UNIVERSITI MALAYSIA KELANTAN

Recycled Polystyrene as The Binder For PCM-Impregnated Particleboard: Effect of Adhesive Percentage on The Physical and Mechanical Properties

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A reported submitted in fulfilment of the requirements for the degree of Bachelor of Applied Science (Forest Resources Technology) with Honours

FACULTY OF BIOENGINEERING AND TECHNOLOGY

UMK

2023

DECLARATION

I declare that this thesis entitled "Recycled Polystyrene as The Binder For PCM-Impregnated Particleboard: Effect of Adhesive Percentage on The Physical and Mechanical Properties" is the results of my own research except as cited in the references.

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ACKNOWLEDGEMENT

I am thankful for the beauty of Allah (SWT), who is the Most Gracious and Most Merciful. I was able to finish my paper with the divine help of Allah (SWT). With Allah's (SWT) help, I was able to keep going through many problems and finish this paper. I learned and grew a lot on this trip, both in school and in my daily life. I am very thankful to the Prophet Muhammad (SAW), whose lessons have always helped me figure out what to do with my life.

The people I met and worked with on this project were very helpful in helping me learn new things and get a better understanding of my thesis topic, which is "Recycled Polystyrene as The Binder For PCM-Impregnated Particleboard: Effect of Adhesive Percentage on The Thermal and Mechanical Properties."

Thank you to my study professor, Associate Prof. Madya Dr. Ts. Mohd Hazim Bin Mohamad Amini, for all the great advice he gave me and all the help he gave me with my project. Learning the best ways to do study and show results was an honour because he taught me them. I want to thank him very much for everything he has done for me. We really appreciate how nice and helpful he is.

Thanks also go to my classmates for helping me and being there for me. Finally, I want to say how grateful I am to my parents for giving birth to me, caring for me, and helping me with my studies. Their unending love, prayers, care, and sacrifices have made me ready for what's to come. Finally, I want to thank all the lab helpers who helped me with my experiment and everyone else who helped me finish my study.

Recycled Polystyrene as The Binder For PCM-Impregnated Particleboard: Effect of Adhesive Percentage on The Physical and Mechanical Properties

ABSTRACK

This research investigated the potential of utilizing phase change materials (PCM), specifically palmitic acid (PA), and recycled polystyrene (RPS) as a binder. This is one of the solutions to reduce excessive energy consumption and synthetic resins for the development of particleboard-based product. By creating wood composites mixed with 36g of PM and RPS to 10%, 15%, and 20%, we can analyse the qualities of sawdust impregnated with PA as the PCM and RPS as a binder assess the physical and mechanical properties of wood composites formed of rubber wood, PA and RPS. The evaluation involved the rubber wood sawdust test it is TGA, DSC, FT-IR and XRD, and wood composite testing it is bending test, density, moisture content, water absorption and thickness swelling. For example, the result found in this thesis is a test from the XRD test which is a 20% sample in the wood that has undergone the impregnation process, the degree of crystallinity is 33.3% which is caused by typically, a melt or diluted solution needs to be cooled below its melting point to become crystallized. The latter may cause single crystals to form. Stretching a polymer can also cause crystallization. Based on this research sawdust wood composite shows weakness in RPS15% sample due to the lack of presence of RPS, the composite is slightly weaker because of the pores the space produced through the test bet while the pore space produced for the sample mixed with RPS, seen in results such as bending, tensile, and others, showing the wood composite to be stronger to hold sawdust in composite production.

Keywords: Phase Change Material, Rubber wood Sawdust, Palmitic acid, and rubber wood sawdust test.

Polistirena Kitar Semula sebagai Pengikat Untuk Papan Zarah PCM-Diresapi: Kesan Peratusan Pelekat pada Sifat Fizikal dan Mekanikal

ABSTRAK

Penyelidikan ini menyiasat potensi penggunaan bahan perubahan fasa (PCM), khususnya asid palmitik (PA), dan polistirena kitar semula (RPS) sebagai pengikat. Ini adalah salah satu penyelesaian untuk mengurangkan penggunaan tenaga yang berlebihan dan resin sintetik untuk pembangunan produk berasaskan papan zarah.Dengan mencipta komposit kayu bercampur dengan 36g PA dan RPS hingga 10%, 15%, dan 20%, kita dapat menganalisis kualiti habuk papan yang diresapi dengan PA sebagai PCM dan RPS sebagai pengikat menilai sifat fizikal dan mekanikal komposit kayu yang terbentuk daripada kayu getah, CA dan RPS. Penilaian melibatkan ujian habuk papan kayu getah iaitu TGA, DSC, FT-IR dan XRD, dan ujian komposit kayu ia adalah ujian lenturan, ketumpatan, kandungan lembapan, penyerapan air dan bengkak ketebalan. Sebagai contoh, hasil yang terdapat dalam tesis ini adalah ujian dari ujian XRD yang merupakan sampel 20% dalam kayu yang telah menjalani proses impregnasi, tahap kekristalan adalah 33.3% yang disebabkan oleh biasanya, larutan cair atau cair perlu disejukkan di bawah takat leburnya menjadi terhablur. Yang terakhir ini boleh menyebabkan kristal tunggal terbentuk. Regangan polimer juga boleh menyebabkan penghabluran. Berdasarkan kajian ini komposit kayu habuk papan menunjukkan kelemahan dalam sampel 15% kerana kekurangan kehadiran RPS, komposit sedikit lebih lemah kerana liang-liang ruang yang dihasilkan melalui taruhan ujian manakala ruang liang yang dihasilkan untuk sampel bercampur dengan RPS, dilihat dalam hasil seperti lenturan, tegangan, dan lain-lain, menunjukkan komposit kayu menjadi lebih kuat untuk memegang habuk papan dalam pengeluaran komposit.

Kata kunci: Bahan Perubahan Fasa, Habuk Papan getah, Palmitik Asid, dan ujian habuk papan kayu getah.

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CHAPTER 1

INTRODUCTION

1.1 Background of Study

Adding phase change materials (PCMs) to building materials has gotten a lot of attention lately because it could make them more energy efficient in many situations, like building construction and thermal energy storage systems (Cui, 2017). With their special ability to store and release thermal energy during phase changes, PCMs help structures better control temperature and save energy (Zhang et al., 2018).

Particleboard has been used a lot in building materials because it can be used in many ways, is cheap, and is good for the earth. The glue that is used in particleboard is very important to its general function and dynamic qualities. Synthetic resins and other traditional binders have been used a lot in the production of particleboard, but there is growing interest in finding more environmentally friendly options that are in line with the principles of the cycle economy.

One option that shows promise as a particleboard glue is recycled polystyrene (RPS), which is easy to find in post-consumer trash and works well with many other materials. RPS has been used successfully in other situations, showing that it could be used as an eco-friendly glue (Martínez-Sanz et al., 2019; Zhang et al., 2021).

But not much research has been done on how RPS can be used as a binding for PCM-impregnated particleboard or how the amount of glue affects the final product. The goal of this study is to fill in that gap by looking into what happens to the thermal and dynamic qualities of PCM-impregnated particleboard when the amount of recovered polystyrene in the glue changes. It is important to know how different amounts of RPS affect the composite material's general performance in order to make the best recipe for its use in building and energy storage.

This study adds to what is known about environmentally friendly building materials and how to use phase change materials to make buildings more energy efficient. The results should help us figure out if it's possible to use reclaimed polystyrene as a glue in PCM-impregnated particleboard. This could lead to more environmentally friendly and energy-efficient building materials.

1.2 Problem Statement

In Malaysia, the increased demand for wood composite shelving and cabinets, specifically particle boards, is motivated by attributes including durability, robustness, and economical pricing. On the contrary, the traditional application of synthetic polymers as binder materials in the production of particleboard gives rise to ecological apprehensions on account of their finite resources and possible enduring consequences. Moreover, the woodworking sector produces a considerable volume of waste, among which polystyrene occupies a substantial portion of landfill capacity. Given the environmental impact of synthetic polymers and the escalating waste management issue associated with polystyrene disposal, this highlights the need for a more sustainable and environmentally friendly alternative in the production of particleboards. One possible approach to address these concerns is to replace conventional synthetic polymers used as particleboard binders with recycled polystyrene.

To address this concern, the investigation would entail the formulation of particleboard samples incorporating recycled polystyrene as the binder and the subsequent adjustment of the adhesive concentration during production. The mechanical and physical properties of the produced particleboard will be compared in order to determine the optimal adhesive percentage for producing particleboard with the desired properties. This transition not only acknowledges the ecological consequences of resin utilisation but also repurposes byproducts, thereby conforming to sustainability objectives. The integration of recycled polystyrene into particleboard production enables the company to deliver a product that is more ecologically sustainable while maintaining its mechanical integrity. In addition, the incorporation of palmitic acid or alternative phase change materials can augment the thermal capabilities of the particleboard, thereby offering supplementary advantages including energy conservation and temperature control.

By incorporating palmitic acid or phase change materials into particleboard formulations, their thermal properties can be significantly improved. These substances possess the capacity to both absorb and discharge thermal energy during phase transitions, thereby facilitating enhanced indoor temperature regulation. Through the integration of phase change materials, particleboard has the capability to function as a thermal energy storage medium, thereby offering the furniture industry energy-efficient solutions. The study's results indicate that implementing phase change materials and substituting recycled polystyrene for synthetic resins as a binder offers a comprehensive and sustainable approach to mitigate environmental issues, increase the functionality of particleboards on the Malaysian market, and decrease waste.

1.3 Expected Output

One new element of the research is the use of recycled polystyrene in particleboard manufacture together with palmitic acid as a phase transition material. Incorporating palmitic acid into particleboard is part of a larger plan to evaluate the physical and chemical characteristics of particleboard made from recycled polystyrene, with the hope of improving its thermal qualities. With a new emphasis on thermal performance, this study aims to thoroughly assess weight % increase, anti-swelling efficacy, water absorption, bulk impact, and density.

The thermal performance of the particleboard is anticipated to be improved by the addition of palmitic acid, a phase transition compound. During phase transitions, the phase change material may absorb and release heat, making it a possible thermal energy storage medium. This has the potential to increase the particleboard's insulating characteristics by lowering its heat conductivity. In order to find the best combination that enhances thermal performance while maintaining other important features, this research will examine how recycled polystyrene, palmitic acid, and acetone as a binder interact with one another.

Moreover, the study will evaluate the effect of adhesive % on particleboard qualities and investigate the properties of wood composites manufactured from recycled polystyrene. Insights into the particleboard's overall performance, durability, and safety should be provided by the predicted outcomes, allowing makers, builders, and customers to make educated decisions. According to the study's main goals, the results will help figure out if the material is good for a variety of uses in building, furniture, and other sectors.

1.4 Objective

i. To study the impact of different recycled polystyrene adhesive concentrations on the physical and mechanical properties of PCM-impregnated particleboard.
ii. To investigate the thermal performance enhancement achieved by incorporating palmitic acid into the particleboard formulation.

1.5 Scope of Study

The production of particleboard using rubberwood as the primary component is the subject of this investigation. An eco-friendly binder called recycled polystyrene (RPS) and a phase change material (PCM) called palmitic acid are used in this process. Contributing significantly to the field of sustainable building materials, the research aims to investigate the thermal and mechanical properties of the manufactured composite. In keeping with the goal of promoting sustainable practices in the woodworking industry, rubberwood is used, as it is both easily available and environmentally conscientious. Both the environmental problems associated with traditional synthetic resins and the challenge of properly disposing of polystyrene waste are handled when RPS is used as a binding agent.

The use of palmitic acid as a phase change material (PCM) is also an investigation into the particleboard's potential as a medium for thermal energy storage, with the goal of improving its thermal efficiency. The mechanical properties of the particleboard will be investigated in detail as a function of the adhesive concentration in recycled polystyrene.

Additionally, it will assess the improvements in thermal efficiency that were achieved by including palmitic acid into the combination. Finding out how using rubberwood, recycled polystyrene, and palmitic acid in particleboard production works and what kind of improvements are possible is the main goal of this study. This substitute might be a good fit for the building and furniture industries because to its sustainability and energy efficiency.

1.6 Significance of Study

In the course of its investigation into the production of particleboard, this study analyses the possibility of including recycled polystyrene (RPS) as a binder and palmitic acid as a phase change material (PCM). Both of these are environmentally friendly alternatives. Traditional methods of manufacturing particleboard, which include the use of synthetic resins that are not renewable, are responsible for the creation of environmental issues. This research investigates the use of RPS, a binder generated from post-consumer waste, as an alternative to regular resins in order to address the environmental challenges that are created by the usage of traditional resins.

As an additional benefit, the incorporation of palmitic acid as a PCM into particleboard results in the inclusion of a new functional dimension. As a result of its capacity to retain heat, palmitic acid has the potential to improve thermal performance and make it simpler to maintain a temperature that is pleasant inside interior situations. The purpose of this study is to examine the mechanical properties, thermal conductivity, and overall performance of a particleboard that is made up of recycled polystyrene, palmitic acid, and rubberwood. The findings should throw light on the possibilities of this new particleboard composition, which, according to the research, might be an alternative that is more environmentally friendly and energy-efficient for the construction and furniture industries. The research that was carried out here is in keeping with the present global trend towards environmentally friendly construction practices, the implementation of ideas connected to circular economies, and the search for innovative methods to tackling environmental challenges that are associated with woodworking.

CHAPTER 2

LITERATURE REVIEW

2.1 Rubber Wood (*Hevea Brasiliensis*)

Hevea brasiliensis, commonly referred to as rubberwood, is a substantial evergreen tree with the potential to attain a height of up to 40 meters. The tree features a straight trunk reaching a diameter of approximately 50 centimetres and branches out extensively at its apex, forming a dense canopy. Indigenous to Bolivia, Brazil, Colombia, Peru, and Venezuela, *Hevea brasiliensis* is classified as such (Yi Peng Teoh, 2011).

Rubber tree | Rubber tree latex | Rubber tree seed

Figure 2.1: Picture of rubber tree, latex, and rubber tree seed

2.2 Polystyrene

Polystyrene is a polymer that is widely sought after in a variety of scientific and industrial disciplines due to its peculiar properties and the many applications it has throughout the years. Polystyrene is a material that is often used for a variety of applications, including insulation, packaging, and the production of disposable goods (Andrady and Neal, 2009). According to Hantanasirisakul et al. (2017), one of the reasons polystyrene is one of the most widely used materials in the construction sector is due of its strong thermal insulation properties. Even though polystyrene has a wide range of applications, there are some people who are concerned about the impact that its production and disposal have on the environment. In light of the fact that polystyrene pollutes the environment and remains there for such a long period of time, it is imperative that a sustainable alternative to polystyrene be developed (Moussa and Khoury, 2018).

Research has been conducted to determine whether or not recycled polystyrene (RPS), which is produced from post-consumer waste, might be a viable solution to these issues. According to Martínez-Sanz et al. (2019), RPS offers a sustainable alternative by recycling and reusing resources, which is in accordance with the principles of the circular economy. According to Zhang et al. (2021), research has shown that RPS may be used in a range of applications, including as a binder in the production of particleboard. This demonstrates the material's potential to be employed in environmentally friendly applications. This literature review addresses the many applications of polystyrene, the environmental impacts that are associated with its conventional use, as well as the new developments in the use of recycled polystyrene as a more environmentally friendly alternative.

2.3 Recycled Polystyrene as a Binder for Particleboard

Researchers have investigated the possibility of mixing recycled polystyrene with traditional particleboard binder in an effort to make the product eco-friendlier and more long-lasting (Chen et al., 2018). In place of conventional binders such resins derived from formaldehyde, particleboards made from recycled polystyrene have better mechanical properties and produce less formaldehyde (Lee et al., 2019). Another way that recycled polystyrene helps the circular economy is by reducing landfill rubbish (Okajová et al., 2020).

2.4 Palmitic Acid as Phase Change Material (PCM)

Many people are interested in using palmitic acid, a medium-chain fatty acid with the molecular formula $C10H20O2$, as a phase change material (PCM) for thermal energy storage. The organic compound's ability to change its phase from solid to liquid at very low temperatures makes it an attractive material for thermal energy storage systems and construction materials (Mehling & Cabeza, 2008). Palmitic acid's beneficial phase change temperature and high latent heat of fusion make it an ideal PCM because of its capacity to absorb and release heat during phase transitions (Tyagi et al., 2015). The potential of palmitic acid to enhance the thermal performance of materials when incorporated into composites and to maintain a steady phase transition temperature were highlighted by research conducted by Sharma et al. (2015). The non-toxicity and compatibility of palmitic acid with different matrices further support its use for thermal energy storage in eco-friendly applications (Sharma et al., 2015; Alkan et al., 2016). According to the research, palmitic acid has the ability to have a big impact on thermal energy storage technology developments because of its adaptability and efficiency as a phase transition material.

2.5 Incorporation of Phase Change Materials (PCMs)

Because of their temperature-regulating and energy-storing abilities, phase change materials (PCMs) have recently attracted interest for use in particleboard manufacture (Wei et al., 2021). During phase transitions, PCMs may absorb and release latent heat, making them helpful in insulation and other related disciplines. Adding phase change materials (PCMs) to particleboards might make them more energy efficient and provide better thermal comfort (Dong et al., 2017). By using recycled polystyrene as a binder and PCM impregnation, it becomes feasible to produce thermally enhanced composites in an environmentally friendly manner.

2.6 Effect of Percentage Adhesive on Particleboard Properties

There has been a lot of research in the field of sustainable building materials on how the amount of glue, especially polystyrene, affects the characteristics of particleboard. As an alternative binder in particleboard manufacture, polystyrene has shown promise due to its adaptability and compatibility with different materials (Martínez-Sanz et al., 2019; Zhang et al., 2021). Scientists have investigated the effects of different adhesive concentrations in particleboard formulations on the material's mechanical properties, such strength, durability, and performance.

According to (Bi & Huang, 2021), particleboard's mechanical characteristics are heavily influenced by the kind and amount of adhesive used, which means that the binder choice and percentage greatly impact the board's strength and deformation resistance. In their 2020 study, Sarı et al. expanded upon this investigation by looking at how dimensional stability in particleboard is influenced by the proportion of adhesive. Their research shown that the concentration of adhesives has a pivotal role in reducing swelling and warping, two problems that are critical to the structural integrity of particleboard in the long run. Essentially, research highlights the importance of fully comprehending the impact of adhesive percentage on particleboard's basic characteristics, particularly when it comes from sustainable sources like polystyrene. This knowledge will enable the construction industry to formulate materials with greater knowledge and less environmental impact.

CHAPTER 3

MATERIALS AND METHOD

3.1 Material Preparation

A technique of producing particle boards that is less harmful to the environment was developed via a collaborative effort between researchers at Universiti Malaysia Kelantan and local producers in Jeli, Kelantan. After being cut, dried, and then crushed into particles that fell within a certain size range, the rubber wood (*Hevea brasiliensis*) that was supplied by local producers in Jeli was used. At the same time, the components of PCM (Phase Change Material), which comprised acetone and palmitic acid, were collected from the laboratory of the university, which was located at the Universiti Malaysia Kelantan Jeli Campus. Both of the processes that were employed to recycle acetone and polystyrene, two essential components of particle board, made use of the resources that were available at the institution. The components that were necessary for the completion of this research project were polystyrene, palmitic acid, acetone, and rubber sawdust. Through the use of rubber sawdust impregnation, a long-lasting particle board composite was produced. This was an essential component in the manufacturing process. X-ray diffraction, differential scanning calorimetry, Fourier transform infrared spectroscopy, and thermogravimetric analysis were used to characterise and evaluate the materials that were produced as a consequence.

3.2 Method

3.2.1 Preparation of Rubberwood Material Sample

Before being produced, the samples of rubberwood material were meticulously cleansed to ensure that there were no pollutants present. Rubberwood was hacked or chopped into very small pieces in order to produce the wood dust that was utilised in the production of particleboard. It was by hand that the rubber plants that were utilised to produce sawdust were selected. With the help of a meticulous drying process that took into consideration the natural moisture content of the wood, the high moisture content of rubberwood was brought down to a level that was appropriate for use in particleboard. Drying the rubberwood material samples that were collected, either by air drying or through the use of a kiln, was done in order to guarantee that they successfully met the required standards.

Figure 3.1: Preparation of dry rubberwood.

3.2.2 Preparation of Recycled Polystyrene

Polystyrene garbage was gathered from a broad range of items, including building waste, electronics, and packaging, among other things including construction debris. Polystyrene must be isolated from other materials throughout the collection process in order to ensure that recycling is carried out in the most efficient manner possible. This is because polystyrene has a unique mix of physical and chemical properties. Following the collection of the polystyrene, it was subjected to a mechanical shredding process using machinery specifically designed for recycling polystyrene.

After that, the shredded polystyrene was dissolved or diluted with acetone, which was the next step. Following that, it was mixed with rubber wood in a series of different proportions, ranging from ten percent to twenty percent. During the manufacturing process, the creation of this binder or solution was essential in order to guarantee that the polystyrene particles would continue to be cohesive. This, in turn, reinforced the overall structure and integrity of the recycled materials.

3.2.3 Preparation of PCM-impregnated Particleboard

Palmitic acid was first dissolved in acetone, which was the first step in the process. Following the complete dissolution of the palmitic acid, the subsequent stage consisted of thoroughly combining the palmitic acid with the rubberwood particles. It is possible to ensure that the palmitic acid is dispersed evenly throughout the particleboard to achieve this result. After all of the mixing was finished, the mixture was dried in an oven that was preheated to 45 degrees Celsius for a period of three hours. In order to produce a PCM-impregnated particleboard that was stable, it was required to dry the rubberwood particles. This was done in order to get rid of any excess moisture and to make the palmitic acid impregnation more solid.

3.2.4 Particleboard Making

For the purpose of sifting the rubberwood particles till they reached the desired size, a grinder machine was used. After that, the pieces of rubberwood were dried in an oven at 105 degrees Celsius for two hours in order to eliminate any moisture that was still present. After that, the polystyrene foam was either chopped or crushed into very small pieces in order to provide a more equal distribution of the foam throughout the particleboard. Polystyrene that had been melted was combined with palmitic acid (PCM) after being dissolved in acetone. Typically, it took between five and ten minutes for the components to be mixed together until they were dispersed equally throughout the mixture. Following that, the inclusion of the rubberwood particles into the overall mixture was carried out.

The completed mixture was placed into a particleboard mould or press that measured 30 centimetres by 30 centimetres by 1 centimetre. The density of each board was meant to be 0.8 grammes per cubic centimetre. A wide range of adhesive percentages, from ten percent to twenty percent, were used in the production of different batches. The mixture was dispersed and smoothed out in a regular manner inside the mould so that the board would have a density and thickness that were consistent throughout. In order to provide heat and pressure to the mould, a hot press or oven was used subsequent to this step. Immediately after a two-minute pre-pressing at 500kgcm^{-2}, the mat was heated to 150 degrees Celsius for ten minutes.

Following the completion of the pressing cycle, the particleboards were subjected to a process of cooling and curing under pressure. This was done to ensure that they were robust and unbroken at the end. Following the completion of the cooling process, the particleboards were removed from the press or mould.

Figure 3.2: Particleboard making from rubberwood and polystyrene.

3.3 Characterization

Rubber wood that had been impregnated with Phase Change Material (PCM) was the focus of one experiment and study. Among the techniques that were used in order to assess the impregnation process were leakage testing, thermal analysis/differential scanning calorimetry (TGA/DSC), Fourier-Transform infrared spectroscopy (FT-IR), and X-ray diffraction (XRD). The approach was followed in a scientific manner in order to define the form of the impregnated rubber wood as well as its physiochemical characteristics.

I. Thermogravimetric analysis (TGA) & Differential scanning calorimetric (DSC) (TGA/DSC)

The thermogravimetric analyser, often known as the TGA, was one of the most essential instruments for conducting material examination in the laboratory. In a wide variety of scientific fields, including those dealing with the environment, food, medicine, and petroleum, thermogravimetric analysis (TGA) was used to provide a description of a variety of chemicals. Position-independent weighing, the best minimum weight performance, the greatest weighing accuracy and precision, and an automated internal calibration weight throughout a wide measurement range are all possible outcomes that may be accomplished with the help of TGA/DSC weighing technology. Using the SDT Q600-TA Instruments, the TGA and DSC measurements were carried out at a rate of 10 degrees Celsius per minute from room temperature all the way up to 700 degrees Fahrenheit.

II. Fourier-transform infrared (FT-IR) machine

It is possible to investigate the composition of a substance using FTIR spectra regardless of whether the material is in a solid, liquid, or gaseous condition. Verifying materials that were entering and leaving the manufacturing facility, as well as detecting components that were unknown, were the most common kind of applications. As a general rule, the data was highly specific, which made it feasible to discern between items that seemed to be comparable by providing a greater level of specificity among them. During the course of this experiment, a powder sample was scanned using a Fourier transform infrared spectrometer (IRAffnity-1S) from 400 cm^{-1} to 4000 cm^{-1}.

III. X-ray diffraction (XRD)

The use of X-ray diffraction (XRD), which is a technique that does not involve any destruction, has become more popular as a method for characterising crystalline materials. By evaluating the average grain size, crystallinity, stretch, and crystal defects of a sample of wood, it was possible to get insights about the structure, phase, and crystal orientation of the wood. For the purpose of the investigation, we used a Cu K XRD machine (Rigaku model, Japan) operating at 35 Kv and 30 Ma to complete the scanning process, which ranged from 5 to 70 diffraction angles (2) per minute.

3.4 Evaluation of Properties of Particleboard

The physical and mechanical qualities of manufactured particleboards were discussed in the following chapters.

3.4.1 Moisture Content of Particleboard

The relative humidity was calculated following the technique outlined in the Japanese Standard (JIS A 5908, 2003). A minimum of twenty grammes of beginning weight was given by a piece of particleboard that was cut to dimensions of thirty millimetres by thirty millimetres. The sample was weighed both before and after it was dried in an oven that was set to 102 degrees Celsius for a whole night. This allowed for the determination of the sample's ultimate weight. It was necessary to repeat the technique once the final weight had reached a stable state. After doing the procedure three times, we collected the results and calculated the average of them.

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

Where m_H is the initial mass of the test piece in grams and m_0 is the mass of the test piece after drying in grams.

3.4.2 Density of Particleboard

Using the Japanese Standard (JIS A 5908, 2003) and a modified sample size, we were able to determine the density of particleboards. The thickness of the particleboards was reduced to 10 mm. Overnight, the test objects were placed in a conditioning chamber maintained at 25°C and 50% humidity. The analytical balance was used to determine the sample's density, and a calliper was used to remeasure the sample's dimensions. The density was determined by solving for x in the equation.

$$\text{Density } (\text{kg.m}^{-3}), \rho = \frac{m}{b_1 \times b_2 \times t}$$

Where m is the mass of test piece, b_1 is the width of test piece, b_2 is the length of test piece and t is the thickness of the test piece.

3.4.3 Thickness Swelling and Water Absorption of Particleboard

The extent to which particleboard swells when submerged in water was measured in accordance with Japanese Standard (JIS A 5908, 2003). We trimmed and conditioned 30 mm × 30 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 taken out of the water, the excess water was drained, and the pieces' new dimensions were measured. Samples were weighed in order to quantify the water absorption rate. The ability to swell in thickness and absorb water was determined using the following equation.

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

Where m_i is the weight of the wet material and m_0 is the weight of the dry material.

3.4.4 Bending Strength of Particleboard

The bending strength of particleboards was measured according to JIS A 5908, 2003, the Japanese Standard. A conditioning chamber was set up with 25 degrees Celsius, 50% relative humidity, and particleboards cut to 200 mm x 50 mm. An Instron 5582 tensile testing machine was used to examine the test piece. The tests were conducted at a loading rate of 10 mm/min. Both the modulus of elasticity and the bending strength were calculated using the equation.

$$E_m = \frac{l_1^3\ (F_2 - F_1)}{4\ bt^3\ (a_2 - a_1)}$$

Where,

modulus of elasticity = *E*m (in N/mm2)

l_1 is the distance between the centres of the supports, in millimetres.

B is the width of the test piece, in millimetres

t is the thickness of the test piece, in millimetres

$F_2 - F_1$ is the increment of load on the straight-line portion of the load-deflection curve, in N. F_1 shall be approximately 10 % and F_2 shall be approximately 40 % of the maximum load.

$A_2 - a_1$ is the increment of deflection at the mid-length of the test piece (corresponding to $F_2 - F_1$)

and bending strength

$$Bending\ strength, f_m\,(Nmm^{-2}) = \frac{3\ F_{max}\ l_1}{2\ b\ t^2}$$

Where

F_{max} is the maximum load, in newtons.

L_1, *b*, and *t* are in millimetres.

Figure 3.3: Bending test preparation.

CHAPTER 4

RESULT AND DISCUSSION

4.1 Wood Composite Testing

4.1.1 Bending Test

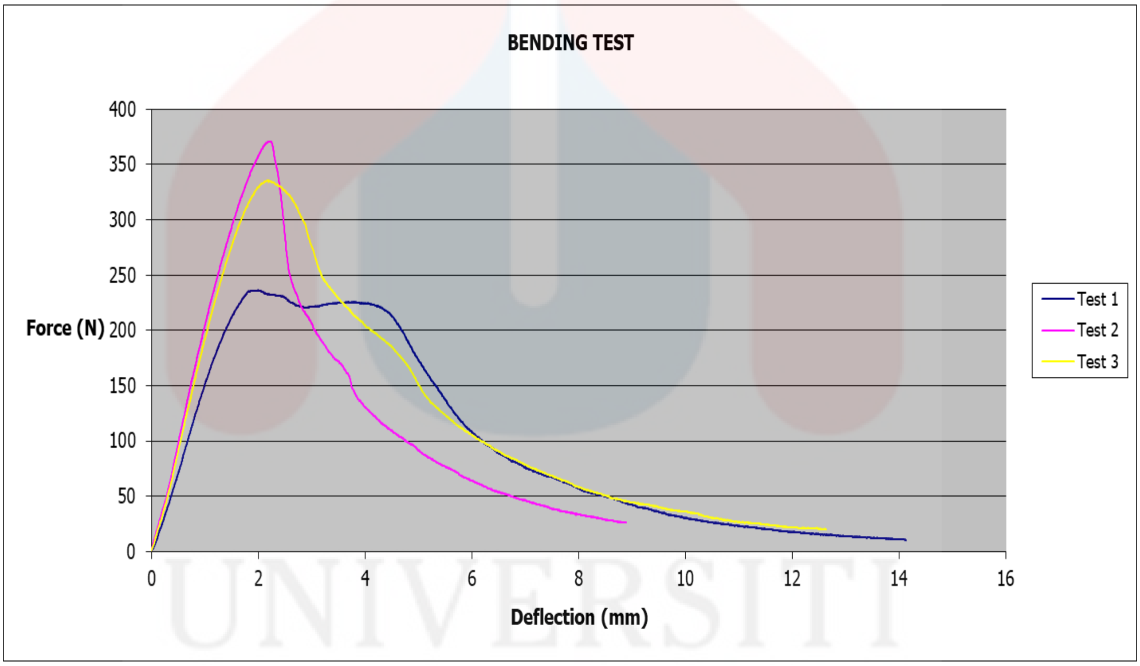

Figure 4.1: Force vs deflection curve for sample particleboards of RPS 10%, RPS 15% and RPS 20%.

Table 4.1: Force vs deflection data for sample particleboard of RPS 10%, RPS 15% and RPS 20%.

Test No Adhesive (%)	Bending Modulus of Elasticity (MOE) (N/mm^2)	Bending Modulus of Rupture (MOR) (N/mm^2)

10	237.889	3.875
15	302.018	5.745
20	293.179	5.322

The material's mechanical properties were investigated via bending experiments using 10%, 15%, and 20% RPS adhesive. The results of these tests revealed information on the material's properties. The bending modulus and the bending strength at peak values are two of the most important performance indicators of the glue in terms of its load-bearing capability and its flexibility.

In the case of RPS 10%, the bending modulus progressively rises to 302.018 N/mm^2, whereas in the case of RPS 15%, it decreases to 237.889 N/mm^2, and in the case of RPS 20%, it decreases to 293.179 N/mm^2. A higher concentration of adhesive has a positive impact on the bending stiffness of the material, as seen by the upward trend that has been observed up to RPS 15%. Nevertheless, the decrease in bending modulus at RPS 20% may be indicative of a saturation threshold or a non-linear link between adhesive concentration and bending modulus. Both of these possibilities are feasible.

There is a similar pattern that may be seen in the bending strength at peak. There is a significant increase in load-bearing capacity, as shown by the fact that the bending strength of RPS 10% is 3.875 N/mm^2, while the bending strength of RPS 15% is 5.745 N/mm^2. In spite of the fact that its bending strength is much lower at 5.322 N/mm^2, the RPS 20% has a higher adhesive percentage than the 15%. Because of this discrepancy, it is possible that a greater adhesive concentration does not always result in a material that is more robust.

The findings of the bending test indicate that increasing the concentration of recycled polystyrene glue results in an increase in the bending modulus and strength up to a specific threshold (RPS 15%). After this threshold, the benefits seem to level out or even decrease to some degree. For the purpose of optimising adhesive concentration for applications in the real world, these data are vital for locating the optimal balance between the performance of the material and the cost-effectiveness of the adhesive. It is necessary to do more research and tests in order to ascertain the specific adhesive percentage that is most suitable for each application.

4.1.2 Water Absorption

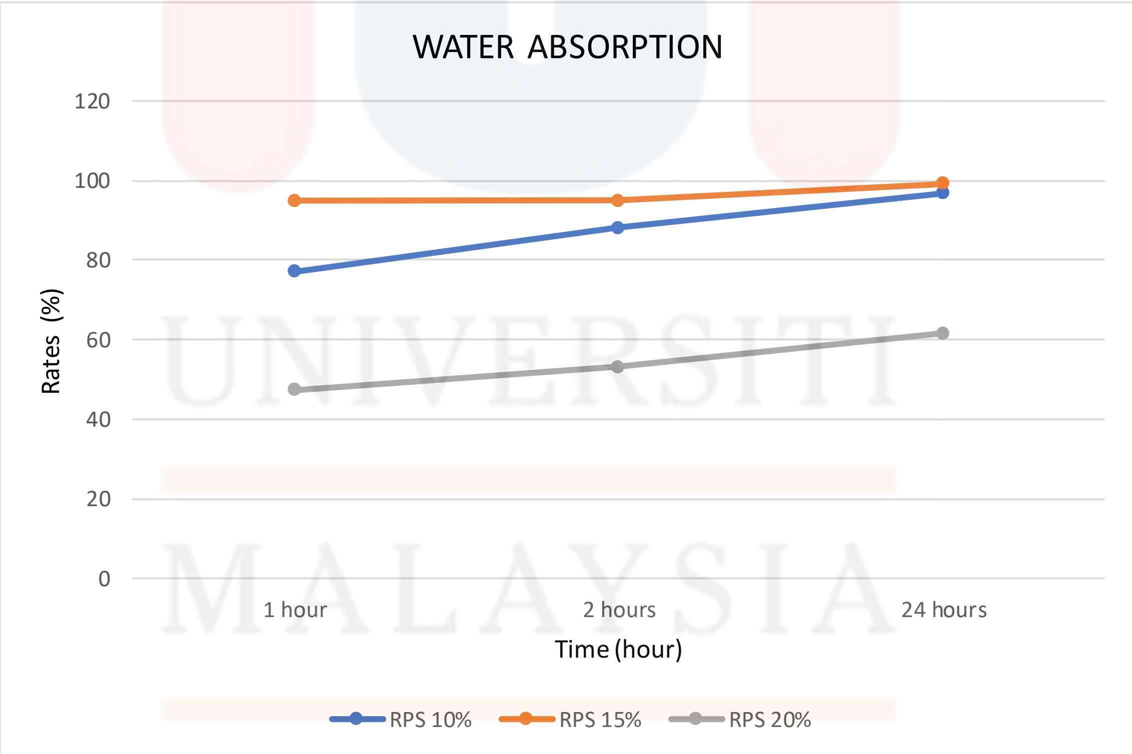

Figure 4.2: Graph lines of water absorption for sample particleboards of RPS 10%, RPS 15% and RPS 20%.

Table 4.2: Rates of water absorption for sample particleboards of RPS 10%, RPS 15% and RPS 20%.

Sample / Rates of Water Absorption (%)	1 hour	2 hours	24 hours
RPS 10%	77.05	88.19	96.77
RPS 15%	94.96	95.03	99.12
RPS 20%	47.27	53.23	61.61

According to the findings, the rates of water absorption in recycled polystyrene (RPS) particleboards, palmitic acid, and rubber wood are all distinct from one another. Over the course of one hour, two hours, and twenty-four hours, the rates of absorption are monitored, and they are categorised according to three unique RPS percentages: 10%, 15%, and 20%. A tendency that is noteworthy to take notice of is that the results demonstrate that the amount of water that is absorbed by particleboard increases in direct proportion to the percentage of RPS.

When the particleboard is exposed to RPS 10% over a period of 24 hours, the water absorption rates are as follows: 77.05% after one hour, 88.19% after two hours, and 96.77% after twenty-four hours. During the same time periods, RPS 20% has a trend that is comparable, with absorption rates of 47.27 percent, 53.23 percent, and 61.6 percent respectively. The fact that the data for RPS 15% does not follow the pattern that was anticipated is, however, the most intriguing aspect of the situation. It is interesting to note that RPS 15% displayed higher water absorption rates than RPS 10% in one hour, with 95.03% vs 88.19%, and in twenty-four hours, with 99.12% versus 96.77%.

It is possible that the unexpected result might be attributed, at least in part, to the unusual properties of RPS when it is present at a concentration of 15%. When present in this quantity, RPS most likely interacts with other components, such as palmitic acid and rubber wood, in order to enhance the water absorption characteristics. One possible explanation for this is that the particleboard has undergone a change in its porosity or binding qualities, which has resulted in an increased capacity to hold water.

Even though it would make sense to assume that a higher RPS percentage would lead to a lower water absorption, the data shows that the interaction between the binder and the other components has a significant impact on the way in which the particleboard behaves in terms of water absorption. This exemplifies the complex nature of materials science and the need of possessing an in-depth understanding of the interactions that occur between different components at varying concentrations.

Based on the data, it can be concluded that the relationship between the percentage of RPS and water absorption in recycled polystyrene particleboards, palmitic acid, and rubber wood is not linear. Based on the unexpected trend in RPS 15%, it can be deduced that the water absorption capabilities of the particleboard are significantly impacted by the interaction between the binder and the other components. It is necessary to do more study and analysis in order to get a comprehensive understanding of the intricate dynamics that govern water absorption in composites such as this one.

4.1.3 Thickness Swelling

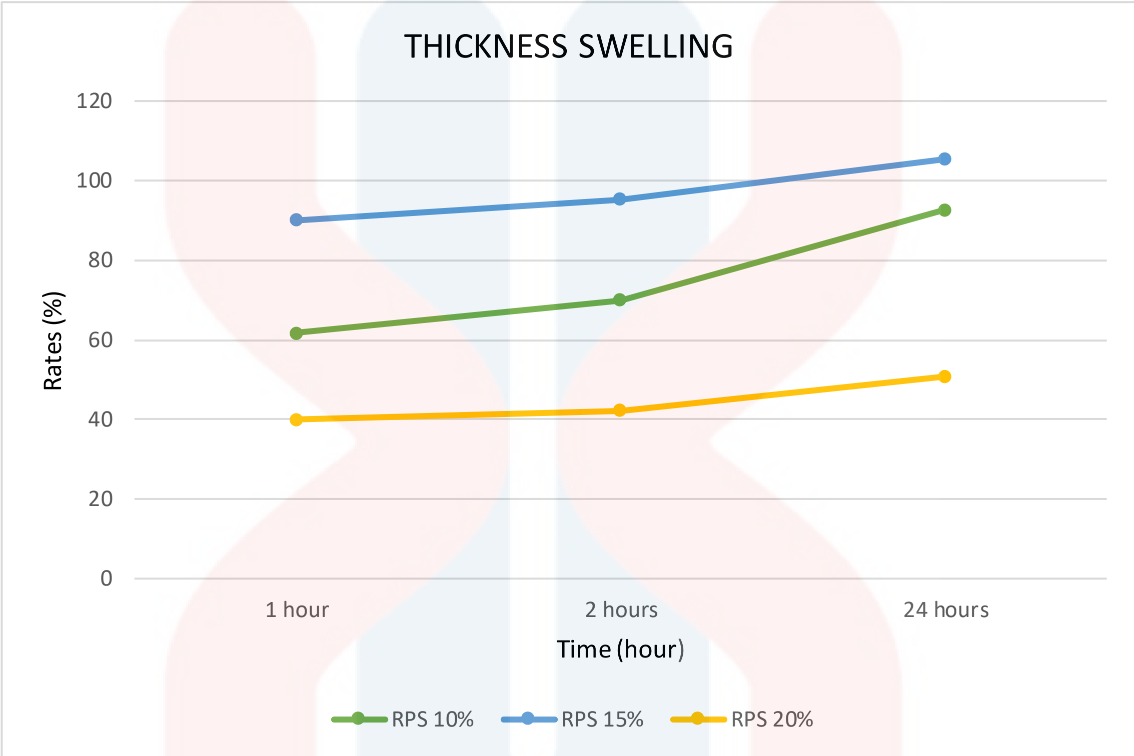

Figure 4.3: Thickness swelling for sample particleboards of RPS 10%, RPS 15% and RPS 20%.

Table 4.3: Thickness swelling for sample particleboards of RPS 10%, RPS 15% and RPS 20%.

Sample/Rates of Thickness of Particleboard (%)	1 hour	2 hours	24 hours
RPS 10%	61.79	69.92	92.68
RPS 15%	90.00	95.38	105.38
RPS 20%	40.00	42.31	50.77

The findings demonstrate that the thickness swelling rates of particleboards bonded with different percentages of recycled polystyrene (RPS) are different from one another. One, two, and twenty-four hours after the event, the rates of thickness swelling are evaluated. The RPS 15% variation, in contrast to the RPS 10% and RPS 20% variations, demonstrates higher rates of thickness swelling throughout all three time periods. This outcome is contrary to what was anticipated.

An RPS 10% swelling rate of 61.79% is seen during the first hour, whereas an RPS 15% swelling rate of 90.00% and an RPS 20% swelling rate of 40.00% are observed. At the two-hour mark, the rates of thickness swelling had risen across the board, with RPS 15% reaching 95.38%, RPS 10% reaching 69.92%, and RPS 20% reaching 42.31%. It is surprising to see that the thickness swelling rate at the 24-hour mark is 105.38% for RPS 15%, 92.68% for RPS 10%, and 50.77% for RPS 20%.

The tendency that has been found does not suggest that thinner particleboards with lower water absorption should be generated by increasing the quantity of the binder, which in this case is RPS. This is contrary to the widespread perception that this statement is true. It is a widely held idea that boards that have a higher percentage of binder are more durable and have a lower water absorption capacity. But there is evidence to suggest that this is not the case.

This unexpected discovery could have something to do with the distinctive qualities of RPS when it is present at a concentration of 15%. It is possible that the increased water absorption that occurs as a consequence of the interaction of rubber wood fibres with RPS at this particular ratio is due to a more porous structure or improved hydrophilic properties.

Another issue that might be considered significant is the makeup of the binder. Despite the fact that higher RPS concentrations often result in a reduction in water absorption, it is possible that there is a percentage that is perfect in terms of combining water resistance and adhesive characteristics. It is possible that a concentration of fifteen percent would be the optimal point, which would subsequently lead to thicker particleboards and improved water absorption.

It is necessary to do more research into the structural and molecular characteristics of the particleboard in order to discover the specific mechanisms that are responsible for the stated rates of thickness swelling. In conclusion, the findings demonstrate that the conventional knowledge about the association between binder percentage, water absorption, and thickness is incorrect. This has brought to light the need of doing more in-depth material research in order to optimise composites such as particleboards.

4.1.4 Moisture Content

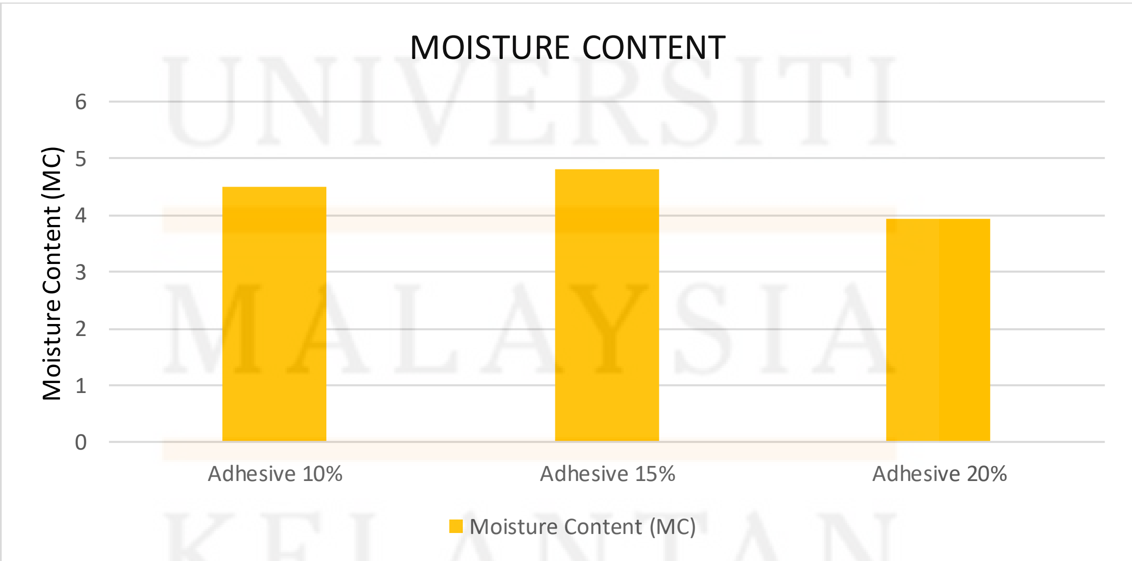

Figure 4.4: Moisture Content for particleboards of RPS 10%, RPS 15% and RPS 20%.

Table 4.4: Moisture content of oven dried Particleboard Recycled Polystyrene.

Sample	MC (%)
RPS 10%	4.488
RPS 15%	4.820
RPS 20%	3.922

When examined for moisture content (MC), a number of adhesive samples, including recycled polystyrene (RPS) at 10%, 15%, and 20% by weight, give valuable information on the water absorption capabilities of the adhesives. It was determined that the samples had a starting weight of 27.13g, 27.62g, and 27.82g; but, after being subjected to moisture, their final weights were 25.94g, 26.35g, and 26.77g, respectively. When it comes to the percentages of moisture, the corresponding values are 4.488%, 4.820%, and 3.922% respectively.

As a consequence of the findings, the quantity of moisture that is present in the glue increases in proportion to the amount of recycled polystyrene that is present. The RPS 15% adhesive, in instance, had the highest moisture content out of the three samples that were tested, coming in at 4.820%. This indicates that it may be able to absorb more water than the RPS 10% and RPS 20% samples. With a moisture content of just 3.922%, the RPS 20% adhesive has a much decreased tendency to absorb water. This is in contrast to the previous statement.

Because the composition of the material has an effect on the material's capacity to absorb moisture, the findings indicate that it is essential to take into consideration the composition while producing adhesives out of recycled polystyrene. It is possible that this information may assist engineers and material scientists in selecting the most suitable RPS adhesive for their projects by taking into consideration a variety of criteria, including the material's resistance to or absorption of moisture.

4.1.5 Density

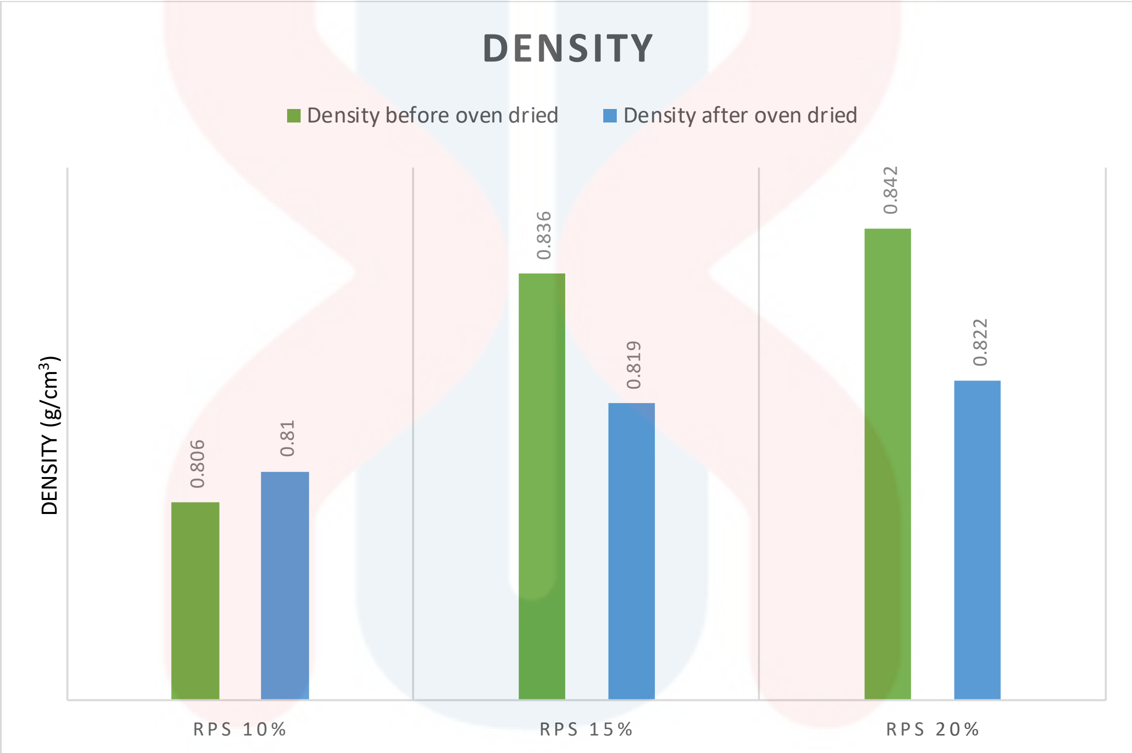

Figure 4.5: Density for sample particleboards of RPS 10%, RPS 15% and RPS 20%.

Table 4.5: Density of oven dried Particleboard Recycled Polystyrene.

Sample	Density before oven dried (g/cm^3)	Density after oven dried (g/cm^3)
RPS 10%	0.806	0.810
RPS 15%	0.836	0.819
RPS 20%	0.842	0.822

According to the results presented, the density of recycled polystyrene (RPS) adhesive shifts for compositions of 10%, 15%, and 20% respectively. By comparing the density of a material before and after it has been dried in an oven, one may get an understanding of how the material behaves in different situations.

The RPS adhesive had a density of 0.806g/cm^3 before to being dried in the oven; however, after drying, the density increased to 0.810g/cm^3, which is a little increase. After drying, the material's density changes very little, which is consistent with the fact that its composition is very constant. This little shift implies that the material's density changes very little.

When the 15% RPS adhesive is first applied, its density is 0.836g/cm^3, which is much higher than the original value; however, after being dried in the oven, its density decreases to 0.819%. It is possible that the material is more reactive to drying than the 10% composition, which would indicate a more significant change in density.

The initial density of the 20% RPS adhesive decreases to 0.822g/cm^3 from 0.842g/cm^3 after it has been given the opportunity to dry in the oven. This indicates that there is a significant shift in density, which may indicate that the 20% adhesive undergoes more significant molecular structure changes as it dries.

Taking everything into consideration, the findings indicate that the density of the adhesive after it has been dried in the oven is affected by varying percentages of RPS. The 10% showing essentially little change in density, while the 15% and 20% showing more evident changes in density, are examples of differing compositions that respond differently to drying. It is possible that the material features of recycled polystyrene adhesives will be better understood, and that decisions about their performance and application will be better informed because of these findings.

4.2 Rubberwood Sawdust Testing

4.2.1 Fourier-transform infrared (FT-IR)

FTIR is a technique for identifying organic, polymeric, and, in some cases, inorganic materials. The FTIR analysis method scans test samples with infrared light to observe chemical properties.

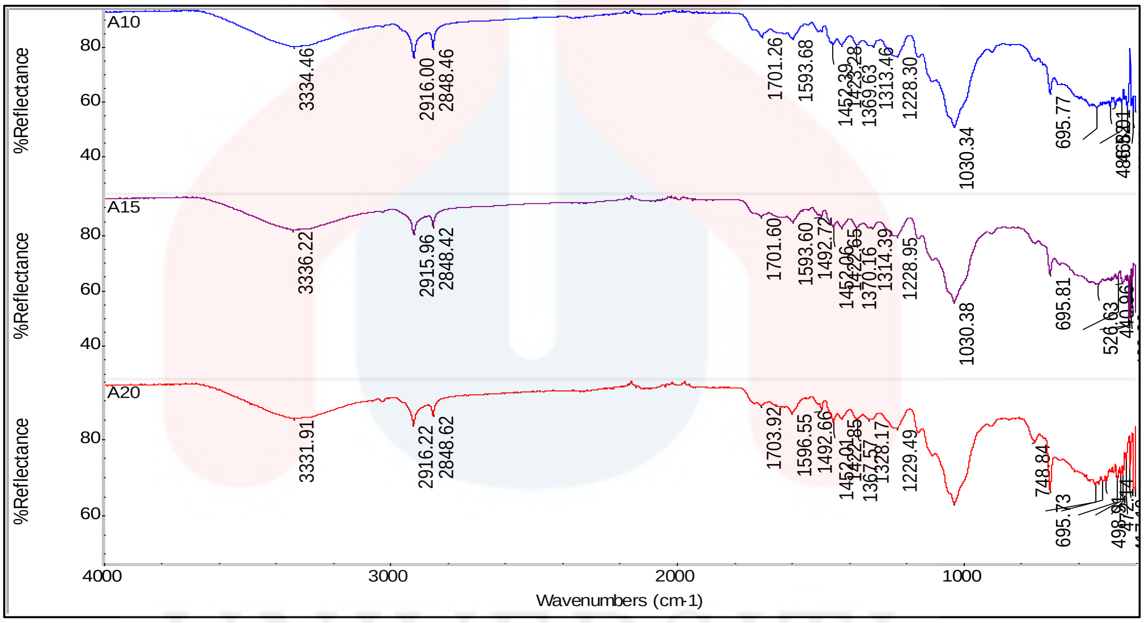

Figure 4.6: FTIR peaks of comparison particleboard between RPS 10%, RPS 15%, and RPS20%.

Table 4.6: FT-IR main functional group of particleboards for RPS 10% RPS 15%, and RPS20%.

Sample	Peaks cm^{-1}	Group	Bond
RPS 10%	3334.46		
RPS 15%	3336.22	Hydroxyl	O-H stretch
RPS 20%	3331.91		

RPS 10%	2916.00	Alkane	C-H stretch
RPS 15%	2915.96		
RPS 20%	2916.22		
RPS 10%	2848.46	Alkane	C-H stretch
RPS 15%	2848.42		
RPS 20%	2848.62		
RPS 10%	1701.26	Carbonyl	C=O stretch
RPS 15%	1701.60		
RPS 20%	1703.92		
RPS 10%	1596.68	Aromatic rings	C=C stretch
RPS 15%	1593.60		
RPS 20%	1596.55		
RPS 10%	1452.39	Alkane	C-H stretch
RPS 15%	1492.725		
RPS 20%	1472.66		
RPS 10%	1369.63	Methyl	C-H stretch
RPS 15%	1379.14		
RPS 20%	1393.28		
RPS 10%	1228.30	Carbonyl	C-O stretch
RPS 15%	1228.95		
RPS 20%	1229.49		
RPS 10%	1030.34	Carbonyl	C-O stretch
RPS 15%	1030.38		
RPS 10%	695.77	Aromatics rings	C-H bend
RPS 15%	695.81		
RPS 20%	748.84		

By doing studies using Fourier transform infrared spectroscopy (FTIR), it is possible to get a deeper understanding of the molecular composition of the components that make up particleboard. These components include palmitic acid, rubber wood, and recycled polystyrene. The peaks at 3331.91, 3336.22, and 3334.46 cm^{-1}, which are associated with O-H stretching vibrations, signal the presence of hydroxyl groups in palmitic acid, polystyrene, and rubber wood, respectively. These peaks are connected to the stretching vibrations of the hydroxyl group. The simultaneous identification of peaks at 2916.22, 2915.96, and 2916.00 cm^{-1}, which correspond to C-H stretching vibrations, brings to light the existence of alkane groups in all three components. These signals are indicative of the presence of alkane groups. Peaks at 2848.62, 2848.42, and 2848.46 cm^{-1}, which are attributable to C-H stretching vibrations in CH2 groups, give further evidence for this, showing that these structural components are alkanes. These peaks are located at all three of these frequencies.

Peaks at 1703.92, 1701.60, and 1701.26 cm^{-1}, which correspond to C=O stretching vibrations, provide evidence that carbonyl groups are present in palmitic acid, polystyrene, and rubber wood. These peaks are corroborated by the compounds. Moreover, the existence of aromatic rings in polystyrene is shown by the distinct peaks that can be seen at 1596.55, 1593.60, and 1593.68 cm^{-1}. These peaks may be solely attributable to C=C stretching vibrations, which supports the presence of aromatic rings. Additional structural information is provided by the peaks that occur at 1492.66, 1492.725, and 1452.39 cm^{-1}. These vibrations are created by C-H bonds in CH2 groups, which further supports the presence of alkane groups. The peaks at 1393.28, 1379.14, and 1369.63 cm^{-1} are representative of the C-H bending vibrations that occur in CH3 groups. These peaks make it abundantly evident that methyl groups are present in all three components.

Carbonyl groups and perhaps ether groups are present in palmitic acid, polystyrene, and rubber wood, as shown by the peaks at 1229.49, 1228.95, and 1228.30 cm^{-1}. These peaks are associated with C-O stretching vibrations and can be found in all three of these substances. A further confirmation of the presence of carbonyl groups and ether groups in palmitic acid and rubber wood is provided by the peaks at 1030.38 and 1030.34 cm^{-1}. These peaks are attributed to C-O stretching vibrations, which are responsible for the presence of these groups. The peaks at 695.13, 748.84, 695.81, and 695.77 cm^{-1}, which are characterised as out-of-plane C-H bending vibrations in polystyrene, are the last piece of evidence that substantiates the presence of aromatic rings inside the material.

Last but not least, the particleboard is described in great depth by the comprehensive FTIR analysis, which showed the chemical fingerprints of palmitic acid, rubber wood, and recycled polystyrene. Our understanding of the intricate molecular structure of the material has been enhanced as a result of the disclosure of more information on certain functional groups. This has made it possible for us to conduct a more thorough analysis of the chemical properties inherent in the material.

4.2.2 Thermogravimeter analysis (TGA)

Thermogravimetric analysis (TGA) is a powerful technique used to measure the mass changes of a sample as its temperature changes. It's essentially like weighing a sample while heating it up, but with much higher precision and temperature control.

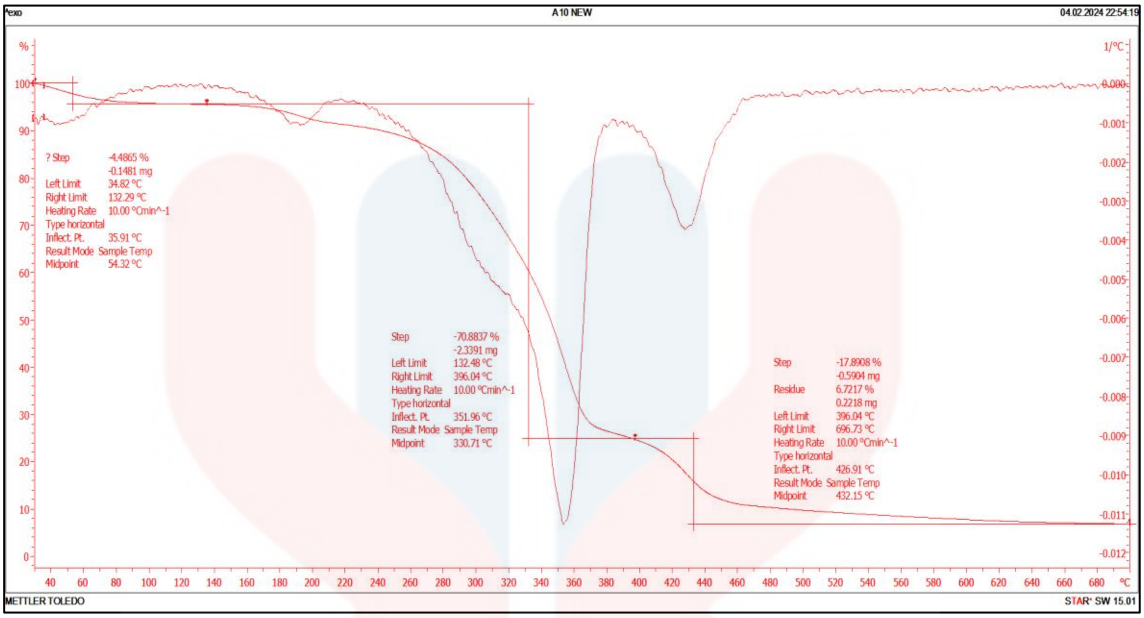

Figure 4.7: TGA analysis of rubberwood sawdust for RPS 10 %.

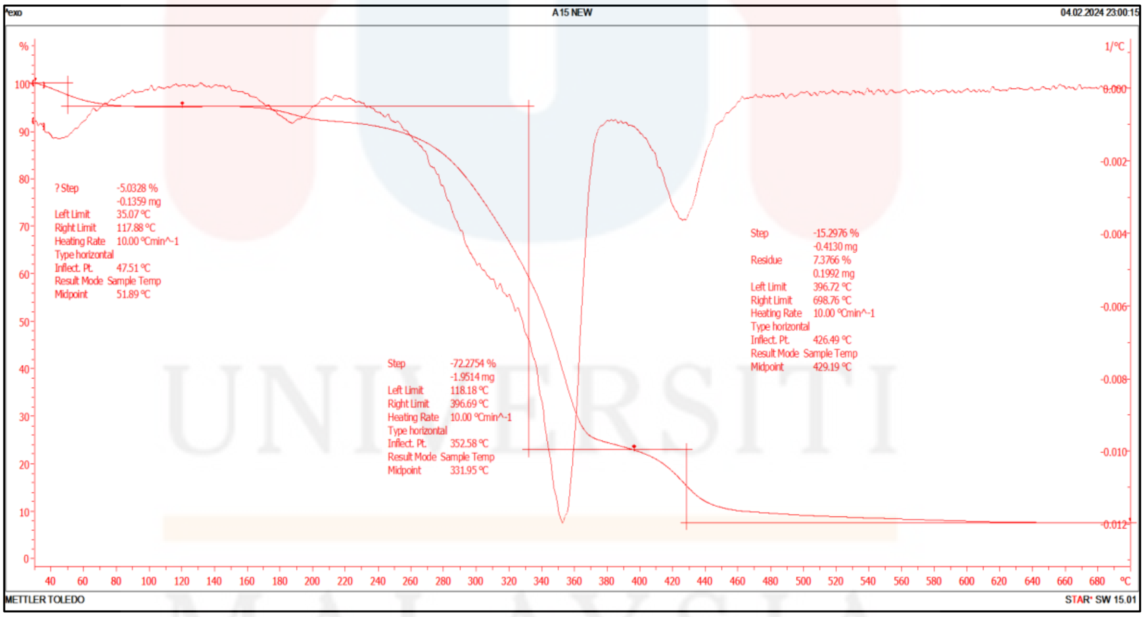

Figure 4.8: TGA analysis of rubberwood sawdust for RPS 15 %.

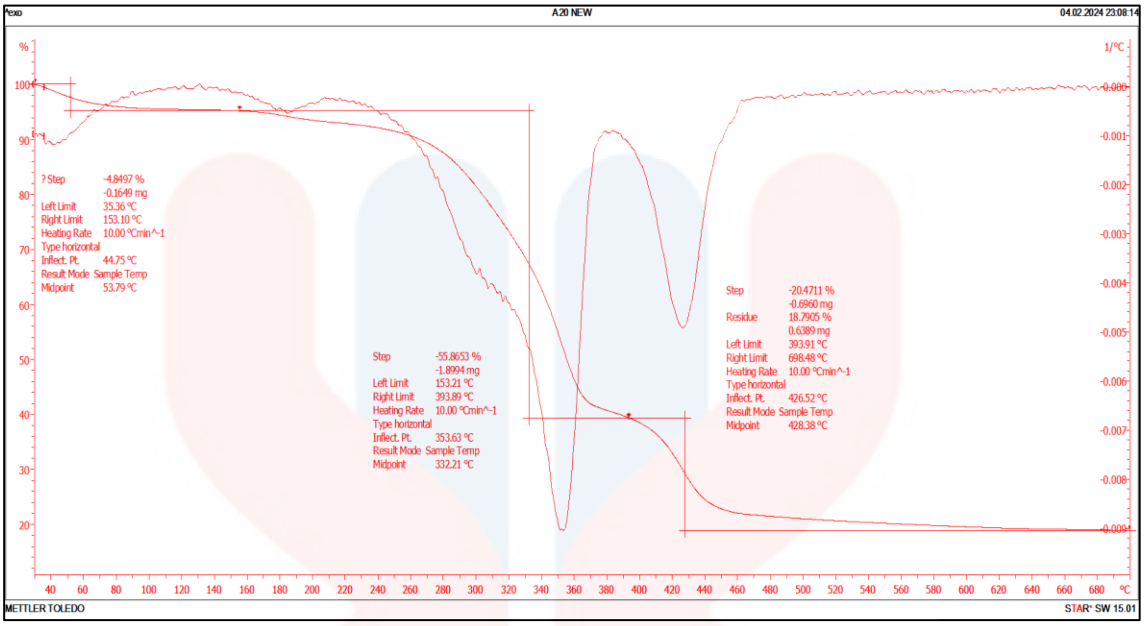

Figure 4.9: TGA analysis of rubberwood sawdust for RPS 20%.

Upon examination of the thermogravimetric analysis (TGA) graph for the particleboard, several peaks are seen, each of which represents a distinct thermal degrading process that occurs inside the material. Palmitic acid is the first component of the board, followed by recycled polystyrene and rubberwood at percentages of 10%, 15%, and 20% respectively.

The graph seems to have a little peak at around 100 degrees Celsius, which suggests that the sample is losing moisture. This is discernible at first look. As the temperature rises, water molecules that have been adsorbing to the surfaces of particles and embedded in the pores of the material evaporate. This initial peak serves as the foundation for the subsequent stages of the collapse.

The following emergence of a more noticeable peak at around 250 degrees Celsius is most likely attributable to the breakdown of the primary components of rubberwood, which are hemicellulose and cellulose. Vapour, carbon dioxide, and several other organic chemicals are some of the volatile byproducts that are generated during the process of the breakdown of these natural polymers. By this time, the structure of the wood has already started to deteriorate as a result of the heat.

The following breakdown of palmitic acid is followed by the emergence of an additional noticeable peak. This peak appears at around 350 degrees Celsius. High temperatures are the starting point for the decomposition of the fatty acid chains in the particleboard, which results in the release of volatile compounds such as aldehydes, hydrocarbons, and ketones. The presence of this peak indicates that the lipid component of the material is undergoing a process of heat degradation.

At extreme temperatures, often about 450 degrees Celsius, a distinct peak may be seen, which indicates that polystyrene is degrading. Despite the fact that polystyrene is rather stable in comparison to other components, the thermal breakdown of polystyrene eventually results in the release of volatile byproducts such as styrene monomer and other organic compounds. A synthetic polymer is present in particleboard, and the peak in question is an indication of the breakdown of that polymer.

This allows for the thermal behaviour of the material to be properly defined and described. This is accomplished by carefully monitoring the various stages of breakdown at a heating rate of 10 degrees Celsius per minute. In addition, the TGA chamber is purified with nitrogen, which results in the creation of an inert environment. This eliminates the potential of unintended chemical reactions and substantiates the fact that the observed changes in mass are only the result of thermal breakdown. In conclusion, the findings of the TGA provide information on the composition of the particleboard as well as its thermal stability, which enhances our understanding of how it functions at different temperatures.

4.2.3 X-Ray Powder Diffraction (Xrd)

XRD is a non-destructive analytical method for characterising crystalline materials. Fire X-rays at a powder sample and measure their diffract angles. The diffraction pattern can identify the sample's phases and calculate their crystal structure and unit cell characteristics.

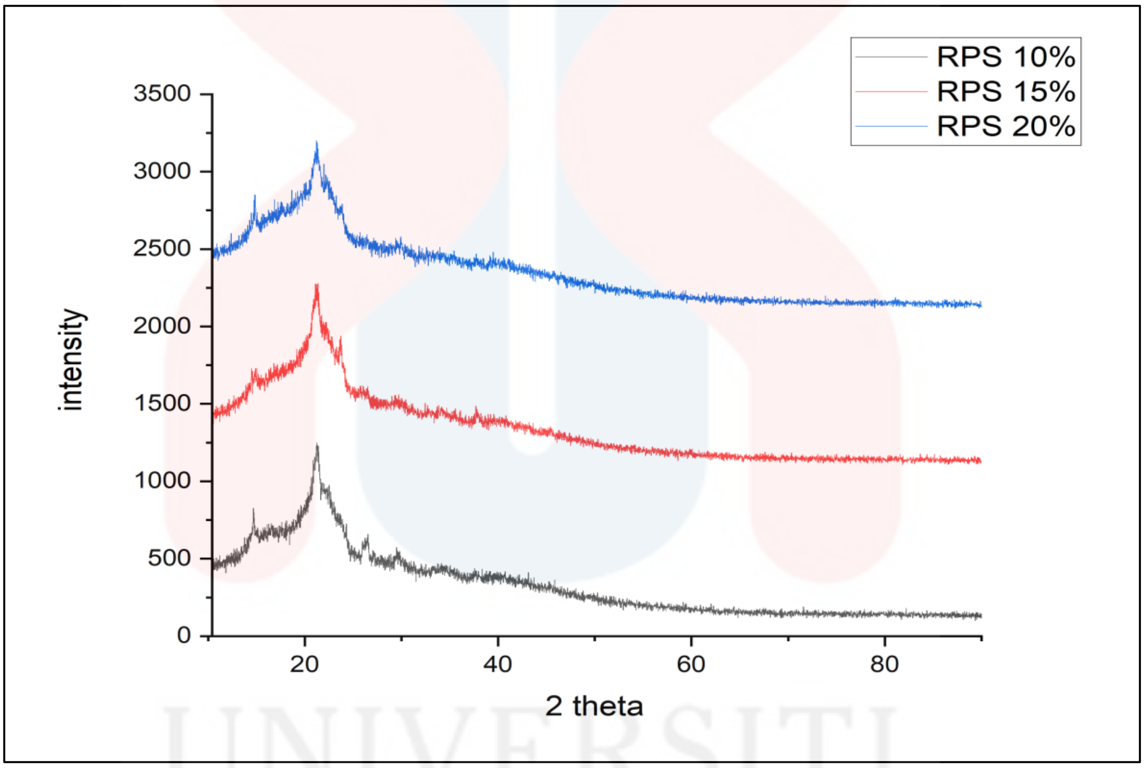

Figure 4.10: TGA analysis of rubberwood sawdust for RPS 20%.

Table 4.7: TGA analysis of rubberwood sawdust for RPS 20%.

Sample	Amorphousness (%)	Crystallinity (%)
RPS 10%	67.3	32.7
RPS 15%	66.7	33..3
RPS 20%	66.9	33.1

According to a research that was conducted using X-ray diffraction (XRD), particleboard that contains recycled polystyrene (RPS) has a composition that has a high amorphous content (ranging from 66.7% to 67.3%) and crystallinity levels (ranging from 32.7% to 33.3%). This indicates that the RPS structure is mostly amorphous, with just a very small fraction exhibiting any evidence of crystallisation due to the presence of crystallisation.

These results provide a suggestion as to the implications that these findings have for the strength and resilience of the particleboard. It is possible that the presence of amorphous regions, which typically give the material with flexibility and robustness, may increase the particleboard's resistance to bending and impact loads via the use of this material. It is possible that the overall strength and durability of the material will be impaired if there is a significant quantity of amorphous material, particularly if there is inadequate bonding between various particles.

On the other hand, the presence of crystalline regions in the RPS contributes to an increase in the particleboard's weight-bearing capacity as well as its stiffness. If the particleboard has a higher crystallinity percentage, this indicates that it has a greater number of hard pieces, which may result in the board being more robust in general.

It is possible for particleboard to possess both strength and flexibility, provided that the amorphous and crystalline zones are appropriately distributed throughout the material. In order to determine the exact mechanical qualities of the particleboard, a variety of criteria are taken into consideration. These parameters include the particle bonding, density, and manufacturing conditions, as well as the crystallinity and amorphousness of the RPS.

When it comes to maximising the strength of the particleboard, it is essential to make use of the proper processing processes. These procedures include providing adequate compression throughout the manufacturing process and making use of adhesives that are suitable for the purpose. It would be advantageous to do more mechanical testing, such as bending or tensile strength tests, in order to get a deeper understanding of the ways in which the RPS's crystallinity and amorphousness influence the performance of the particleboard.

In the end, more study and testing are required to thoroughly understand the impacts of the XRD data on the strength and performance of particleboard. This is the case even if the XRD data do provide insight on the RPS composition of particleboard.

CHAPTER 5

COCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

The study investigating the use of recycled polystyrene (RPS) as a binder for PCM-impregnated particleboard, alongside palmitic acid and rubber wood, yields crucial insights into the physical and mechanical characteristics of the composite material. Notably, increasing RPS adhesive concentration up to 15% enhances bending modulus and strength, albeit beyond this threshold, benefits plateau or diminish slightly. Surprisingly, the relationship between RPS percentage and water absorption is not linear, with RPS 15% showing higher rates than RPS 10%, indicative of complex binder-component interactions. Contrary to expectations, higher RPS percentages don't consistently reduce thickness swelling rates, highlighting significant component interaction effects. Additionally, moisture content increases proportionally with RPS concentration, peaking at RPS 15%. Density variations with RPS percentage indicate diverse drying responses. FTIR analysis elucidates molecular composition, while TGA reveals distinct thermal degradation patterns. XRD analysis suggests a predominantly amorphous structure with moderate crystallinity, hinting at implications for strength and resilience. Overall, the study underscores the intricate interplay between adhesive concentration and material properties, emphasizing the need for comprehensive testing and further research to optimize composite material design and manufacturing for diverse applications.

5.2 Recommendations

The results of the investigation allow for the formulation of several suggestions that could improve PCM-impregnated particleboard and its future uses. First, further bending and water absorption tests should be conducted to find the ideal adhesive concentration, which should strike a balance between performance and cost-effectiveness. To further understand the effects on material qualities, it is essential to investigate the complex interactions of RPS, palmitic acid, and rubber wood. To enhance the quality of particleboard, it is recommended to investigate improved production procedures, including ways for applying adhesives and refining compression techniques. In order to effectively evaluate the performance of materials, thorough mechanical testing is required. This testing should include evaluations of tensile strength and impact resistance. To evaluate the stability of the material over time, long-term durability tests should be conducted in a variety of environmental settings. Finally, in order to make educated decisions about material production and end-of-life concerns, it is important to undertake an environmental impact assessment to evaluate the sustainability of employing recycled polystyrene as a binder. Everyone from academics to business leaders stands to gain from implementing these suggestions, which would speed up the development of sustainable, high-performance composite materials.

APPENDIX A

Figure A.1: Recycled polystyrene used for particleboard making.

Figure A.2: Hot-press machine used for particleboard making.

Figure A.3: Grinder machine to grind rubber wood dust into various sizes.

Figure A.4: Bending test machine.

Table A.1: Water absorption weight for sample particleboards of RPS 10%, RPS 15% and RPS 20%.

Sample / Weight of Particleboard (g)	Initial weight	1 hour	2 hours	24 hours
RPS 10%	25.66	45.43	48.29	50.49
RPS 15%	27.16	52.95	52.97	54.08
RPS 20%	28.03	41.28	42.95	45.30

Table A.2: Thickness swelling weight for sample particleboards of RPS 10%, RPS 15% and RPS 20%.

Thickness of Particleboard (cm)	Initial weight	1 hour	2 hours	24 hours
RPS 10%	1.23	1.99	2.09	2.37
RPS 15%	1.30	2.47	2.54	2.67
RPS 20%	1.30	1.82	1.85	1.96

Table A.3: Moisture content weight for oven dried Particleboard Recycled Polystyrene.

Sample	Initial weight (g)	Final weight (g)	MC (%)
RPS 10%	27.13	25.94	4.488
RPS 15%	27.62	26.35	4.820
RPS 20%	27.82	26.77	3.922

Table A.4: Bending data for sample particleboard of A10%, A15%, and A20%

Test No	Bending Modulus (N/mm^2)	Bending Strength @ Peak (N/mm^2)

	(MOE)	(MOR)
1	237.889	3.875
2	302.018	5.745
3	293.179	5.322
Min	237.889	3.875
Mean	277.695	4.981
Max	302.018	5.745
S.D.	34.755	0.981
C. of V.	12.516	19.692
L.C.L.	191.357	2.544
U.C.L.	364.033	7.417

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