UNIVERSITI MALAYSIA KELANTAN

RECYCLE POLYSTYRENE AS A BINDER OF PCM-IMPREGNATED PARTICLE BOARD: EFFECT OF DENSITY

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DECLARATION

I declare that this thesis entitled 'Recycle Polystyrene as a Binder of PCM Impregnated Particle board: Effect of Density' is the result of my own research except as cited in the references.

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Properties of Phase Change Material Impregnated with polystyrene as binder in Particle board

ABSTRACT

This research investigates the environmental and thermal properties of wood composites produced using polystyrene resin as an adhesive and sawdust infused with palmitic acid as a phase change material (PCM). The composites were developed to explore their potential as eco-friendly alternatives in construction and thermal regulation applications. Utilizing rubber wood dust bound with polystyrene resin aimed to reduce environmental impact compared to conventional synthetic polymers. Furthermore, impregnating sawdust with palmitic acid aimed to enhance energy efficiency by leveraging the phase change capabilities of the acid.

Various tests, including Leaking test, TGA, DSC, FT-IR, as well as physical and mechanical evaluations, were conducted on the wood composites. The thickness swelling test indicated that the composite with a density of 0.6 g/cm^3 exhibited the lowest water absorption, indicating promising performance. Overall, the evaluation suggested that the wood composites possessed superior strength and durability across multiple tests.

The findings imply that utilizing polystyrene resin as an adhesive and impregnating sawdust with PCM could yield environmentally friendly wood composites with enhanced thermal properties. These composites hold potential for applications in sustainable construction and energy-efficient building systems, contributing to reduced energy consumption and environmental mitigation. Further research is needed to explore optimization techniques and scale-up possibilities for practical implementation.

Keywords: PCM, polystyrene, Leaking test, TGA, thickness swelling.

Sifat Bahan Perubahan Fasa Diresapi dengan polistirena sebagai pengikat dalam papan Zarah

ABSTRAK

Penyelidikan ini menyiasat sifat alam sekitar dan terma komposit kayu yang dihasilkan menggunakan resin polistirena sebagai pelekat dan habuk papan yang diselitkan dengan asid palmitik sebagai bahan perubahan fasa (PCM). Komposit telah dibangunkan untuk meneroka potensi mereka sebagai alternatif mesra alam dalam pembinaan dan aplikasi peraturan terma. Menggunakan habuk kayu getah yang diikat dengan resin polistirena bertujuan untuk mengurangkan kesan alam sekitar berbanding polimer sintetik konvensional. Tambahan pula, impregnasi habuk papan dengan asid palmitik bertujuan untuk meningkatkan kecekapan tenaga dengan memanfaatkan keupayaan perubahan fasa asid.

Pelbagai ujian, termasuk ujian Bocor, TGA, DSC, FT-IR, serta penilaian fizikal dan mekanikal, telah dijalankan ke atas komposit kayu. Ujian pembengkakan ketebalan menunjukkan bahawa komposit dengan ketumpatan 0.6 g/cm^3 mempamerkan penyerapan air yang paling rendah, menunjukkan prestasi yang menjanjikan. Secara keseluruhannya, penilaian mencadangkan bahawa komposit kayu mempunyai kekuatan dan ketahanan yang unggul merentasi pelbagai ujian.

Penemuan ini membayangkan bahawa menggunakan resin polistirena sebagai pelekat dan habuk papan dengan PCM boleh menghasilkan komposit kayu mesra alam dengan sifat terma yang dipertingkatkan. Komposit ini berpotensi untuk digunakan dalam pembinaan mampan dan sistem bangunan cekap tenaga, menyumbang kepada pengurangan penggunaan tenaga dan pengurangan alam sekitar. Kajian lanjut diperlukan untuk meneroka teknik pengoptimuman dan kemungkinan skala untuk pelaksanaan praktikal.

Kata kunci: PCM, polistirena, papan partikel, TGA, bengkak ketebalan.

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LIST OF ABBREVIATIONS

PS	Polystyrene
PCM	Phase Change Material
VOC	Volatile organic compounds
EPS	expanded polystyrene
CO2	Carbon dioxide
CH4	Methane
N20	Nitrous oxide
SO2	Sulphur dioxide
CO	Carbon monoxide
NOx	Nitrogen oxide
FT-IR	Fourier transform infrared spectroscopy
UF	Urea formaldehyde
MDF	Medium density fibreboard
TGA	Thermogravimetric analysis
DSC	Differential scanning calorimetric
XRD	X-ray diffraction
G	Gram
CM^2	Centimetres cubic
kV	Thousand volt
mA	milliamps
Cu Kα	Cu K-αlpha
mmHg	Millimetres of mercury
CM	Centrimetres
Kg	Kilogram

mm	Millimeter
Min	Minutes
M	Mass
T	Thickness
W	Watt
PA	Polymide
Mw	Medium wave
J·g-1	Heat

LIST OF SYMBOLS

°C	Degree Celcius
θ	Teta
%	Percentage
Mw	Medium wave
J·g-1	Heat
g/cm^3	Gram per cubic meter

CHAPTER 1

1 INTRODUCTION

1.1 Background of Study

Polystyrene (PS) is a synthetic polymer made from monomers of the aromatic hydrocarbon styrene. It can be solid or foamed, and it is known for being clear, hard, and brittle and a plastic derived from petroleum-based and the monomer styrene (vinyl benzene). Almost 50% is used to make a polystyrene. Since its first commercial production in 1930, it has been utilised for numerous commercial, packaging, and construction purposes (Farrelly & Shaw, 2017) these employed the catalytic dehydrogenation of athylbenzene, a process that is still used nowadays. Despite its severe impact on both human health and the environment, the usage of polystyrene in the packaging sector has been expanding in many nations. The World Health Organization's International Agency for Research on Cancer has categorised styrene, the basic building block of polystyrene, as a possible carcinogen, and chronic exposure to it can be hazardous to human health. Polystyrene disposal necessitates many procedures and considerable prices due to its non-biodegradable nature, necessitating recycling to mitigate its environmental impact. To test the physical and mechanical properties of particle board soaked with polystyrene as a binder, one study investigated the usage of phase change materials (PCM). When a material's phase changes, it can absorb and release energy making it an effective technique for saving energy and maintaining isothermal conditions (Linquib Teams, April 2023). The advantage of using phase change materials is that they can melt and solidify at specific temperatures, making them suitable for temperature control in various applications. Additionally, materials that are liquid and can absorb heat are more efficient in storing thermal energy than materials that are sensitive to heat energy, meaning a smaller amount of material is required to store thermal energy in a phase change material than using a non-phase change material.

1.2 Problem Statement

Currently, polystyrene is the most extensively used packaging material in the globe. However, the pervasive use of polystyrene harms both humans and the environment. In particular, the accumulation of non-biodegradable polystyrene contributes to contamination. In addition, the traditional production of particle board with formaldehyde-based compounds has a negative impact on the environment and can contribute to health concerns. Using such polymers can produce volatile organic compounds (VOCs) that are detrimental to consumers and contribute to air pollution and climate change (Vasilachi et al., 2021). Recycled polystyrene has previously been investigated as a possible alternative binder for particleboard production. However, the research to assure the commercial viability of the density that will impact particle boards' physical and mechanical properties needs to be revised. To determine the optimal effect that will be generated, it is vital to determine the influence of this density. Incorporating palmitic acid into sawdust and PS dissolved in acetone to create this particle board impregnated with PCM is one of the innovations that can recycle polystyrene while reducing pollution.

1.3 Expected Output

In this research project, particle board was be prepared with PCM that has impregnated polystyrene as a binder. The preparation of the structure and properties of this wood are used palmitic acid and acetone as the main ingredients. Therefore, it is expected that this combination positively improved its physical and mechanical properties as well as the density of particle board made using recycled polystyrene (PS) that can be evaluated well. The test was carried out according to the standards set to ensure the accuracy of the particle board.

1.4 Objective

1. To evaluate the effect of density on physical and mechanical properties of particleboard.
2. To characterize particle board made using recycled polystyrene.

1.5 Scope of Study

Research aims to look into the possibility of using recycled polystyrene as a binder for PCM-impregnated particle board for thermal energy storage in building applications. This study was investigating the properties and characteristics of recycled polystyrene as a binder, as well as the effect of employing PCM in impregnated particle board, such as thermal properties and energy capacity. It will put the board through bending and compression testing. The project also included evaluating prospective uses for recycled polystyrene-PCM impregnated particle board and optimising the manufacturing process. In addition, comparisons with other materials utilised for thermal energy storage in building applications also has been made. Overall, the findings of this work can shed light on the practicality and potential of employing polystyrene as a binder for PCM-impregnated particle board in building applications.

1.6 Significant of Study

The goal of this research is to create a low-cost, ecologically friendly PCM-impregnated particle board with recycled polystyrene as a binder. This is due to the increased thermal conductivity of particle boards with PCM energy storage capability when recycled polystyrene is used as a binder. This study also investigates particle board's mechanical and thermal properties, including compressive and bending strength, thermal conductivity, and thermal stability. Particle board with desired qualities can be produced by optimising the production process by altering particle size, binder amount, and pressing conditions. This research was showed that employing recycled polystyrene as a binder for PCM-impregnated particle board can provide a sustainable alternative for thermal energy storage in construction applications.

CHAPTER 2

2 LITERATURE REVIEW

2.1 Rubberwood

Figure 1: Rubberwood tree

Rubberwood, known scientifically as *Hevea brasiliensis*, is a sustainable and environmentally benign hardwood highly prized in the furniture industry. It is native to Brazil but predominantly obtained from plantations of rubber trees in Southeast Asia, including Malaysia, Thailand, and Indonesia (Medlock, E., 2022). Unique to Rubberwood is its sustainable harvesting method. When rubber trees reach the end of their latex-producing cycle (typically after 25 to 30 years), they are harvested for their wood, allowing for the efficient use of resources and reducing waste. In terms of appearance, rubberwood has a light to medium yellow hue and a textured pattern that is uniform and smooth. It has a clear and uniform appearance because there are few tangles and flaws. It provides a neutral background that can be stained or completed to match various styles and design preferences, making it an ideal material for furniture manufacturing (Meier, E., 2015).

Rubberwood is classified as a medium-density hardwood, similar to maple and birch. It balances strength and weight, making it suitable for various applications. While not as rigid as oak or teak, it still provides a respectable amount of durability and resilience. Due to this

quality, Rubberwood can withstand the demands of daily use in furniture and other woodworking projects. Rubberwood's workability is one of its most notable advantages. It is comparatively straightforward to manipulate with both hand and mechanical instruments. Craftsmen and manufacturers favour Rubberwood due to its responsiveness to cutting, moulding, and sanding. Additionally, it absorbs adhesive and varnishes well, allowing for versatility in woodworking techniques and surface treatments.

Rubberwood has numerous benefits, but it is important to recognise its limitations. It is not inherently resistant to degradation or insect infestation, so it must be treated or protected before being used outdoors or in high-humidity environments. In addition, Rubberwood's moderate hardness may make it more susceptible to fractures and blemishes than firmer hardwoods. These limitations can, however, be mitigated through appropriate care and maintenance. Rubberwood can also produce particleboard, offering an alternative to conventional wood particles. Rubberwood is cut into small pieces or fibres and combined with a synthetic resin or adhesive during manufacturing. Under tremendous heat and pressure, these rubberwood particles are pressed and bonded to form solid panels of rubberwood particle board.

Overall, rubberwood particle board provides an eco-friendly alternative to conventional particle board by combining the renewable nature of Rubberwood with the adaptability and affordability of particle board. It contributes to waste reduction and supports sustainable forestry practises by offering an attractive and workable material for various applications.

2.2 Polystyrene

Polystyrene is a popular packaging material that is widely used nowadays. It is regarded for characteristics such as its inexpensive cost and high bonded strength. Polystyrene is a petroleum product with no apparent recycling path after usage. Polystyrene recycling may be done using mechanical, chemical, or thermal processes. Due to the fact that its qualities are not dramatically altered even after going through numerous processing steps, high-impact polystyrene is a viable material for mechanical recycling. The reaction conditions have a considerable impact on whether liquid or gaseous products are formed due to the chemical reaction. The catalyst that is employed is very selective for the formation of gaseous as well as liquid products (T. Maharana et al., 2007). Polystyrene is frequently used for packaging purposes. Polystyrene waste poses a severe threat to the environment, particularly in developing nations where disposal facilities are scarce and proper management is difficult because it is difficult to recycle. Although the industry is trying to integrate a small percentage in the manufacturing process, it is well known that their management necessitates high transportation, storage, and disposal costs. Large quantities of polystyrene waste are disposed of in landfills, recycling facilities, or incinerators due to the apparent absence of effective and appropriate recycling strategies. In this facility, polystyrene waste is dissolved by leachate from the decomposition of other organic materials. Similarly, the gases produced by the combustion of polystyrene are hazardous. Masri et al. (2018) examined the possibility of using polystyrene as a binder to produce wood composites with added value. Where the researcher successfully created particle boards using expanded polystyrene waste material (EPS) and dates, and where it was shown that the flexural strength and stiffness of the board had achieved acceptable levels, together with a satisfactory fibre-matrix interface. In this study, uses life cycle assessment to investigate the environmental implications of different polystyrene life phases and the accompanying environmental impacts in order to enrich the argument on optimal polystyrene

end-of-life management (Marten, B.,2018, February 1). Due to its valid shipping qualities, polystyrene recycling is now uncommon due to its high cost and difficulty of processing. However, the negative impacts of polystyrene on the environment may be mitigated via recycling.

2.3 The benefit of polystyrene

Utilising polystyrene as a binder in producing particle boards has several advantages, including the conservation of resources, as polystyrene can be derived from waste materials such as waste expanded polystyrene (EPS). This material can be recycled and reused by utilising polystyrene residue as a binder, thereby contributing to resource utilisation and waste reduction. Afterwards, enhanced Physical and Mechanical Properties. According to studies, particleboard manufactured with polystyrene as a binder has enhanced physical and mechanical properties. These characteristics include improved dimensional stability, water resistance, and strength. Polystyrene can enhance the efficacy of particleboard by enhancing particle or wood fibre adhesion and bonding.

The unit weight of particleboard produced with polystyrene as an adhesive can be reduced compared to conventional particleboard (Boruszewski et al., 2022). Others are cost efficiency, in which polystyrene is a comparatively inexpensive material, making it an economical choice as a binder for particle board production (Abdulkareem et al., 2017). This can reduce manufacturing costs and make particle boards more affordable for consumers.

Polystyrene as a binder in particleboard production offers numerous advantages, including resource utilisation, enhanced physical and mechanical properties, decreased unit weight, versatility, and cost-effectiveness.

2.4 Particle board

According to an article published by International Timber on July 6, 2015, a particle board is composed of thin veneers of solid timber adhered to sheets with chemical compounds and adhesive. It is a panel composed of long-chain cellulosic material, typically wood, that consists primarily of discrete fragments or particulates instead of fibers and a synthetic resin or another suitable binder. Particleboard, also known as chipboard or low-density fiberboard, is composed of recycled materials and timber fragments manufactured by machine. Particleboard is also a composite panel that was created as an alternative construction material. These recycled materials consist of crumbs, leftovers, and debris. After connecting the semiconductors, they are heated and formed into a circuit board. Then, it is desiccated and subsequently split into various sizes. Particleboard is frequently used in furniture and interior applications because it is less expensive than solid timber and is suitable for moist or humid environments. Particleboard is denser and heavier than nearly every variety of solid wood, but it lacks durability and moisture resistance.

There are several primary characteristics of particle board. Particle board, which can be covered with laminate or wood veneer to create the appearance of wood at a lower cost than real wood, is frequently used as a budget-friendly alternative to wood. However, it lacks the strength and beauty of genuine wood (2017).

2.5 Phase Change Material

Also, there are three varieties of PCM accessible in this study: organic, inorganic, and eustatic. Palmitic acid was employed as the PCM in this investigation. A palmitic acid ($C_{16}H_{32}O_2$) is a form of organic PCM that contains saturated fatty acid. It is the most common saturated fatty acid found in animals, plants (palm oil and palm kernel oil) and microorganisms and certain kinds of milk.

It occurs in the form of esters (glycerides) in oils and fats of vegetable and animal origin and is usually obtained from palm oil, which is widely distributed in plants. Palmitic acid is used in determination of water hardness and is an active ingredient of *Levovist*TM, used in echo enhancement in sonographic Doppler B-mode imaging and as an ultrasound contrast medium. This is due to the excellent characteristics of fatty acids and their wide melting temperature range. However, because of the higher prices, judgments between organic and inorganic PCM should be made cautiously. It is nearly hard to re-impregnate PCM into wood once it has been treated. As a result, heat storage stability is a crucial feature of PCM for wood. According to this, PCM is a latent particle that is effective at storing heat energy. This article discusses the insertion of phase change materials (PCM) into the wood as an efficient technique to manage the heat load of wood. PCM can store and transfer latent heat energy within a certain temperature range, making it a feasible technology for managing thermal conditions. The high amount of energy used in the construction industry results in the emission of greenhouse gases and other pollutants; hence, the utilisation of PCM in wood is driven by the need for energy management. Carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), and other air pollutants including sulphur dioxide (SO_2), carbon monoxide (CO), and nitrogen oxide (NOx) are all examples of what is being released into the atmosphere (Sulaiman & Mohamad Amini, 2022). It is hypothesised that wood can be used to regulate energy. This article examines the

challenges of mixing wood and wood-based goods with PCM and looks into the usage of organic and eutectic mixtures as PCM types. The study then investigates the use of polystyrene waste (PS) as a binding agent in the production of particle boards from rubber wood. PS waste is thought to be a safer alternative to formaldehyde resin-based adhesives, lowering health risks and pollution.

The study aimed make particle boards from PS waste, analyse their physical and mechanical properties, and evaluate its density. Furthermore, wood serves as a support material for PCM, resulting in structural holes ranging in size from millimetres to nanometres where there is a helix structure that allows for good contact (Adnan & Hermawan, 2022).

Using polystyrene and PCM, this study discovered that wood impregnated with PCM could decide its heat, capacity, and thermal stability properties. Several studies have been performed on PCM-impregnated wood to assess its physical and mechanical qualities, as well as its chemical structure. Fourier transform infrared spectroscopy (FT-IR) studies reveal chemical components in PCM-impregnated wood, suggesting that no new chemical components have been produced and vice versa if the interaction happens chemically. Moreover, acetone is a non-polar solvent (as opposed to water, which is quite polar), and polystyrene is composed of polystyrene and foam. Acetone can dissolve polystyrene's carbonhydrogen bonds due to their similar polarity.

Overall, the density of the wood that will be utilised in the study is in the range of $0.6 g/cm^3$, $0.7 g/cm^3$ and $0.8 g/cm^3$ to generate particle boards derived from PS waste. JIS A 5908 yields $0.4 g/cm^3$-$0.9\ g/cm^3$ through the specified research. Returning to the goal at hand, (Liao, R., Xu, J., and Umemura, K., 2016), particle board with high density has several particles per unit volume. As a result, the particles' tight bonding will reveal their mechanical

characteristics. Then, density is quite significant. However, if use too much PS, the density will be poor due to the fact that this PS contains fewer wood particles.

2.6 Urea-formaldehyde (UF)

Formaldehyde-containing synthetic resin is frequently used as a binder in wood-based panel products such as particle boards, fibreboard, and plywood. Urea-based resins and phenol are the two most commonly used resins in constructing panels made from formaldehyde materials (Chrobak et al., 2022). Formaldehyde and urea or phenol are reacted with formaldehyde to produce a thermoset resin that can bind wood particles together. Nonetheless, formaldehyde-based polymers have garnered attention due to their potential toxicity.

Urea-formaldehyde (UF) is a non-transparent thermosetting resin or polymer that is produced from urea and formaldehyde. UF resins are commonly used in adhesives, plywood, particle board, medium-density fibreboard (MDF), and molded objects (Vedantu.,2022). Urea formaldehyde (UF) also a recognized carcinogen. UF is a colourless chemical substance with a pungent odour. The active component in the manufacturing of adhesives and formaldehyde resins is formaldehyde. The glue that holds particle board together and may also be found in other building materials such as oriented strand board, fibreboard, and laminate flooring. Because of its capacity to preserve tissue and cells, it is also used as a disinfectant and embalming agent. As a result, because polystyrene is more ecologically friendly, it was used as a binder in this investigation. UF may potentially be harmful to human health. Among these are those that can cause eye discomfort, cancer, and respiratory difficulties.

2.7 Thermogravimetric analysis (TGA) & Differential scanning calorimetric (DSC) (TGA/DSC)

Thermogravimetric analysis (TGA) is an analytical method that measures the weight change that occurs when a sample is heated at a constant pace (K.R. Rajisha, B. Deepa, L.A. Pothan, S. Thomas., 2011). This allows researchers to determine a material's thermal stability and volatile component percentage. TGA/DSC weighing technology provides:

- Position-independent weighing.
- An automatic internal calibration weight with an extensive measurement range.
- The best minimum weight performance.
- The most excellent weighing accuracy and precision.

Overall, TGA and DSC are essential instruments for investigating the thermal properties of materials. TGA measures variations in sample mass over a temperature range, whereas DSC measures sample heat flux over the same temperature range. Both techniques provide valuable information on a material's thermal stability, decomposition, oxidation (May et al, 2019). Behaviour, and glass transition temperature, melting point, and crystallisation characteristics.

2.8 Fourier transform infrared (FT-IR)

FT-IR spectra evaluate the composition of solids, liquids, and gases, making them useful for identifying unknown materials and verifying manufacturing components. The information provided by FT-IR is extremely specific, allowing for accurate discrimination between similar substances. Due to its rapidity and sensitivity, FT-IR analysis is beneficial for screening and further research. FT-IR analysis can measure the infrared region of the electromagnetic spectrum, which has a longer wavelength and lower frequency than visible light (Mathias, 2022). Common applications of FT-IR include evaluating the quality of incoming and outgoing materials, analysing small material samples to identify contaminants, analysing thin films and coatings, monitoring emissions, and analysing failures.

This is accomplished by exposing the sample to infrared radiation, which is subsequently analysed to determine the frequency of light absorbed by the sample. The resulting spectrum provides a unique "fingerprint" of the sample that can be used to identify the substance's chemical composition.

CHAPTER 3

3 MATERIAL AND METHOD

3.1 Material Preparation

At Universiti Malaysia Kelantan Jeli Campus, rubber wood *(Hevea brasiliensis)* was available from a nearby local factory which is Evergreen Rubberwood Production. The major PCM (palmitic acid) and acetone was received from the university laboratory. The critical raw materials employed in this investigation are rubber sawdust, palmitic acid, acetone, and polystyrene. Prior to grinding, the rubber wood will be cut and dried. The wood chips then were sieved to eliminate dust before the particles are reduced in size. During the PCM process, the rubber sawdust impregnation will be decided. FTIR, TGA/DSC, and XRD investigations was used to characterise the PCM composite.

3.2 Method

3.2.1 PCM impregnation process

Polystyrene is dissolved in acetone then it is left to melt for several minutes and then has been mixed with wood powder that has been impregnated by PCM. Then it will be put into a mould measuring 30 cm X 30 cm X 1 cm and then hot pressed into an empty oven for 10 minutes at a unit pressure of less than 15 kg/cm^2 and a temperature of 180°C. After extraction of the specimen from the heating apparatus, the phase change material in its fluid state will be counted and calculated according to the ASTM D 1413 protocol using the following equation:

$$\text{Retention } g/cm^3 = \frac{\left(\{G \times C \frac{1}{2}\right)}{V} \text{ X } 10$$

To calculate how mush PCM solution the rubberwood needs to absorb, following equation were used: where G is the treatment's mass (in grammes), C is the PCM solution's concentration (in millimoles), and V is the sample's volume (cm^3) (Temiz et al., 2020).

3.3 Particleboard making

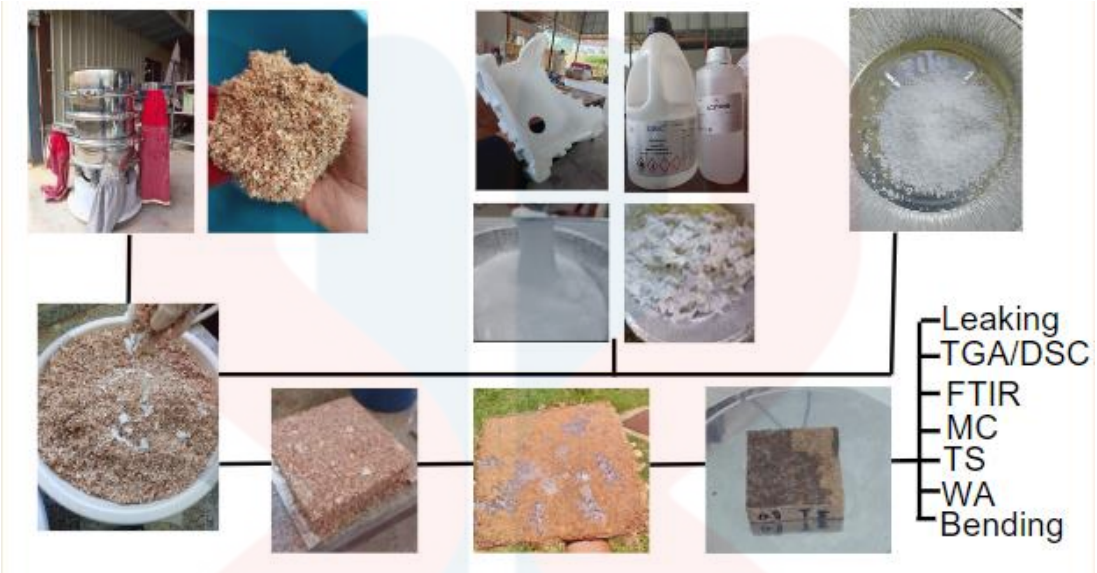


Figure 2: The process of particle board making

Universiti Malaysia Kelantan Jeli Campus was providing rubberwood particles which had been taken from a nearby factory. The wood chips were ground and sieved to obtain various sizes until they are crushed to remove small particles that can affect the particle board. Polystyrene is melted and mixed with acetone before being mixed with wood particles and palmitic acid to produce particle board, which is then manually placed in a 30cm x 30cm x 1 cm mold with a density of 0.6 g/cm^3, 0.7 g/cm^3, and 0.8 g/cm^3 for each particle board that be produced. This combination then be compacted before being 500kg hot-pressed for 10 minutes at 180°C.

3.4 Characterization

The investigation of recycled polystyrene as a binder in the impregnation of the phase change material (PCM). The leakage test, TGA/DSC, FT-IR, was used to characterise the impregnation. By following the process, the morphology and physio-chemical properties also be characterised.

3.4.1 Leaking Test

To determine whether the composite was leaking or not, it was baked in oven for 20 minutes at 55°C on filter paper. The filter paper was observed for any leakage of melted PA from the testing samples.

3.4.2 Thermogravimetric analysis (TGA) & Differential scanning calorimetric (DSC) (TGA/DSC)

Before conducting the TGA and DSC analysis, a representative sample of the particleboard material was be assembled. The sample used must be clean from impurities. The sample was pulverized into a fine powder to improve its accuracy and taken by 0.05 mm for this test. To ensure accurate measurements and avoid sample loss during analysis, the sample was be stored safely in a container or crucible. A nitrogen gas atmosphere will be used for this testing.

In TGA and DSC analysis, it is important to provide an inert environment that minimizes the effects of oxidation or unwanted reactions during the heating process; otherwise, the sample will turn to ash. (SDT Q600-TA instrument) has taken TGA and DSC readings at a heating rate of 10°C/min from room temperature up to 700°C during the testing process.

3.4.3 Fourier-transform infrared (FT-IR) machine

When carrying out the FT-IR analysis, a sample of the particleboard material that is typical of the whole was produce. The samples are in the form of tiny flakes or particles that have been finely powder. The particle board sample was placed on a surface that is both clean and flat. Then the sample was checked to verified does not include any impurities that could affect the results of the FT-IR study. The instructions provided was followed by the manufacturer to calibrate the FT-IR device properly. The instrument was measured, correcting

the beam alignment, and verifying the device's performance using the proper calibration standards. During this inquiry, the FT-IR apparatus (IRAffnity-1S) was doing a scanning between the ranges of 400 and 4000 cm (-1). The FT-IR measurements are used to gather the infrared spectrum of the board sample particles as the first step in the data-collecting process. The instrument was illuminating the sample with infrared light, and the amount of light that is absorbed, reflected, or transmitted as a consequence of the illumination was recorded.

3.5 Evaluation of properties of particle board

Manufactured particleboards were evaluated for their physical and mechanical and properties as shown in the following subchapters.

3.5.1 The moisture content of particle board

According to Japan's national standard (JIS A 5908, 2003), the moisture percentage was determined. To get a starting weight of 20 g, a piece of particleboard with a size of 5 cm × 5 cm was cut. After the initial weighing, the sample was dried in an oven at 102°C overnight and then weighed again after being stored in a desiccator. The practice was repeated until the final weight was steady. Three separate tests were conducted, and the average findings were plugged into the following formula:

$$Moisture\ content, \% = \frac{m_H - m_0}{m_0} \times 100$$

Where wet sample weight (in grams) is denoted by m_H, wheres dry sample weight (in grams) indicated by m_0.

3.5.2 Density of particle board

The particle board density was determined using the Japanese Standard (JIS A 5908, 2003) and modified sample size. Particle boards were sized down to a uniform 50 mm in both directions. The test objects spent the previous night in a conditioning room set at 25°C and 50% humidity. Again, a calliper and analytical balance were used to determine the sample's dimensions and mass.

$$Density\ (kg.m^{-3}), \rho = \frac{m}{b1\ x\ b2\ x\ t}$$

Specifically: *m* test of mass, b_1 = test piece width, b_2 = test piece length, and t = test piece thickness.

3.5.3 Particle board thickness swelling and water absorption

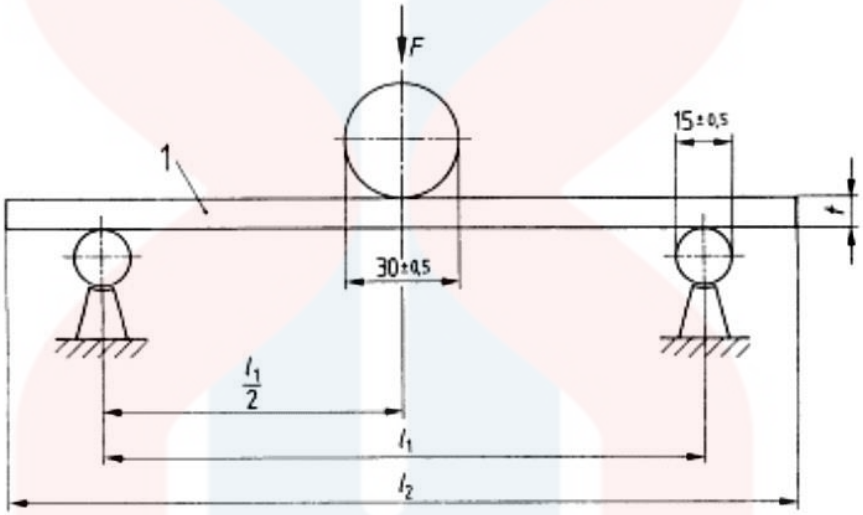
The thickness of particle board was measured before and after being submerged in water according to the Japanese Standard (JIS A 5908, 2003) trimmed and conditioned 50 mm × 50 mm pieces of particleboard at 25 °C and 50% relative humidity for a whole day. Dimensions including length, width, and thickness were recorded before the sample was immersed in water for analysis. After 24 hours, the test pieces were removed from the water, the excess water was collected, and the new dimensions of the test pieces were measured. Weighing specimens enabled to quantify the water absorption.

$$Swelling\ or\ Water\ absorbtion, \% = \frac{m_i - m_0}{m_0}\ x\ 100$$

Where m_0 represents the measurement before immersion and m_i represents the measurement after immersion.

3.5.4 Bending strength of particle board

The bending strength of particle board was evaluated using the Japanese Standard method (JIS A 5908, 2003). The particleboards were cut to 200 mm x 50 mm and conditioned at 25 °C and 50% relative humidity in a conditioning chamber. The component was tested using an Instron Tensile Machine Model 5582.



1= test piece

F= load

T= thickness

$l_1 = 20t$

$l_2 = l_1 = 50mm$

Figure 3: Arrangement of the bending apparatus (JIS A 5908, 2003)

CHAPTER 4

4 RESULT AND DISCUSSION

4.1 RUBBERWOOD SAWDUST (CHARACTERIZATION TESTING)

4.1.1 Leaking test

Figure 4: The sample of particle board with different density before and after baked in oven for 20 minutes at 55°C on filter paper.

The leaking test conducted on particle board samples with polystyrene as a binder and PCM-impregnation revealed promising results within 20 minutes at a temperature of 55°C. Three distinct samples with varying densities of 0.6 g/cm^3, 0.7 g/cm^3, and 0.8 g/cm^3 were subjected to the test, and notably, none exhibited any signs of leakage. This positive outcome suggested that the composition and manufacturing process effectively sealed the boards, preventing PCM and polystyrene leakage under the specified temperature conditions.

The absence of leakage could be attributed to the cohesive nature of the particle board and the bonding properties of polystyrene as a binder. However, a potential factor influencing the results was worth noting – the samples may have been left outside for an extended period after the hot press stage of production. Further investigations into the impact of extended exposure on the samples might have provided insights into any changes in their performance and

durability. Nonetheless, the initial test results indicated promising characteristics of the particle board in containing PCM even at elevated temperatures. This may also be due to the PCM content, which is a good heat absorber, allowing wood to be repaired with PCM well without any leakage.

4.1.2 Thermogravimeter analysis (TGA)

This research aimed to assess the efficacy of particle board production methods utilizing PCM-impregnated polystyrene as the binder. The thermogravimetric analysis aimed to determine the quantity and rate of change of a sample subjected to temperature variation.

Figure 5: TGA analysis of rubberwood sawdust with density 0.6 g/cm^3

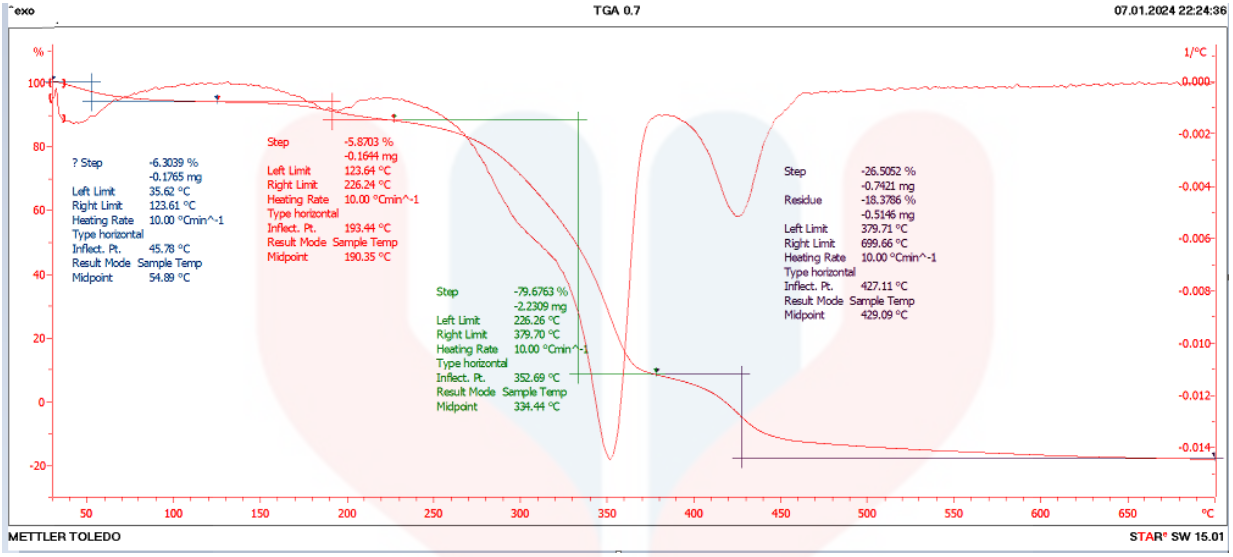


Figure 6: TGA analysis of rubberwood sawdust with density 0.7 g/cm^3

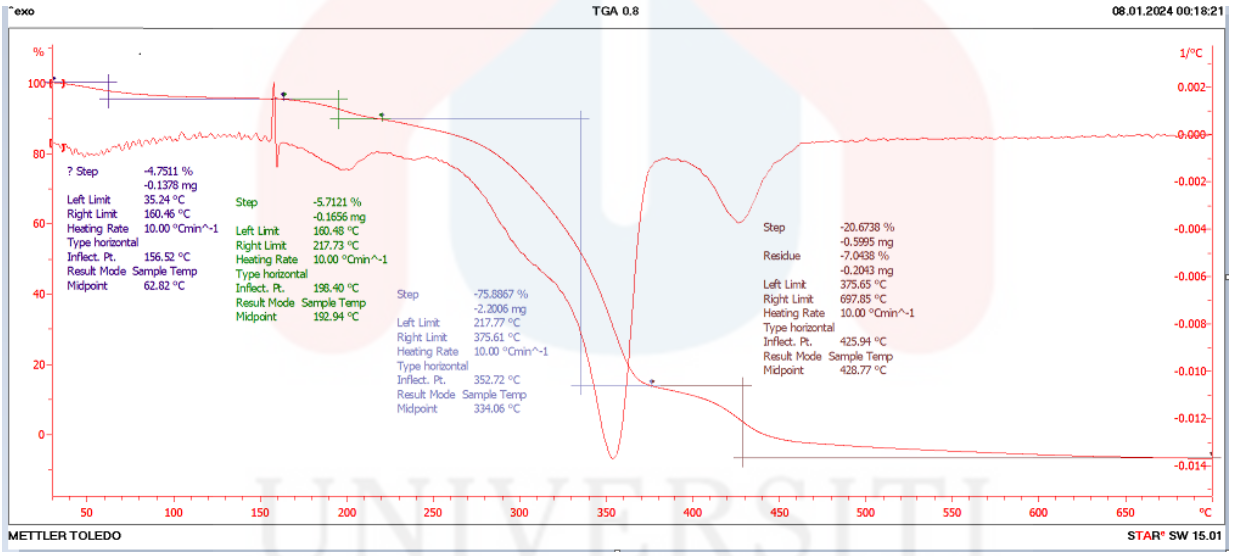


Figure 7. TGA analysis of rubberwood sawdust with density 0.8 g/cm^3

The chemical makeup of rubber wood consists of 40% - 44% cellulose, 25% - 30% hemicellulose, and 200% -225 lignin. Figure 5 shows the results of TGA analysis for density 0.6 g/cm^3, where polystyrene is a binder with palmitic acid as PCM is impregnated. According to Figure 5, the TGA analysis of this sample was carried out with a mass of 0.0035 grams and a temperature range of 30°C to 700°C. Both the mass percentage and the derivative of the mass loss rate in the sample are shown in the figure above. The plot is a function of the sample

temperature. Beginning at a temperature of 43°C, this sample went through a considerable deterioration rate, indicating that the sample had lost water. According to that measurement, the overall mass sustained a water loss equal to 2.7948%. The thermal degradation of particle board dust combined with polystyrene as a binder and palmitic acid is responsible for the percentage of sample weight decrease. Although many phases are associated with the degradation process in the sample, the overall percentage of sample weight reduction may be ascribed to this process.

Next, the findings of the TGA research regarding the second sample, which has a density of 0.7 g/cm^3, indicate that the mass rate used was 0.0028g, and the temperature rate utilized was the same, between 30°C and 700°C. The percentages of mass are plotted, and graphs are used to display the mass loss rate as a function of the temperature of the sample. This sample began to burn at a temperature of 55°C, resulting in a quick deterioration rate. The quantity of water loss achieved due to the fire was 5.9349%. These phases, which are associated with the degradation process in the sample, are responsible for the drop-in heat that has been seen.

The TGA analysis for the 0.8 g/cm^3 sample is shown in Figure 7, and it can be seen that the sample had a drop-in weight beginning at a temperature of 200°C, which is the water loss time for the 0.8 g/cm^3 sample. This can be seen in the figure, the percentage of water that was lost is 3.9949 %. The sample's mass decreases due to this reduction, which is a thermal process.

Cellulose starts to break down at temperatures ranging from 220°C to 315°C; at this point, it transforms into a gas that cannot be condensed and produces organic vapors that can be condensed. According to Mihai B. and Cornelia V.'s 2009 research, lignin decomposes at 200°C to 500°C slower than cellulose and hemicellulose compositions found in biomass. Then, the process includes the removal of hemicellulose, which indicates the drop-in sample weight produced by the evaporation of organic material (Hafizal Y., 2017). This is the reason why the TGA curve for this particle board happens. In addition to the impacts of the atmosphere, the

second reaction is considered an essential element while doing TGA analysis. An additional factor that might cause the sample to lose mass is the presence of absorbed moisture, solvent residues, and additives that have the potential to cause harm to the data analysis (Joseph D., 2009).

Last but not least, beginning at a temperature of 500°C, all three sample graphs that the sample has vanished or that only dust made of rubber wood is left behind. This is likely the consequence of the thermal activity during the sample analysis.

4.1.3 Differential Scanning Calorimetry (DSC)

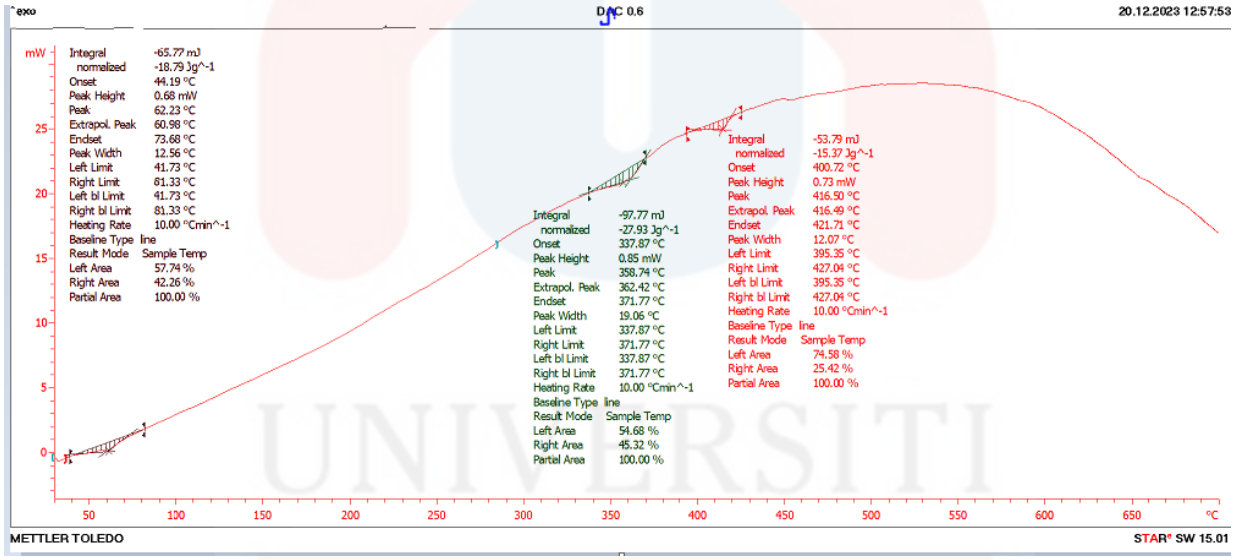


Figure 8: DSC analysis of rubberwood sawdust with PCM impregnated of density $0.6 g/cm^3$

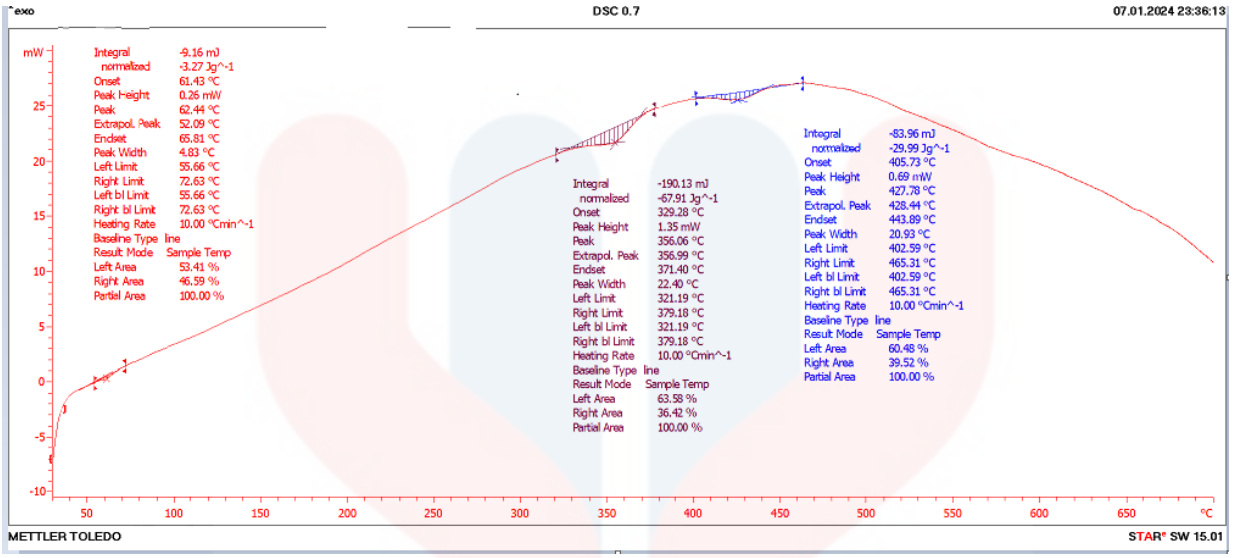


Figure 8: DSC analysis of rubberwood sawdust with PCM impregnated of density 0.7 g/cm^3

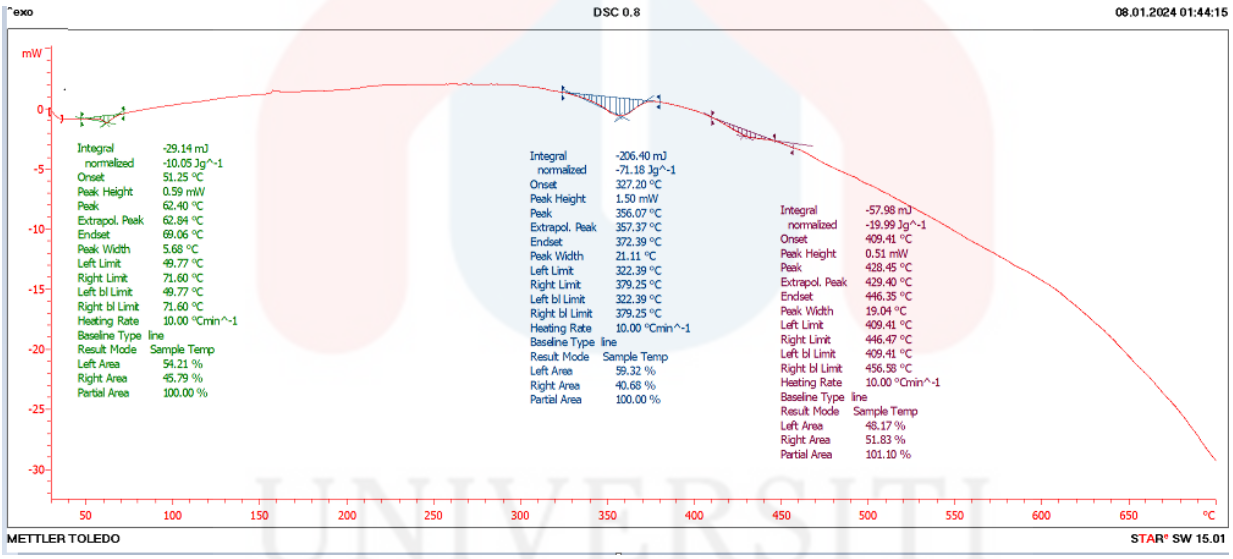


Figure 10: DSC analysis of rubberwood sawdust with PCM impregnated of density 0.8 g/cm^3

Table 1: DSC data of rubber wood sawdust with polystyrene as a binder with PCM impregnated for density of $0.6g/cm^3$, $0.7g/cm^3$ and $0.8g/cm^3$

Sample name (g/cm^3)	**Melting enthalpy variation (J·g-1)**	**Peak height (Mw)**	**Left limit (°C)**	**Right limit (°C)**
Density 0.6	-18.79	6.68	41.73	81.33
Density 0.7	-3.27	0.26	55.66	72.63
Density 0.8	-10.05	0.59	49.77	71.60

Differential scanning calorimetry (DSC) was used for analysis. DSC was used to assess the heat storage capability of polystyrene impregnated with palmitic acid-impregnated rubber sawdust (PCM), and polystyrene served as the binder. Through this analysis, the physical parameters of the sample are measured about the passage of time and temperature variation. This investigation was carried out on rubber sawdust samples mixed with 5% PCM at densities of $0.6g/cm^3$, $0.7g/cm^3$ and $0.8g/cm^3$. This analysis aimed to determine the thermophysical characteristics of materials, such as specific heat capacity, latent heat, and phase change material.

Additionally, this analysis is carried out for the three samples that have been mixed with various component values depending on the required density at the heating rate. For example, the TGA analysis is performed at 10.00 Cmin/-1 using nitrogen dioxide gas (N2) at temperatures ranging from 30°C to 700°C.

The DSC analysis results can be seen on the graph shown in Figures 8,9 and 10. With a peak height of 6.68 Mw in the 41.73°C - 81.33°C curve region for the 0.6g/cm^3 sample in Figure 8, the melting enthalpy variance for the controlled sample curve is -18.79(J·g-1). The following data shows a sample with a melting enthalpy variation of -3.27(J·g-1) and a peak height of 0.26 Mw in the curve section, including temperatures ranging from 55.66°C - 72.63°C. Last but not least, it is shown in Figure 10 that sample 0.8 g/cm^3 has been recognized as having a melting enthalpy variation of -10.05(J·g-1), a peak height of 0.59 Mw, and a melting point that falls between 49.77°C and 71.60°C, as was previously mentioned.

A very significant value can be seen in the melting point enthalpy variation curve for all three samples. This value harms all of the samples, which is the lowest level in the value of wood samples. The first curve was obtained for all samples because the temperature ranged from 50°C to 100°C which was the most suitable value point to evaluate. This is because this temperature is equivalent to the temperature at which PCM begins to melt when it is burnt.

4.1.4 Fourier-transform Infrared (FT-IR)

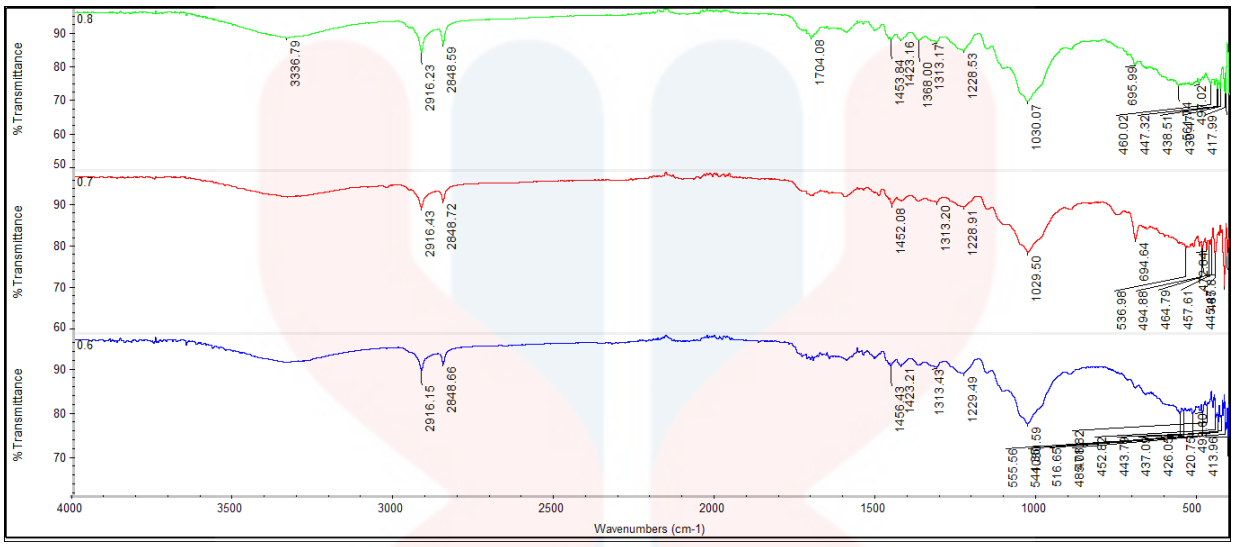


Figure 11: FT-IR peaks of comparison rubber wood sawdust of PCM with different density

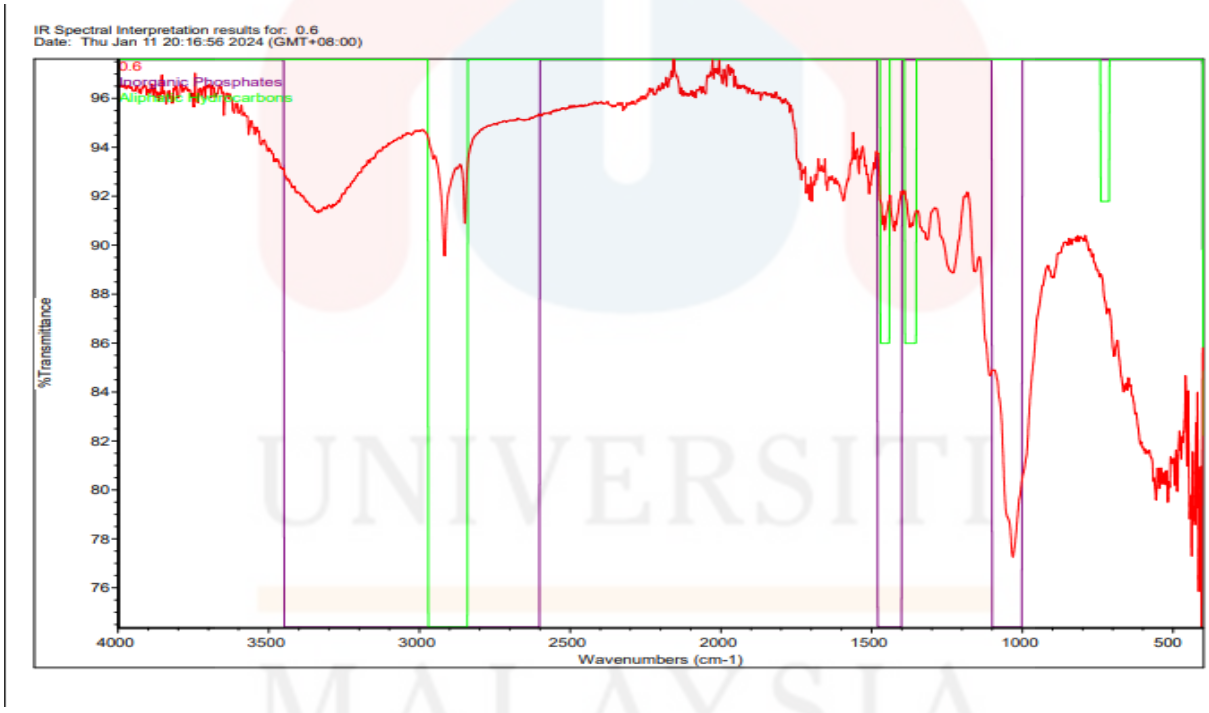


Figure 12: FT-IR peaks of comparison rubber wood sawdust for density $0.6 g/cm^3$

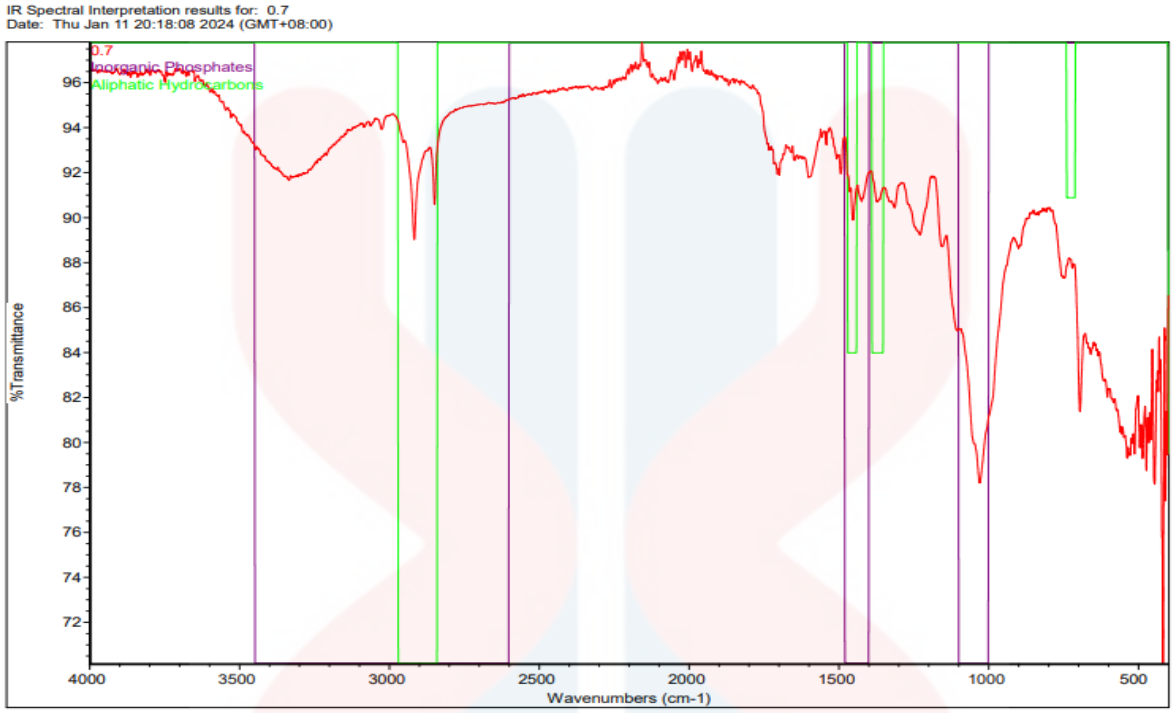


Figure 13: FT-IR peaks of comparison rubber wood sawdust for density $0.7 g/cm^3$

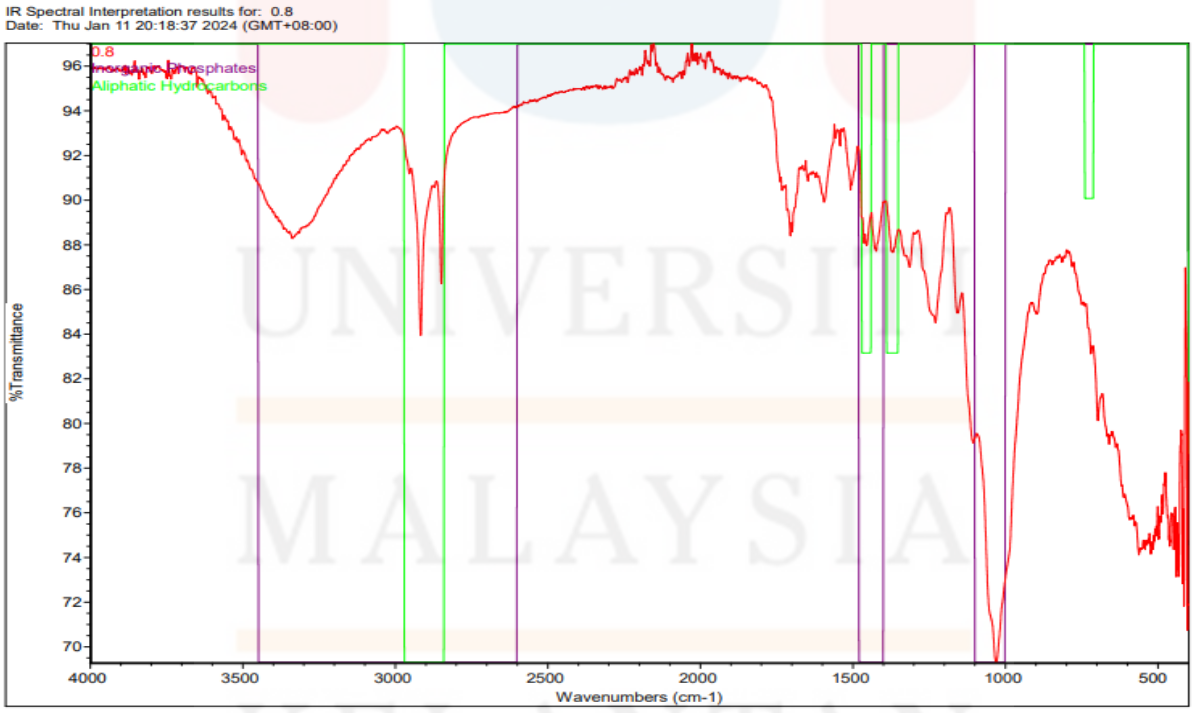


Figure 14: FT-IR peaks of comparison rubber wood sawdust for density 0.8 g/cm^3

Table 2: FT-IR peaks main functional group of rubber wood sawdust for density

Functional group	Peaks cm-1	Compound name	Bond
Inorganic Phosphates	1001.84 cm-1, 1098.26 cm-1, 2602.47 cm-1	Chrolophenylthio Chloromethyl 4-chlorophenyl sulphide Potassium phosphate	C-O stretch C-H (medium to strong)
Aliphatic Hydrocarbons	736.21 cm-1, 1387.53 cm-1, 1467.14 cm-1, 2841.60 cm-1	Hexane Aldehyde Gramicidin from Bacillus Brevis	C-H stretching C-C

FTIR, or Fourier transform infrared spectroscopy, is the most used method for analyzing the aging of polymers produced by ultraviolet irradiation. It is popular, quick, and accurate in its operation. The infrared spectrum indicates the presence of functional groups, such as carbonyl groups, which were created from polymer radicals produced during the degradation process. (Ville M., et, 2015). This investigation investigated several physical and mechanical features of particle boards that have been created utilizing wood waste and recycled polystyrene combined with acetone and impregnated with PCM with the same concentration but according to different densities. The results of this study were presented in the form of a comprehensive analysis. The Fourier transform infrared (FTIR) technique was used to analyze the microstructure and components of the particleboard sample.

After mixing rubber sawdust with differing densities of 0.6 g/cm^3, 0.7 g/cm^3, and 0.8 g/cm^3, the FTIR spectrometer detected the various functional groups in the sawdust. This allows for the identification of the various functional groups. Table 2 provides a list of the functional groups that are present in composite rubber wood that has PS as the binder and PCM that has been impregnated. The graph and vertices based on the figure located above are related to this table. Inorganic phosphates and aliphatic hydrocarbons are two examples of functional groups included in the list.

Table 2 also displays the FT-IR peak of the primary functional group of rubber sawdust, as found in the previous sentence. According to this peak, three compounds are present in inorganic phosphate that can be regulated because of the discovered primary functional groups. Chlorophenylthio and potassium phosphate are the compounds in question. Chloromethyl 4-chlorophenyl sulphide peaks at 1098.84 cm-1, whereas chloromethylthio peaks at 1001.84 cm-1 and 2602.47 cm-1. These three chemicals are connected in some way. Hexane and aldehyde are two examples of chemicals that fall under the group of aliphatic hydrocarbons. Both of these compounds exhibit a peak on the C-H stretch bond that ranges from 1467.14 cm-1 to 736.21 cm-1 of wavelength. These molecules are examples of hydrocarbons belonging to the aliphatic group. When they are in their respective forms, these two compounds are examples of aliphatic hydrocarbons. Not only is there the leading aliphatic hydrocarbon functional group, but other compounds are also regarded as members of the aliphatic hydrocarbon functional group. One of these chemicals is called gramicidin, obtained from Bacillus brevis. The peak of the Gramicidin molecule may be found on the C-C stretching bond at a frequency of 2841.60 cm-1.

At some time in their careers, infrared spectroscopists will undoubtedly come across various compounds, including aliphatic groups. This consists of a wide range of chemicals. The vibrational modes that include distorted C-H bonds are the ones that provide the most tremendous

significance. Atoms directly bound to aliphatic groups can bring about significant increases or decreases in frequency. When atoms with a high electronegativity are located close to one another, it results in a rearrangement of the band, particularly with regard to higher frequencies.

4.2 WOOD COMPOSITE (PHYSICAL TESTING)

4.2.1 Moisture Content

According to the IS3087 standard, the moisture content of particle board should be between 5% and 15%. Any number that exceeds the specified range would influence the board's size, both linearly and vertically (Harshavardhan & Muruganandam, 2017). If the moisture content were low, the board would flex evenly, but the board's strength would be compromised if the moisture concentration was excessive. The values for the board created from rubber wood dust were provided in the table, and they included polystyrene and palmitic acid, as shown by moisture content figures. The particle board with polystyrene as a binder and PCM-impregnated density of 0.8g/cm^3 had the lowest total moisture content.

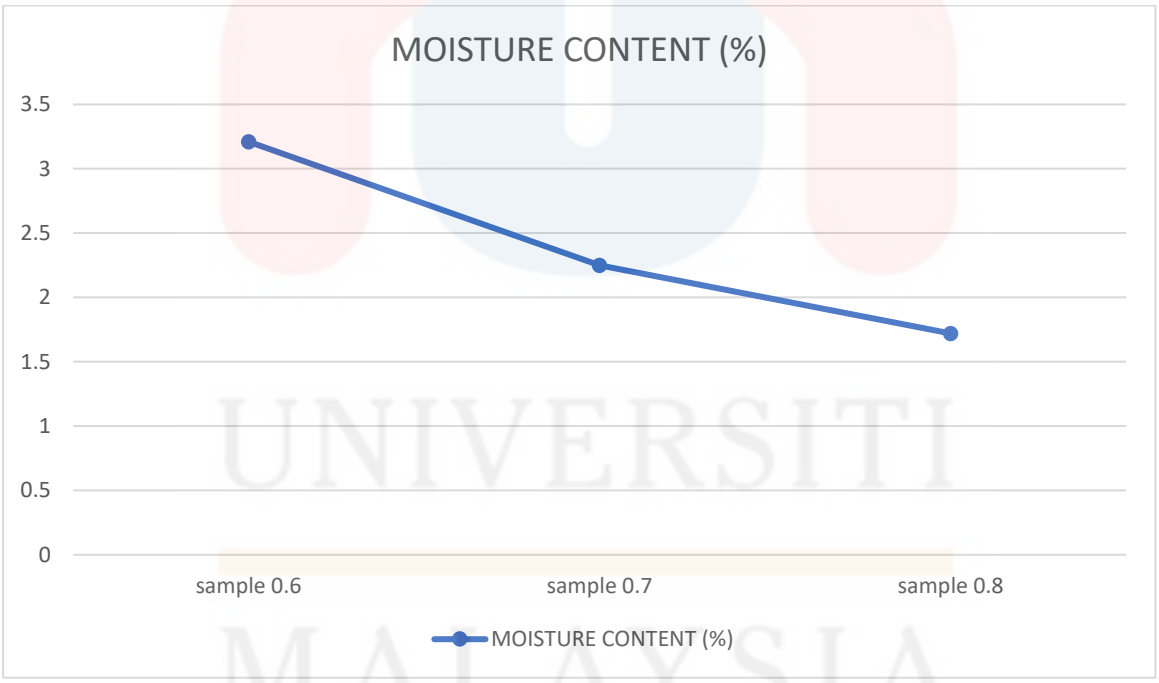


Figure 15: Show the graph of moisture content of sample density 0.6 g/cm^3, 0.7 g/cm^3 and 0.8 g/cm^3

Table 3: The moisture content (%) of three sample

Sample (g/cm^3)	Moisture content (%)
Density 0.6	3.21
Density 0.7	2.25
Density 0.8	1.72

Table 3 shows the moisture content data for all three samples. This test can determine how much water content has been lost in a sample by baking it in the oven for 24 hours with polystyrene as a binder and PCM impregnated and then weighing it. The received data will then be computed using the MC formula to determine how much moisture content has changed. The most excellent moisture content was density $0.8 g/cm^3$ with 1.72%, followed by density $0.7 g/cm^3$ with 2.25%, and $0.6 g/cm^3$ concentration had the highest MC with 3.21%, as indicated in Table 3.

This occurs because the sample density of $0.8 g/cm^3$ minimizes the free space in the particle board and lowers the sample's initial moisture content, which happens over time (Antônio, Amélia G, 2015). Combining these components explains the link between moisture content and density in particle board using polystyrene as a binder and impregnated with phase change material (PCM). The kind of binder and manufacturing technique influence particle board's moisture content and density. In research aimed at producing particle boards utilizing polystyrene as a binding medium, it was discovered that the moisture content of the particle board drops as density rises, as shown in the $0.8 g/cm^3$ sample with a moisture content of 1.72%. This suggests that increased density reduced moisture content in the particle board. PCM inclusion may have an even more significant impact on the relationship between moisture content

and density, much as PCM impregnation can change the particle board's total moisture absorption and release capabilities.

The overall connection between moisture content and the density of a substance provides information. This demonstrates that a material's moisture content influences its water conductivity, which is connected to its thickness. Furthermore, the density of composite boards varied with moisture content, demonstrating the dependency of these two parameters (Idehai O. Ohijeagbon, Adekunle A., et al., 2020).

In summary, the connection between moisture content and density in particleboard with polystyrene as a binder and PCM impregnation is that increased density corresponds to lower moisture content. This connection is impacted by the binder type, manufacturing technique, and the PCM's impregnation capability.

4.2.2 Density of Particle board

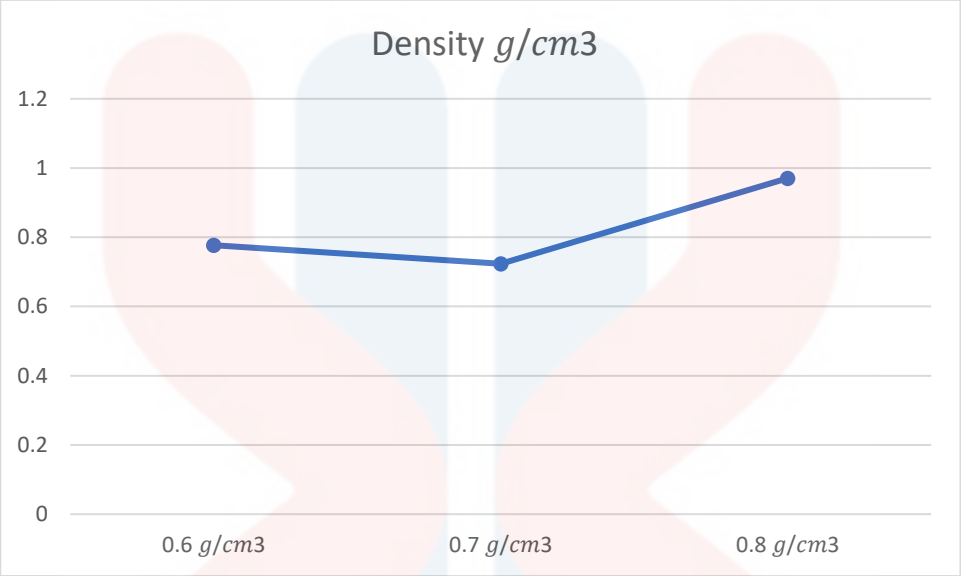


Figure 16: The graph of density for sample $0.6g/cm^3$, $0.7g/cm^3$ and $0.8g/cm^3$

Table 4: the initial and weight after for sample $0.6g/cm^3$, $0.7g/cm^3$ and $0.8g/cm^3$

Sample (g/cm^3)	**Initial weight (g)**	**Final weight (g)**	**Density (g/cm^3)**
Density 0.6	20.59	19.95	0.7774
Density 0.7	23.62	23.10	0.7234
Density 0.8	30.71	30.19	0.9704

After being placed in an oven for 24 hours at 100°C, the final weight of all three samples decreased, as shown in Table 4. Compared to the 0.6 g/cm^3 sample, which saw a weight decrease of 0.64g, the 0.7 g/cm^3 sample and 0.8 g/cm^3 exhibit the same amount of weight loss, which is reduced by 0.52g.

The density percentages for samples with densities of 0.6 g/cm^3, 0.7 g/cm^3, and 0.8 g/cm^3 are shown in the graph in the figure. As can be seen, 0.7 g/cm^3 has the best density to use the characteristics of the material used, which results in the material's thermal properties changing. Compared to the 0.6 g/cm^3 and 0.8 g/cm^3 samples, the performance of the 0.7 g/cm^3 sample in terms of the correct and suitable material ratio showed fewer desirable findings. The decrease in the total percentage density of the particle board is due to the combination of PCM, which has a high capacity for energy storage, and PS, which is a lightweight material. There is also the possibility that the material used changes the quality of the material, as described earlier, which in turn increases the percentage obtained.

According to Table 4, the density of 0.6 g/cm^3 receives a relatively high proportion compared to the actual density, resulting in 0.7774% of the total. The reason for this is that it is highly likely that the sample has an excess content, which leads to a higher content of materials, including PCM.

As a result, the density percentage of sample 0.6 g/cm^3 and sample 0.8 g/cm^3 is somewhat excessive compared to the percentage of sample 0.7g/cm3, which is 0.7234%. The excessive density of particle board with polystyrene binder may be caused by several variables, including those associated with density; however, the difficulty in establishing a uniform distribution of the polystyrene (PS) matrix throughout the board is another possible explanation. Samples with lower density may have difficulty integrating and maintaining PCM uniformly throughout the material, resulting in a lower overall proportion of PCM in the final product. It is essential to balance the density and content of PCM and PS content as needed to maximize the thermal characteristics of the composite material. This will ensure that the composite material can store and release heat effectively for specific applications.

4.2.3 Thickness Swelling

Before immersed in water	After 1 hour	After 2 hours	After 24 hours

Figure 17: The changes that occur in each wood sample after being soaked in water

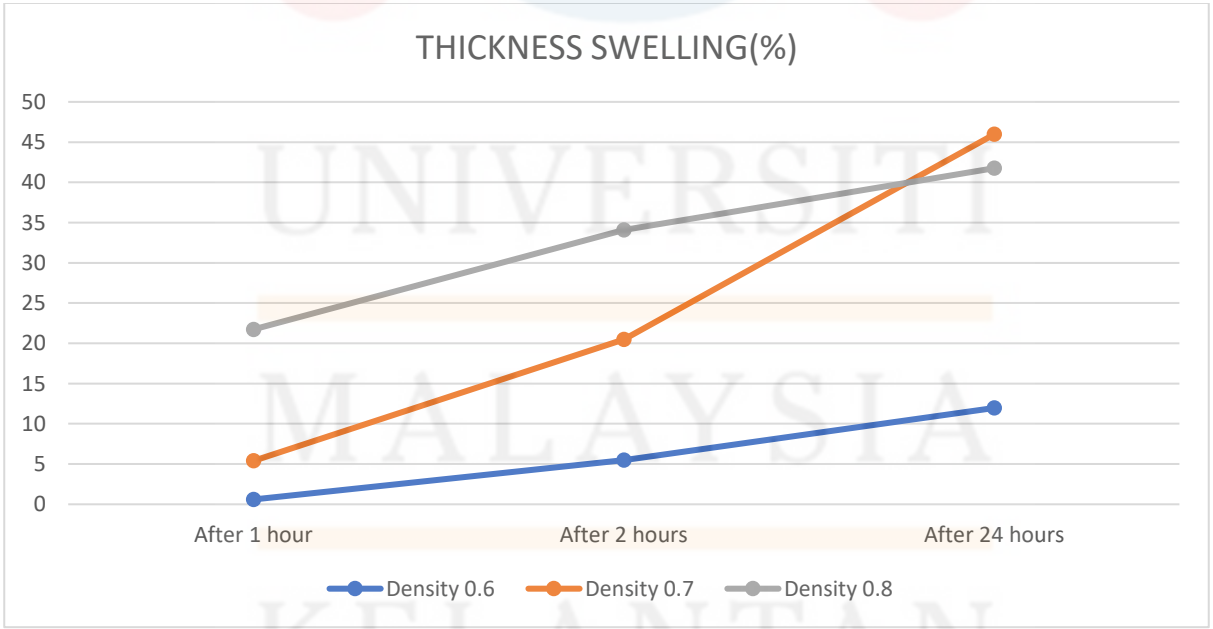


Figure 18: The graph of thickness swelling percentage for sample $0.6g/cm^3$, $0.7g/cm^3$ and $0.8g/cm^3$

Table 5: The percentage of thickness swelling data of sample $0.6g/cm^3$, $0.7g/cm^3$ and $0.8g/cm^3$

	After 1 hour (%)	**After 2 hours (%)**	**After 24 hours (%)**
Density 0.6	0.598	5.484	11.964
Density 0.7	5.391	20.485	45.967
Density 0.8	21.729	34.087	41.761

One of the indications used in testing to determine whether or not particle board may be used for interior and exterior purposes is the thickness of the expansion. After the test sample has been submerged in water at room temperature for 1 hour, 2 hours, and 24 hours, the value of the thickness expansion itself is the entire increase in the thickness of the test sample compared to its starting dimensions. Because the mechanical qualities of particle board have reduced and could not persist for a long time, it is not suited for use outside because it has a high thickness expansion, which shows that it has poor dimensional stability.

According to the findings of the tests, the average value of the expansion of rubber wood particle board thickness at the adhesive rate is the same, which is 15%. However, the density is different, which is $0.6g/cm^3$, $0.7g/cm^3$ and $0.8g/cm^3$. After twenty-four hours, the maximum thickness of the board is 1.755 cm from sample $0.6g/cm^3$. A possible explanation is that the particles contain extractive chemicals, which are thought to cause this phenomenon. An increase in the adhesive rate from particle board results in a decrease in the thickness expansion value. In line with the view of Kartika and Pratiwi (2018), which states that the quantity of adhesive that can cover the pores of the material increases in proportion to the amount of adhesive applied to

the material. On the other hand, the ratio for each material in the samples that were supplied is the same, and based on the density value that was calculated, it is believed that a small quantity of material is preferable to an excessive amount of the primary material, such as the $0.8g/cm^3$ sample. This demonstrates that the binding between the particles is more densely intertwined and adequately formed, making it more difficult for water to penetrate the particle board with sufficient adhesive.

After that, the analysis findings for samples $0.7g/cm^3$ and $0.8g/cm^3$ had a significant impact on the particle board, and this was even more apparent after two hours when the particle board was almost destroyed due to chattering in the water. However, due to the high expansion value of particle board thickness, it is unsuitable for outdoor applications. This is due to the product's poor stability, which may impact its mechanical qualities, which can experience a significant decline in a concise amount of time. Due to the high thickness expansion values like samples $0.7g/cm^3$ and $0.8g/cm^3$, the particle board samples created due to this study are not acceptable for external applications. This is because the sample are very thick. (Cengiz Guler, 2022) In conclusion, the stiff structure of the ratio, such as sample $0.6g/cm^3$, for particle board with high polystyrene, may restrict the change in geometric form, resulting in reduced water absorption and swelling thickness.

4.2.4 Water Absorption

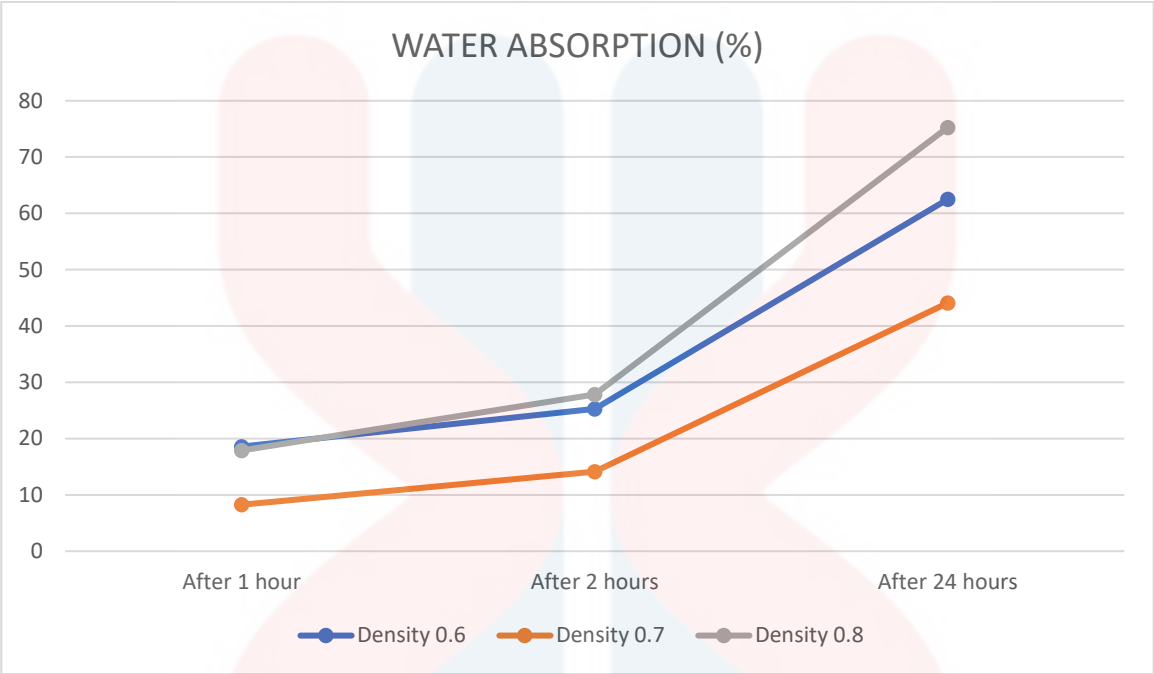


Figure 19: The graph of Water absorption percentage for sample $0.6g/cm^3$, $0.7g/cm^3$ and $0.8g/cm^3$

Table 6: Data for water absorption for 3 samples.

	After 1 hour (%)	**After 2 hours (%)**	**After 24 hours (%)**
Density 0.6	18.589	25.276	62.507
Density 0.7	8.251	14.145	44.086
Density 0.8	17.894	27.822	75.260

Figure 20: Particle board sample was immersed in water for water absorption for 1 hour, 2 hours and 24 hours.

Particleboard is often subjected to water absorption tests to assess the material's capacity to tolerate moisture and to ascertain how well it performs in wet situations. In addition to causing swelling and warping, excessive water absorption may destroy the particle board. This material is being used to gather information on the capabilities of particle board samples, including polystyrene as a binder and PCM impregnated on water.

At room temperature, three samples with densities of $0.6g/cm^3$, $0.7g/cm^3$ and $0.8g/cm^3$ were soaked in a container filled with water for 1 hour, 2 hours, and 24 hours, respectively—the samples measured 5 cm X 5 cm. Table 6 demonstrates that the absorption rate is sluggish from the first hour to the second hour for all three samples. Sample $0.6g/cm^3$ ranged from 22.43g to 23.79g, sample $0.7g/cm^3$ ranged from 27.55g to 29.05g, and sample $0.8g/cm^3$ ranged from 29.45g to 31.9g. The purpose of this test is to determine whether or not the materials that are being used are appropriate for the production of a product that is of high quality.

Based on rough look, the sample of $0.6g/cm^3$ demonstrates a stable combination that functions correctly, and there is no possibility of leaking on any of the particle boards. About the

physical structure, the density of $0.6g/cm^3$ is in a good and robust condition to be compared with the density of $0.7g/cm^3$ and $0.8g/cm^3$, where the sample structure has been altered since after two hours, and eventually, the $0.8g/cm^3$ sample is entirely soft after twenty-four hours. In addition, this can be shown in Figure 17, where the sample of $0.6g/cm^3$ is still in excellent condition after 24 hours, but the samples of $0.7g/cm^3$ and $0.8g/cm^3$ have expanded and broken. This sample becomes cracked and fractured due to considerable physical changes that occur due to the absence of bonding between the particles. It is also possible for this to happen when the absorption power is exceeded, which results in the structural holding power between the adhesive and sawdust being unable to be consolidated owing to the maximum concentration of absorption power.

However, the percentage rate found in table 6 it shows that the best peritus obtained from the second sample of density 0.7 g/cm^3, where after 24 hours, the sample obtained the lowest percentage value which is 44.086% compared to the 0.6 g/cm^3sample, which is 62.507% followed by the sample with the highest percentage which is 75.260%.

According to Hendri Nurdin, 2023, who authored an essay on particle board in conjunction with Nipah trees, samples with a high particle value compared to fillers and binders that might cause particle board thickness to occur will produce significant water absorption as found in the 0.8 g/cm^3 sample. Both of these factors can cause the thickness of the particle board to occur. Despite this, the three samples with densities of $0.6g/cm^3$, $0.7g/cm^3$ and $0.8g/cm^3$ may still be used. The sample with the lowest water absorption capacity can be used for outdoor furniture, while the sample with the highest can be used for interior spaces.

Furthermore, the cracks in samples $0.7g/cm^3$ and $0.8g/cm^3$ may be caused by a lack of adhesive and an excessive amount of sawdust, which both cause water to continue to be absorbed by the sample and result in imperfect leakage.

4.3 WOOD COMPOSITE (MECHANICAL TESTING)

4.3.1 Bending Strength

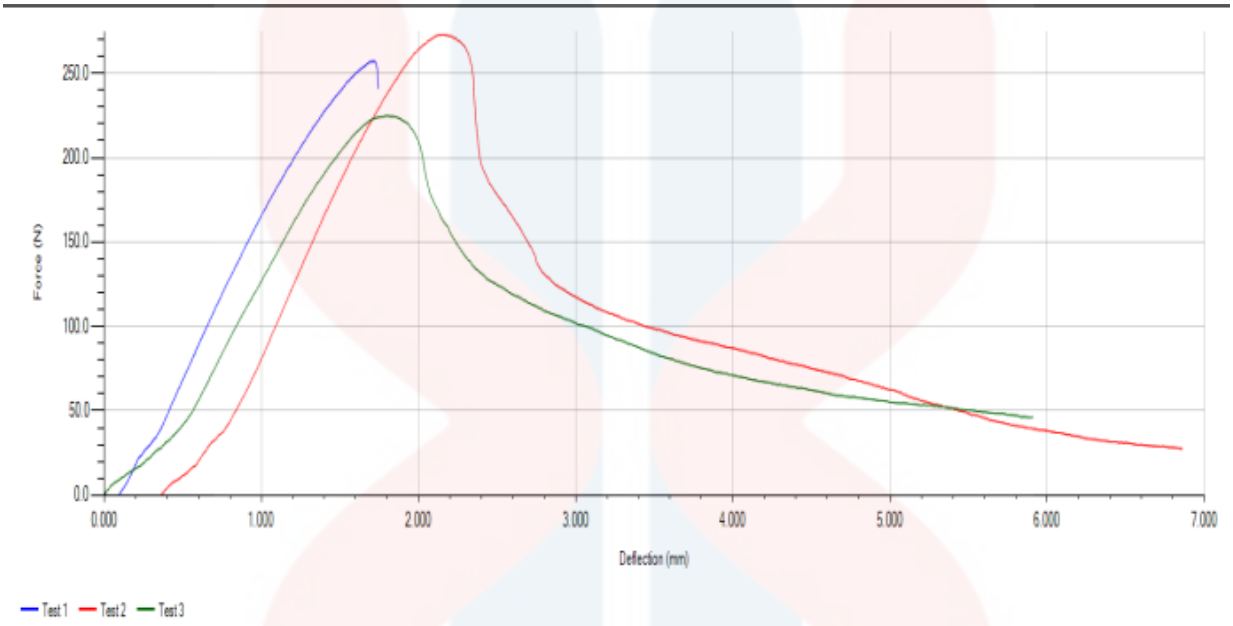


Figure 21: Bending graph of polystyrene as a particle board binder with PCM impregnated density $0.6g/cm^3$, $0.7g/cm^3$ and $0.8g/cm^3$.

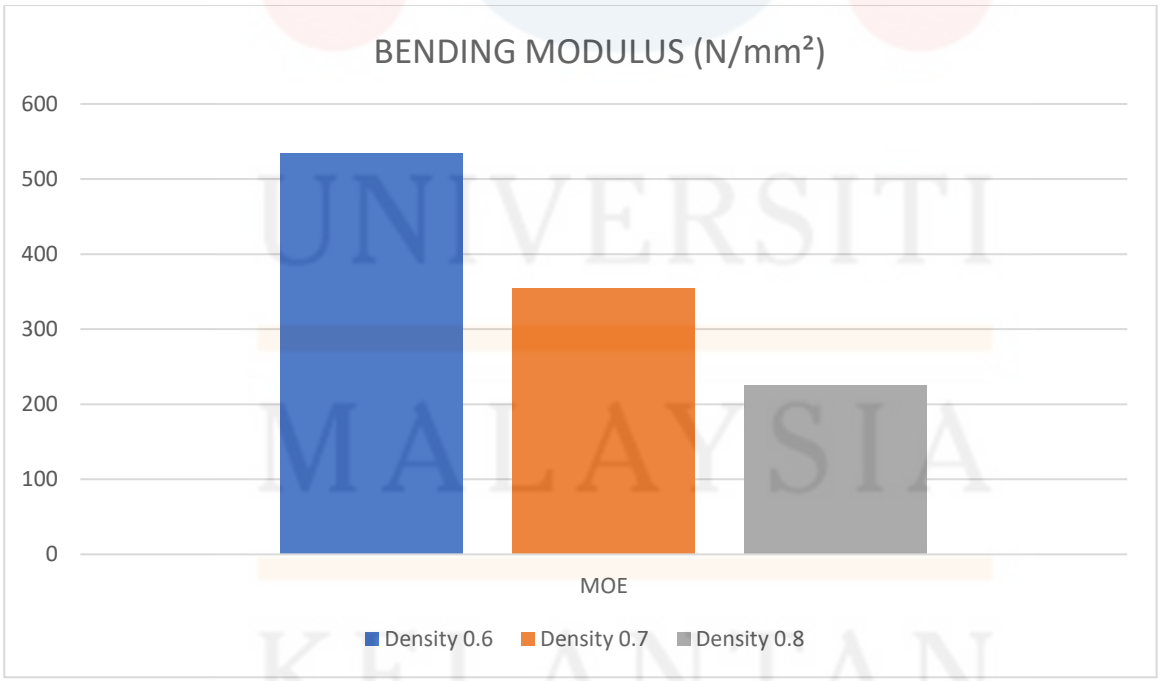


Figure 22: Bending modulus graph for sample $0.6g/cm^3$, $0.7g/cm^3$ and $0.8g/cm^3$

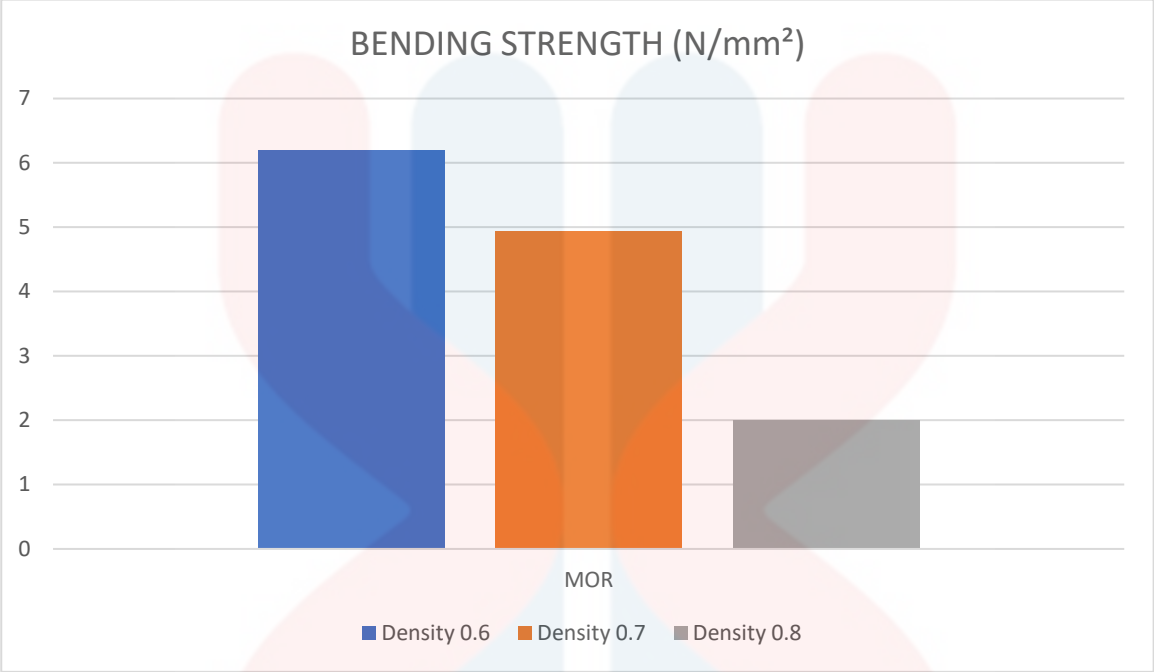


Figure 23: Bending strength @ peaks for sample $0.6g/cm^3$, $0.7g/cm^3$ and $0.8g/cm^3$

Table 7: Bending data of polystyrene as a particle board binder with PCM impregnated density $0.6g/cm^3$, $0.7g/cm^3$ and $0.8g/cm^3$.

Test No	Bending Modulus (N/mm²)	Bending strength @ Peaks (N/mm²)
0.6	534.729	6.198
0.7	354.303	4.938
0.8	225.433	3.272

Figure 24: Particle board sample for bending test

The bending strength of three distinct particle board samples was evaluated, as seen in Figure 21. These samples included about 5% palmitic acid (PCM), 15% polystyrene as a binder and 80% rubberwood sawdust. A different density capacity characterized each of the samples. Figure 17 displays the graphs for samples $0.6 g/cm^3$, $0.7 g/cm^3$ and $0.8 g/cm^3$ to illustrate the data.

As shown in Table 7, sample $0.6 g/cm^3$ exhibits the most prominent peak, 6.198 N/mm. This is followed by samples $0.7 g/cm^3$ and $0.8 g/cm^3$ exhibiting 3.272 N/mm. The sample also breaks the quickest, which is the $0.6 g/cm^3$ sample. The most significant quantity of polystyrene is likely collected in the sample's central region, and this accumulation is not distributed uniformly to the other areas of the sample, which results in the sample breaking rapidly in a matter of seconds. This is because polystyrene that has been heated and dried in the same manner as glass produces a material readily broken when a load crushes it. In the longitudinal direction, the corrugated core sample will fail owing to muscular tension and will not be able to sustain the

composite's strength when exposed to a four-point bending stress. The three samples are subjected to the same test speed, 5.000 mm/min.

The highest result for bending modulus is 534.729N/mm, which belongs to sample $0.6 g/cm^3$. This value is comparable to bending strength @ peak at 6.198N/mm, the ratio value most likely to be employed in producing particle boards. It is quite probable that the outcomes of this test will be accurate and satisfactory because the thickness of every sample is the same, which is 1 cm, throughout the production process.

Therefore, the value of the polystyrene adhesive that was used may be an efficient coupling agent to strengthen the strength of the connection between the strands (Hermawan A. et al., 2010). In addition, the particle board bending characteristics of the sample are $0.6 g/cm^3$ levels lower than those of other samples.

CHAPTER 5

5 CONCLUSSION AND RECOMANDATION

5.1 CONCLUSION

The implications of this research extend far beyond the laboratory, holding promising applications in sustainable construction and material engineering. Through the strategic selection of particleboard density, manufacturers can finely tune properties to address specific needs, including moisture resistance, structural strength, and dimensional stability. The comprehensive thermal and chemical analyses, encompassing TGA, DSC, and FTIR, offer profound insights into the material's behavior under diverse conditions, paving the way for advanced functionalities in particleboard design.

The standout performance of sample 0.8 g/cm^3 in moisture content positions it as a viable option for environments with fluctuating humidity, crucial for maintaining dimensional stability. Sample 0.7 g/cm^3, excelling in density and water absorption, showcases adaptability across scenarios, suggesting versatility from furniture manufacturing to building materials. The incorporation of PCM impregnation adds a dynamic element, potentially enabling temperature regulation within enclosed spaces for energy-efficient structures.

However, the exceptional moisture content performance of sample 0.8 g/cm^3may stem from an abundance of sawdust, highlighting the importance of considering overall material composition. Additionally, practical water absorption testing introduces a real-world perspective, favoring sample 0.6 g/cm^3 over 0.7 g/cm^3, showcasing the nuanced nature of material behavior. This underscores the need for a holistic evaluation, bridging laboratory insights with practical scenarios to ensure materials meet the diverse demands of real-world environments.

In conclusion, this study not only illuminates the promising qualities of particleboards made with polystyrene as a binder with PCM impregnation but also opens avenues for future research and innovation in eco-friendly materials. The nuanced approach to density optimization presented here serves as a foundation for developing advanced materials that align with the dynamic requirements of modern industries, contributing to a sustainable and adaptable future in construction and engineering.

5.2 RECOMMENDATION

Based on the comprehensive findings of this study, several recommendations emerge to guide future research and practical applications in the realm of particleboard production. Firstly, considering the significant impact of sawdust abundance on the exceptional moisture content performance of sample 0.8 g/cm^3, it is recommended to optimize the material composition. Future research should delve into achieving a balanced mix of raw materials, ensuring an optimal interplay between components like polystyrene and sawdust for consistent and reliable outcomes.

Secondly, the observed discrepancy between controlled water absorption testing and real-world observations suggests the importance of incorporating practical scenarios in material evaluation. Future studies should emphasize field-testing to validate laboratory results, providing a more accurate understanding of material behavior in diverse environments. Thirdly, the nuanced approach to density optimization demonstrated in this study suggests that tailoring density for specific applications is crucial. Manufacturers should consider this approach to enhance the versatility of particleboards, aligning density with desired properties for applications ranging from furniture manufacturing to construction materials.

Moreover, the incorporation of PCM impregnation introduces a dynamic element to particleboard production. Future research should explore and fine-tune the potential applications

of PCM impregnation to regulate temperature within enclosed spaces, contributing to the creation of energy-efficient structures. To comprehensively assess the overall sustainability of particleboard production, conducting a Life Cycle Assessment (LCA) is recommended. This holistic approach considers environmental impacts from raw material extraction to end-of-life disposal, providing valuable insights for the development of truly eco-friendly materials. Lastly, fostering collaboration between researchers and industry stakeholders is essential. Engaging with manufacturers, architects, and construction professionals will facilitate the seamless transition of research findings into practical applications, ensuring that the developed materials align with industry standards and requirements.

In conclusion, these recommendations aim to refine the understanding of particleboard properties, optimize material composition, and promote the practical applicability of eco-friendly materials in diverse industries. Through continued exploration and collaboration, the field can advance towards sustainable practices in construction and material engineering.

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APPENDIX A

Table 8: The Experimental conditions and water loss for sample density 0.6 g/cm^3

Sample (g/cm^3)	Heating rate	Sample mass (g)	Purge gas	Temperature range	Water loss (%)
Density 0.6	10.00 Cmin/-1	0.0035	Nitrogen	30-700°C	2.7948
Density 0.7	10.00 Cmin/-1	0.0028	Nitrogen	30-700°C	5.9349
Density 0.8	10.00 Cmin/-1	0.0029	Nitrogen	30-700°C	3.9949

Table 9: The initial and final weight for sample density 0.6g/cm^3, 0.7g/cm^3 and 0.8g/cm^3

Sample (g/cm^3)	Initial weight (g)	Final weight (g)
Density 0.6	20.59	19.95
Density 0.7	23.62	23.10
Density 0.8	30.71	30.19

APPENDIX B

Table 10: The width, length and thick of three sample before, after 1 hour, after 2 hours and after 24 hours.

Sample (g/cm^3)	**0.6**	**0.7**	**0.8**
Width before (cm)	5.109	5.145	5.121
Width after (cm)	5.101	5.130	5.165
Length before (cm)	5.035	5.217	5.125
Length after (cm)	5.031	5.213	5.109
Thick before (cm)	1.0	1.193	1.180
Thick after (cm)	1.0	1.194	1.179
Density (g/cm^3)	0.7774	0.7234	0.9704

APPENDIX C

Table 11: Bending data for sample density $0.6 g/cm^3$, $0.7 g/cm^3$ and $0.8 g/cm^3$

Test No	Bending Modulus (N/mm^2)	Bending Strength @ Peak (N/mm^2)
0.6	534.729	6.198
0.7	354.303	4.938
0.8	225.433	3.272
Min	225.433	3.272
Mean	371.488	4.803
Max	534.729	6.198
S.D.	155.362	1.468

APPENDIX D

Table 12: Thickness swelling data of particle board for density $0.6 g/cm^3$, $0.7 g/cm^3$ and $0.8 g/cm^3$

Sample (g/cm^3)	**Initial thickness (cm)**	**After 1 hour (cm)**	**After 2 hours (cm)**	**After 24 hours (cm)**
Density 0.6	1.003	1.009	1.058	1.123
Density 0.7	1.113	1.173	1.341	1.658
Density 0.8	1.238	1.507	1.660	1.755

Table 13: Data for water absorption for 3 samples.

	Initial weight (g)	**After 1 hour**	**After 2 hours**	**After 24 hours**
Density 0.6	18.99	22.43	23.79	30.86
Density 0.7	25.45	27.55	29.05	36.67
Density 0.8	24.98	29.45	31.93	43.78