husk	• Cement board • Bio-sorbent for dye	(Dungani et al., 2016) (Ponce et al., 2021)
Pineapple leaves	• Pulp and paper • Composite panel	(Sibaly & Jeetah, 2017) (Jain et al., 2019)
Banana tree waste fiber	• Composite panel • Bio plastic bag	(Rao et al., 2021) (Huzaisham & Marsi, 2020)
Empty fruit bunch fiber	• Pulp and paper • Soil amendment • Reinforcement material • Composite insulation panel	(Indriati et al., 2021) (Yavari et al., 2021) (Ramlee et al., 2019) (Ramlee et al., 2021)
Spent mushroom substrate	• Plant fertilizer • Animal feed • Adsorbent • Composite insulation panel	(Collela et al., 2019) (Nuradibah et al., 2020) (Eliescu et al., 2020) (Schritt et al., 2021)

Previous studies reported that the SMS and EFB fibers has a lot of potential applications that can be utilized, including as composite panel towards heat insulation application. However, limited studies were made on the utilization of SMS fiber from oyster mushroom waste source into the development of composite insulation panel. A recent study by Schritt et al. (2021) reported that, the composite insulation panel made from the SMS fiber was successfully produced. However, the study was only focused on the utilization SMS fiber with the incorporation of fresh sawdust fiber into a composite panel. Meanwhile, utilizing the EFB fiber as a composite panel towards heat insulation application was reported in Choh et al (2016) and Ramlee et al. (2021). These studies highlighted on the utilization of the EFB fiber into a composite using a mixing composite method together with the addition of polymers such as epoxy resin and urea formaldehyde (Deraman et al., 2019; Valasek & Ambarita, 2018). There has been a very limited of research focusing on the development of composite insulation panels employing SMS and EFB fibers in conjunction with the sandwich composite technique (Lusiani et al., 2020; Sosu et al., 2011).

2.2 Insulation Panel

Insulation panel has a wide range of applications, and mostly it is implemented in the indoor spaces to insulate walls or ceilings (Patnaik et al., 2015). An insulation panel can be classified as a stand-alone or a fixed layer inside a wall structure used to resist heat from the outside and maintain a comfortable temperature inside a room, or vice versa (Hysek et al., 2019). It has been demonstrated that the insulation panel is capable of reducing a building's high energy consumption and has emerged as an important component in resolving climate change issues (Rojas et al., 2019). Another study concluded that improving a building's thermal efficiency through the use of insulation panels can assist reduce heating and cooling needs, resulting in energy savings (Cetiner & Shea, 2018; Liuzzi et al., 2017; Ramlee et al., 2021).

Apart from the thermal properties, the material used to construct the insulation panels should initially display outstanding mechanical properties in addition to superior insulation performance. Mostly, the majority of insulation panels, such as gypsum panel or polystyrene are constructed as low-density, porous structures in order to provide improvement on thermal efficiency (Kang et al., 2018; Pasztory et al., 2017). Possessing low durability in terms of strength has limited its use in the heat insulation applications that require high durability, curved surfaces, and more sensitive to impact damage (Aghaee et al., 2015). It was reported that the thermal characteristic of insulation panels is easily degraded during the installation process due to damage and impact accidents (Boccarusso et al., 2020). Thus, the mechanical properties of the insulation panel are essential to withstand the least amount of load possible during their handling, installation, and maintenance processes. Considering this, the thermal characteristic and mechanical properties are important elements that should be prioritized throughout the development of insulation panel. Throughout the literature, it was evident that wood fiber is one of the earliest materials employed in construction and building and is also capable of serving as an insulation panel owing to its superior thermal and mechanical properties (Marsono & Balasbaneh, 2015; Sair et al., 2019). Apart from wood fiber, natural waste fiber is also well-known for its outstanding thermal properties and can be generated abundantly, especially in tropical climate countries (Hassanin et al., 2016; Thyavihalli et al., 2019). In this perspective, it may indicate that the use of natural waste fiber in the manufacture of composite insulation panels will almost certainly become a necessary alternative to wood fiber in order to conserve natural resources and mitigate negative environmental impacts (Denes et al., 2019; Rojas et al., 2019). Even though the natural waste fiber has good values as insulation materials, but in the tropical climate, this option is not favorable due to the existence of other types of synthetic materials. With the aim to give an overview of the insulation panel's materials and construction, this section discuss these, addressing their performance in the tropical climate.

The application of insulation panels has been widely implemented in the tropical climate countries to achieve better thermal comfort of occupants in buildings (Nematchoua et al., 2020). The insulation panels are used to reduce heat gain of a building in achieving thermal comfort (Cheung & Jim, 2019; Zune et al., 2020; Rahman et al., 2021). Heat gain and heat of a building depends on the size of its border walls and on the factors of heat leakage boundary walls (through various building elements such as walls, roof, ceiling, floor, etc...). The difference between the outside and inside air temperature of a building is the primary cause of heat gain (Wonorahardjo et al., 2020; Zhou et al., 2014). Recent studies revealed that the daytime outdoor temperature in the tropical climate countries is in the range of 25-35 °C (Deevi & Chundeli, 2020; Morakinyo et al., 2018; Muhieldeen et al., 2020; Yu, Chen, et al., 2020). On the other hand, it was reported that the level acceptance of thermal comfort in the tropical climate building is in the range of 20.97 to 30 °C (Borges et al., 2020; Garcia et al., 2019; Jindal, 2018; Zune et al., 2020). Considering this, the insulation panel is necessary to ensure the heat gain of buildings is minimized.

Moreover, buildings in tropical climate countries are mainly using air-conditioning systems to provide thermal comfort. However, with higher heat gain into the buildings, it contributes significantly to a large amount of energy consumption when the air-conditioning systems are used (Aziiz et al., 2018). For buildings that utilize air-conditioning systems, research have indicated that their energy consumption is substantially less than that of an interior structure that is not equipped with insulation panels (Nazi et al., 2017; Tushar et al., 2019). Thus, the implementation of insulation panels in buildings not only providing better thermal comfort but also assists in reducing the energy consumption of the air-conditioning systems.

In addition, building airtightness which can be affected by the insulation panel within the building structure, is also one of the contributing factors to reduce heat gain or become the most impactful energy savings for air-conditioned buildings (Jamaludin et al., 2014; Somasundaram et al., 2020). A high rate of airtightness of the insulation panel has contributed to reducing the indoor air from escaping and prevent unconditioned air from entering a building. Table 2.2 summarized types of insulation panel or materials and their applications within building structures which depending on their characteristics.

Table 2.2 Types of insulation panel or material and their applications within building structures.

Type of insulation material	Application	Characteristics	References
Polystyrene foam	Building envelope, roofing and packaging	Advantages • High impact absorption • Light weight Limitations • High flammability • Poor mechanical strength • High water resistance	(Cai, Zhang, et al., 2017 ; Husain & Prakash, 2019 ; Mirrahimi et al., 2016 ; Prusa et al., 2020)
Gypsum	Walls and ceiling	Advantages • Fire resistance Limitations • Poor mechanical strength • High brittleness • Heavy weight	(Aghaee et al., 2015 ; Awang et al., 2020; Nazerian & Kamyab, 2013; Padevet et al., 2011;Budiman et al., 2018; Boccarusso et al., 2020)
Natural waste fiber	Wall surfaces, ceilings, and building envelope	Advantages • High mechanical properties • Light weight Limitation • Poor water resistance • High flammability	(Cetiner & Shea, 2018 ; Rojas et al., 2019) (Wang et al., 2018) (Sair et al., 2019)

2.2.1 Common Types used Tropical Climate

Insulation panels can be made from various types of materials. In the tropical climate, polystyrene (Leng et al., 2019), gypsum (Boccarusso et al., 2020), and natural waste fiber (Binici et al., 2020) are the common material that is used in fabricating insulation panels. These material are selected due to their advantages in terms of cost as well as their superior thermal characteristic (Dolezelova et al., 2018; Raut & Gomez, 2017; Venkiteswaran et al., 2017). Thermal characteristic of materials are affected by their properties. Thus, when fabricating insulation panel, the material selection must be made and investigated based on its application requirement with the aim of achieving effective performance (Jdayil et al., 2019; Shiekh et al., 2009).

Technically, insulation is classified into two main categories based on its ability to control heat transfer, which are reflective insulation and mass insulation (Aditya et al., 2017; Michels et al., 2021). Reflective insulation is thermal insulation that reflects radiation heat, preventing heat transfer from one side to another, and is commonly used in home attics, roofing and wall system (Pourghorban et al., 2020). Meanwhile mass insulation is related to the insulation panels that can retard the heat transfer movement by conduction; and they are practically used in non-convection and radiation applications such as indoor walls or ceilings (Aditya et al., 2017). In the tropical climate, heat gain in the high rise buildings not only contributed from solar radiation but also through the ground and outdoor air (Pingel et al., 2017). In order to minimize the heat gain, insulation is essential throughout the building envelopes. By looking at this context, mass insulation mechanism become more suitable in the buildings of tropical climate. Based on materials, insulation can be classified into four distinct categories as shown in Table 2.3.

Table 2.3 Lists of insulation materials in different categories.

Categories of insulation material	Examples	References
Rocks and slags	• Rock-wool • Expanded perlite • Glass beads • Vermiculite • Cinder • Ceramic product	(Liuzzi et al., 2017; Jeon et al., 2017; Lu, 2020)
Petrochemical and coal chemical intermediate products	• Polystyrene, • Polyurethane • Polyethylene	(Leng et al., 2019).
Agricultural waste, forestry waste fiber and industrial plants fiber	• Rice straws • Rice husk • Waste papers • Wood shavings • Cotton • Corn crops fiber	(Binici et al., 2020; Muthuraj et al., 2019)
Metals	• Metal reflection film • Hard metal visor • Radiation plate	(Miloştean & Flori, 2017) (Julian Wang & Shi, 2017) (Zhou et al., 2019)

2.2.1.1 Polystyrene Foam

Thermal insulation material commonly used in the tropical climate countries is a petrochemical-based product such as extruded polystyrene (XPS) and expanded polystyrene (EPS) (Cetiner & Shea, 2018; Venkiteswaran et al., 2017; Wong et al., 2020). The extruded polystyrene foam is produced by extruding the melted mixture of polystyrene and foaming agent through a pressure-release nozzle. While for expanded polystyrene foam, it is made from a mixture of small polystyrene and expansion agent under a heating water vapor process (Kumar et al., 2020). The main factor of polystyrene insulation properties is its production process that generates multiple amounts of void structures inside the panel cavities which is crucial in heat insulation application (Prusa et