RESEARCH AND DEVELOPMENT OF NEW ROOFING MATERIAL USING KENAF CORE

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DEDICATION

Dedicated to

My honourable father, Abu Bakar Bin Shafie

My appreciated mother, Barishah Binti Mat Basir

My supportive brother, Abu Bakri, Abu Sufian, Abu Yazid and Aiman

My lovely sisters, Fatimah Adilah, Afiqah and Alia Izzati,

for giving me moral support, cooperation, encouragement, and understanding.

Thank you so much

ABSTRACT

The research and development of a new roofing material based on the abundant and sustainable resources of kenaf core is the focus of this study. Kenaf, a fast-growing plant with great fibre qualities, has the potential to be a renewable and environmentally beneficial roofing material. The process that been used in this study for the manufacturing of the sample is hand layup process and testing to ASTM standard.The matrix material that been used in this study is polyester resin. The goal of this study is to look at the mechanical, thermal, and durability aspects of the newly produced roofing material. The research includes material characterization studies such as tensile strength,flexural strength,compression strength and absorbent to impact energy,while for physical characterization the research also include thermal conductivity and water absorption testing. Furthermore, the performance of the roofing material showed that the sample with the smaller kenaf core size is performing well in term of mechanical properties where it shows that the sample with kenaf core size of 40 mesh having the highest value force 996.11 N in tensile test,187.25 N in flexural test and 90.12 kN in compression test.For the impacted energy sample with the kenaf core size of <3mm come out on top with the value 54.93 kJ/m^2 of absorbed enegy and value of 4.12 J impacted energy .Physical testing showing a unique result that show sample with the bigger size of kenaf core have a better performance in temperature properties with the sample size of <20 mm size of kenaf core have the highest percentage drop value of 32.36 % in heat testing but sample with the smallest kenaf core size yet again come out on top in the water penetration test with only 10.97 % water lost and the increase of only 0.2 mm thickness in swelling test.To ensure the balance of mechanical and pysical properties of the new roofing material,the kenaf core size of <3mm hase been chosen to be the baseline for performance comparison to ensure a balance between exceptional results and consistent behaviour. Important insights into the feasibility and potential benefits of utilizing kenaf core as a viable roofing material choice are offered by the study's findings.

ABSTRAK

Penyelidikan dan pembangunan bahan bumbung baharu berdasarkan sumber teras kenaf yang banyak dan mampan menjadi fokus kajian ini. Kenaf, tumbuhan yang berkembang pesat dengan kualiti serat yang hebat, berpotensi untuk menjadi bahan bumbung yang boleh diperbaharui dan berfaedah kepada alam sekitar. Proses yang digunakan dalam kajian ini untuk pembuatan sampel ialah proses letak tangan dan ujian kepada piawaian ASTM. Bahan matriks yang digunakan dalam kajian ini ialah resin poliester. Matlamat kajian ini adalah untuk melihat aspek mekanikal, haba, dan ketahanan bahan bumbung yang baru dihasilkan. Penyelidikan termasuk kajian pencirian bahan seperti kekuatan tegangan, kekuatan lenturan, kekuatan mampatan dan penyerap kepada tenaga impak, manakala untuk pencirian fizikal penyelidikan juga termasuk kekonduksian terma dan ujian penyerapan air. Tambahan pula, prestasi bahan bumbung menunjukkan bahawa sampel dengan saiz teras kenaf yang lebih kecil menunjukkan prestasi yang baik dari segi sifat mekanikal di mana ia menunjukkan bahawa sampel dengan saiz teras kenaf 40 mesh mempunyai nilai daya tertinggi 996.11 N dalam ujian tegangan, 187.25 N dalam ujian lentur dan 90.12 kN dalam ujian mampatan. Bagi sampel tenaga impak dengan saiz teras kenaf <3mm keluar di atas dengan nilai 54.93 kJ/m^2 tenaga serap dan nilai tenaga impak 4.12 J .Ujian fizikal menunjukkan hasil unik yang menunjukkan sampel dengan saiz teras kenaf yang lebih besar mempunyai prestasi yang lebih baik dalam sifat suhu dengan saiz sampel <20 mm saiz teras kenaf mempunyai peratusan nilai penurunan tertinggi sebanyak 32.36 % dalam ujian haba tetapi sampel dengan kenaf terkecil. saiz teras sekali lagi muncul di atas dalam ujian penembusan air dengan hanya 10.97 % kehilangan air dan peningkatan hanya 0.2 mm ketebalan dalam ujian bengkak. Untuk memastikan keseimbangan sifat mekanikal dan fizikal bahan bumbung baru, saiz teras kenaf daripada <3mm telah dipilih untuk menjadi garis dasar untuk perbandingan prestasi untuk memastikan keseimbangan antara hasil yang luar biasa dan tingkah laku yang konsisten. Pandangan penting tentang kebolehlaksanaan dan potensi faedah menggunakan teras kenaf sebagai pilihan bahan bumbung yang berdaya maju ditawarkan oleh penemuan kajian.

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LIST OF SYMBOLS AND ABBREVIATIONS

ASTM	-	American Society for Testing and Materials
mm	-	milimiter
RM	-	Ringgit Malaysia
KC	-	Kenaf Core
g	-	gram
kg	-	kilogram
Nm	-	Newton meter
min	-	minute
°C	-	celcius

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CHAPTER 1

INTRODUCTION

1.1 Background

In recent years, the use of composite materials, which are intended to be high-performance materials for engineering applications, has increased. There are two main types of composites which are matrix-based composites and reinforcement-based composites (Sharma et al., 2020). Natural fiber is one of the fiber reinforcements in composites and it is widely used nowadays in various applications. Those natural fiber reinforced composites generally used in engineering applications like aircraft, automobile, building and also other commercial applications (Prabhu et al., 2021). It can substitute synthetic composites in order to provide a greener environment. Tonk (2020) stated that natural fibers are obtained from animals, plants, and mineral sources such as kenat, hemp, jute,flax and silk.

Roofing materials serve an important role in providing structures with protection, insulation, and longevity. It is important to pointed out that roof is one of the fundamental in house or building constructions because it is an important part of the construction because it gives the users cover that can protect its user from bad weather such as rain, storm, hail and others (Alkali et al., 2018). There are several types of material that are being used to make a roof such as clay (Akhtar et al., 2017), concrete (Kreiger et al., 2019), asphalt (Sahito et al., 2020), metal (Saini and Shafci, 2019) and wood (Hoq and Judd, 2020). Each of these materials has their own application. As an example, metal is utilized on large and tall buildings due to its characteristics and for safety reasons. Clay, concrete, and asphalt are often utilized on residential homes, whereas wood is used on historic houses. With a rising emphasis on ecologically friendly and sustainable construction practices, there is a growing demand for new roofing materials that provide better performance while minimizing environmental effect. The purpose of this background study is to provide an overview of the research and development of a new roofing material made from kenaf core.

Kenaf, a hibiscus-family fast-growing plant, has received interest as a potential renewable and sustainable resource for a variety of purposes, including construction. It has various attractive features, including lightweight nature, high strength-to-weight ratio, thermal and acoustic insulation, moisture resistance, and low-cost availability. These characteristics make kenaf an appealing alternative for the development of eco-friendly roofing materials. According to Tholibon et al. (2019), they stated that kenaf fiber can be derived from the bast and core which also known as outer fiber and inner fiber. They also mentioned that there are roughly 35 % of bast fiber and 65 % of core fiber consist in a kenaf stalk. Kenaf fiber provides a lot of potential applications due to it is easily available, economically, and environmentally friendly and also outstanding performance (Tholibon et al.,2019). Mechanical properties of kenaf bast fiber are related to its cellulose (Shrivastava and Dondapati, 2021), the higher the cellulose content resulting the better value of tensile strength.

The goal of the research is to characterize the physical, mechanical, and thermal properties of kenaf core and fiber, as well as to investigate their potential as major components in a composite roofing material. The project is to develop a composite roofing material with optimized composition, production processes, and curing conditions by mixing these elements with appropriate binders or matrices. The research and development of a new roofing material based on kenaf core entails a thorough examination of these materials' features and characteristics. The study's goal is to investigate the possible benefits and drawbacks of using kenaf core as important components in roofing materials. Laboratory studies, material testing, and performance assessments will be used in the research to analyze the mechanical characteristics, thermal insulation, moisture resistance, and durability of the new roofing material.

The outcomes of this research and development study will help to advance sustainable roofing materials while also providing vital insights into the practicality and potential of using kenaf core in the building sector. The new roofing material has the potential to increase performance, minimize environmental impact, and contribute to overall building system sustainability.

In conclusion, the research and development of a new roofing material based on kenaf core is a great opportunity to investigate the use of renewable resources and improve the construction industry's sustainability. This research intends to add to the body of knowledge on new roofing materials and encourage environmentally friendly building design and construction practices.

1.2 Problem Statement

New roofing materials are constantly being developed in order to improve the performance, sustainability, and cost-effectiveness of building construction. Growing environmental issues and concerns have led to an increased focus on the integration of lightweight recyclable materials into retrofitting as well as new construction projects (Shahryar Habibi et al ,. 2020). Because of its potential environmental benefits and favorable mechanical qualities, the use of natural fibers and agricultural waste in composite materials has received a lot of attention. In this context, the exploration and development of a new roofing material based on kenaf core presents an intriguing possibility.

Since the last few decades, researchers have been primarily interested in researching and developing roof tiles by combining common matrix material of roof tiles with natural fiber and agricultural waste such as asbestos fiber reinforced cement (Oberta et al., 2018), sisal fiber reinforced clay (Zaryoun and Hosseini, 2019), and bamboo fiber reinforced concrete (Amin et al., 2021). The current study only developing roof tile with common matrix materials that have been used in building practices since the old time so it resulted In lack of knowledge in current matrix materials which is polyester. The water resistance, high adhesion, good mechanical properties, and chemical resistance of resin are also beneficial in building and construction materials (Mehmet Selcuk Mert et al., 2023). For that reason this study is performed to investigate the ability of polyester resin as a new matrix material for building practice.

In addition, currently used tiles have insufficient flexural strength. When someone stepped on the tiles, it readily cracked. It is a problem for the homeowner since there may be times when an antenna or other equipment will need to be installed on the roof. Furthermore, the likelihood of it breaking during a hailstorm is high. To protect the house from disaster, the roof must be robust and durable. It is a vital feature of the home that can make the owner feel protected and comfortable. It must be determined that the roof tile is sturdy and can be used for a long period by completing material testing.

Lastly the study's goal is to look at the feasibility, performance, and potential benefits of mixing kenaf core and fiber into a new composite roofing material. The research will concentrate on optimizing the manufacturing process, assessing the material's mechanical, thermal, and acoustic properties, determining its long-term durability and resistance to degradation, and analyzing the cost implications compared to conventional roofing materials. The research intends to promote the development of a sustainable and high-performance roofing material using kenaf core by addressing three main problems.

1.3 Objective

The objective of the research are as follows:

a) To fabricate natural composite panel using kenaf core mixed with polyester resin at specific ratios size through simple manufacturing method.

b) To characterize the proposed panel for mechanical and physical properties.

c) To propose the best ratio size based on mechanical and physical performance for new roofing material.

1.4 Scope of Research

The scope of this research are as follows:

a) The research will be conducted to observe the potential of kenaf core at different size when mixed with polyester resin.

b) To investigate the mechanical & physical properties, and also durability of kenaf core as potential for roofing material.

c) To develop a composite formulation and optimum ratio of kenaf core with polyester to achieve the desired properties.

d) To fabricate the sample using hand layup techniques.

e) To conduct testing according to ASTM standard.

f) To develop prototype of roofing using best findings.

g) To test and evaluate the proposed prototype according roofing requirements.

1.5 Rational of Research

The rational of the research are as follows:

a) To create sustainable building practices. With increased environmental concerns, there is an urgent need to produce roofing materials that reduce reliance on nonrenewable resources and have a smaller environmental impact. Kenaf, a fast renewable plant, provides an amazing chance to develop environmentally friendly roofing solutions.

b) Develop lightweight and high strength to weight ratio for roofing material. Concrete or clay tiles, for example, might be heavy and require additional structural support. The development of novel roofing materials can give a lighter and more efficient solution by utilizing kenaf core and fiber, which are known for their lightweight nature and excellent strength-to-weight ratio. This lessens the overall weight of structures, alleviating building load and perhaps lowering construction costs.

c) Flexibility in design and versatility. In terms of design and manufacturing, kenaf-based roofing materials are versatile. Kenaf core can be paired with other appropriate materials or additives to form composite constructions that can be moulded, sculpted, or modified to fit specific roofing specifications. This adaptability enables a wide range of design options and customization.

d) Kenaf plan availability and affordability make it an appealing candidate for manufacturing low-cost roofing materials. In comparison to standard roofing materials, the use of kenaf core and fiber may lower production costs, resulting in more inexpensive roofing solutions for both residential and commercial applications.

1.6 Thesis Arrangement

The purpose of this study is about the research and development of new roofing material using kenaf core and polyester resin as matrix material. This report chapter consists of introduction, literature review, methodology, result, and discussion. PSM 1 will cover Chapter 1, Chapter 2, and Chapter 3 while PSM 2 will cover Chapter 4 and Chapter 5. Chapter 1 is about the introduction of the research outside consist of background study, problem statement, objectives, scope of research and the rational of the research. Chapter 2 is about the literature review of previous research and contains an introduction of roof, type of roofing material, and the testing of the roofing material . Then followed by Chapter 3 describes the methodology in detail regarding the preparation of the raw materials which are kenaf core and polyester resin to produce the roof tile. The method used is handlayup method, and the testing process using the standard test for tensile, flexural, heat test and water absorption test.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction of Roof

A roof is the uppermost part of a building or structure that covers and protects the interior space from the weather elements. It acts as a barrier against wind, sunshine, excessive heat, and wetness, such as rain or snow. The major purpose of a roof is to preserve the safety and dryness of a building's interior while also providing insulation and ventilation to maintain a pleasant internal climate. Since then, human intelligence has advanced and are able to invent machines or devices that can make our daily routine easier and faster. In line with this advances the house design also have been through some development, where each country has embedded their own culture when design and building the houses without disregard the climate of the country or places (Rashid et al., 2021). There are clear differences in the design of the house and the material that was used as a roof.

The continent which has hot climate such as Asia, Australia, America and Africa they adopted green roof in the constructions elements in building their houses (Abass et al., 2020). These houses use an environmental material which does not require a manufacturing process to use it. The material to make a house back then, are easier to collect and does not require a lot of human resources and tools to build it. This reflect in Malaysian house design in the early period where the houses were made very tall as a caution to when the region experience flooding (Chan et al., 1996). But it does come with great disadvantages such as it is flammable, weak and prone to rot. In Figure 2.1 shows different example of house design that are found in places that had hot climate. This design is assimilated with their culture and based on the weather experienced in the region. The house designs that are found in Africa have a rounded shape which possibly for air ventilation. Europe houses had a cone-shaped design which may be because of snow. This design can prevent the snow from sticking onto the roof and make it fall. Other than that Asia and America had similar design, nothing abnormal. The design may because to provide better air entering the house.

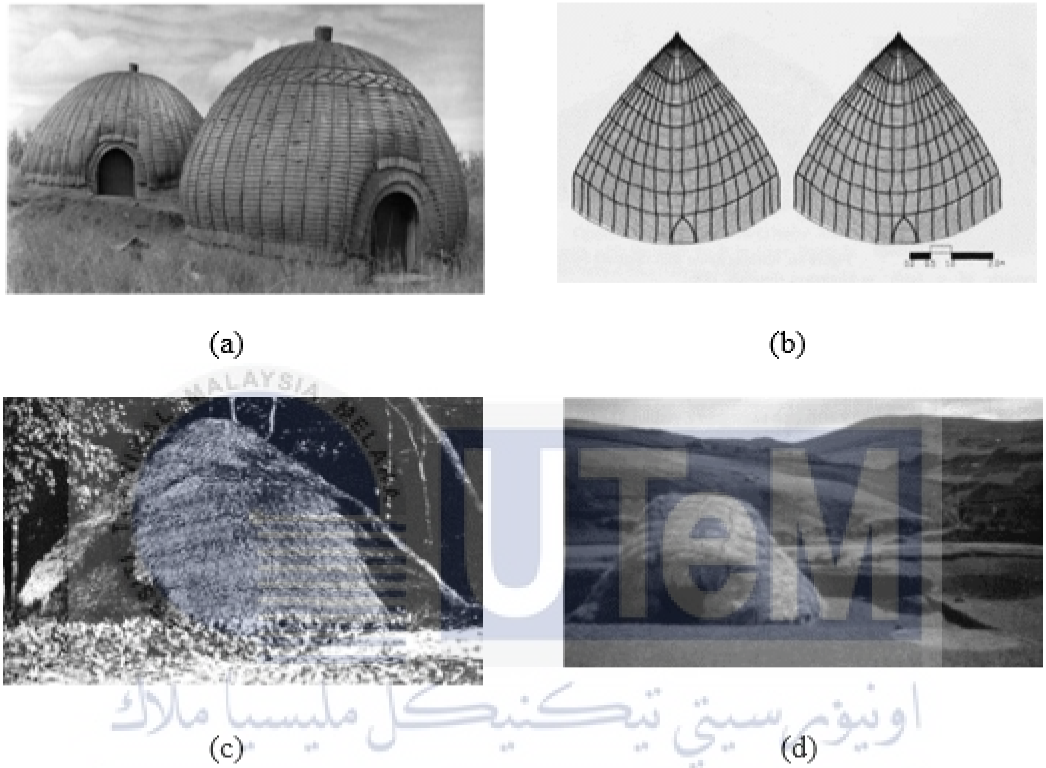


Figure 2.1: Example of roof in hot climate (a) africa, (b) europe, (c) america, (d) asia (Abass et al., 2020)

2.1.1 Function of roof

The primary function of a roof is to provide protection and shelter from the weather elements, such as rain, snow, wind, sunlight, and extreme temperatures. A building's internal space and contents can be protected by a well designed and built roof, which can keep out water and other environmental elements. In addition to offering protection, roofs are crucial for establishing a cozy and secure indoor atmosphere. Roofs do have a role in a building's energy effectiveness. The amount of heat that enters a building, for instance, can be reduced with the use of a roof that is intended to reflect sunlight, which can lower cooling expenses in the summer. A building's roof design may enhance its aesthetic appeal. An attractive and well-designed roof can improve a building's overall appearance and make it mix in with its surroundings.

2.1.2 Type of roof

The roof's purpose is to keep out bad weather and to provide shelter. Each country has its distinctive design. The influence of local culture is due to variations in each type of design. Figure 2.2 shows the different types and designs of roof houses. Design (a) the gable roof is popular due to the straightforward design of the roof timbers and the rectangular shape of the roof sections. Gable roof is a simple, triangular-shaped roof with downward slopes on either side of a ridge. This avoids details that take a lot of work or cost and are prone to damage. Design (b) hipped roof is a type of roof in which all the sides slope downward to the walls, usually with a fairly gentle slope, design (c) hip and valley roof, design (d) hipped roof with dutch gables, (e) skillion roof. According to Tominaga et al. (2015), a roof's pitch has a major influence on the flow of the environment surrounding the building. Every one of these designs has its own set of benefits.

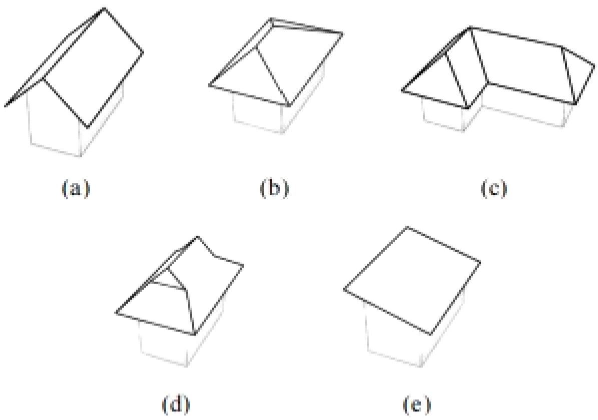


Figure 2.2: Type of roof (a) gable, (b) hipped, (c) hip and valley, (d) hipped with dutch gables (e) skillion (Ponni et al ., 2015)

2.2 Type of Roofing Material

2.2.1 Clay roof

A clay roof, also known as a tiled roof, is a type of roof covering made from fired clay. One of the oldest and toughest types of roofing materials, clay roof tiles have been used for thousands of years. Homes built in the Mediterranean, Spanish, and Southwestern architectural styles frequently have clay roofs, which are renowned for their toughness, beauty, and energy efficiency.

Clay roofing tiles come in a variety of forms, dimensions, and hues, and they can be made to complement almost any architectural design. They can be glazed or unglazed and come in a variety of finishes, from smooth to textured. Each tile is fastened to the roof decking or battens with nails or clips when it is normally set in an overlapping manner. Aside from that, Sh.K. Amin 2022 found that they are typically sold in their natural earthy color, earning them the nickname "terracotta tiles," but they can also be glazed in a color of any choice before being baked into shape.

One of the key benefits of clay roofs is their durability. Clay tiles as shown in Figure 2.3 can last for several decades or even centuries with the right upkeep since they are resistant to fire, insects, and rot. Additionally, clay tiles are great insulators, keeping homes warm in the winter and cool in the summer, which can lower energy costs.

Figure 2.3:Clay roof tiles (Shiyu Liu et al., 2020)

2.2.2 Asphalt roof

An asphalt roof as shown in Figure 2.4 is a type of roofing material made from asphalt and fiberglass, commonly referred to as a composition shingle roof. It is one of the most widely used roofing materials in North America and is renowned for being inexpensive, long-lasting, and simple to install. Asphalt shingles, which are normally rectangular in shape and stacked one on top of the other, are used to construct asphalt roofs. The shingles are created from a fiberglass mat that has an asphalt coating and is then covered in granules for color and texture. From classic three-tab shingles to architectural or dimensional shingles that resemble other roofing materials like slate or wood, asphalt roofs come in a variety of colors and designs.

One of the main benefits of asphalt roofs is their affordability. When properly maintained, asphalt roofs, which are one of the most affordable roofing options, can last up to 20 – 30 years. They may be mounted on most types of roofing structures without the need for extra support because they are also reasonably lightweight.

Williams (2020) have demonstrated that even newer and tighter adhering seal strips can present challenges when repairing relatively new roof surfaces. Besides, Porter (2022) mention the bottom line is that simply removing and replacing damaged shingles in an area that appears to require repair will not necessarily restore the roof's functionality or service life. They reported that asphalt-composition shingles are essentially separate pieces interwoven into a mat of material that covers and protects the roof from the elements. Apart from this, each shingle relies on and supports the integrity of the shingles around it. As a result, the roof must be evaluated as a whole, rather than as individual shingles.

Figure 2.4: Asphalt shingle roof (Porter, 2020)

2.2.3 Concrete roof

A concrete roof is a particular kind of roof constructed from concrete, a powerful and long-lasting building material. Concrete roofs are frequently utilized in commercial, industrial, and residential structures and come in a variety of shapes and sizes. A form or mold is first built on the roof structure to create a concrete roof, and then cement, sand, and water are poured into the form. The form is removed once the concrete has dried, and the finished roof is left in place.

Additionally, Syaiful (2021) describes that a concrete roof is a building material composed of cement, sand, stone, and water that hardens to a stone-like mass. Furthermore, as indicated by Eugênio et al. (2021) despite the fact that several studies on Iron Ore Tailing (IOT) in cementitious composites could be found in the literature due to the aforementioned benefits, no studies on the use of such waste in concrete roof tiles, which have gained attention in recent years due to their practicality, aesthetics, resistance to weather conditions, attractive price, easy fitting, and over 50-year lifespan in most climates.

Concrete roofs as shown in figure 2.5 offer several benefits, including strength, durability, and fire resistance. They can withstand strong winds, hail, and other harsh weather conditions. Concrete roofs can also be made in a variety of colors, textures, and finishes, offering a wide range of customizing possibilities. Concrete roofs do have some disadvantages, though. Given their potential weight, additional structural support might be needed. Additionally, they might be more expensive than other kinds of roofing materials and might need specialized installation and upkeep.

Figure 2.5: Concrete roof Syaiful (2021)

2.2.4 Asbestos roof

A roof type with asbestos fibers is called an asbestos roof. Due to its heat resistance and durability, asbestos, a naturally occurring mineral, was once widely used in the construction industry. Buildings built between the 1930s and the 1970s frequently had asbestos roofs, especially industrial and commercial structures. They were also utilized in residential structures, especially for affordable housing.

Aside from that, as shown in Figure 2.6 asbestos cement sheets are a type of construction material that is commonly used in roofing and siding. In 2022, Soroushian et al. found that to improve weather resistance and corrosion resistance, asbestos fibers were mixed into cement. Because it was lighter than heavy cement also asbestos cement sheeting was popular. Moreover, asbestos also increased the durability and resistance of cement sheets to heat and weather. According to him again, roofing and other building materials can become weathered and damaged as they age. As a result, asbestos cement sheets may emit asbestos fibers into the air.

However, it was later discovered that exposure to asbestos fibers can lead to serious health problems, including lung cancer and mesothelioma. As a result, the use of asbestos in construction was banned in many countries, including the United States.

Figure 2.6: Asbestos cement sheets (Edwin Raczko et al ., 2022)

2.2.5 Metal roof

A metal roof is a type of roofing material made from metal panels or shingles. Due to its strength, energy efficiency, and aesthetic appeal, metal roofs are a popular choice for both residential and commercial buildings. Metal roofs are frequently constructed from steel, aluminum, or copper, and they can be covered with a variety of coatings to improve both their functionality and aesthetic. There are several different types of metal roofs that can be placed, such as standing seams, corrugated, and shingle-style.

One of the main benefits of metal roofs is their durability. Metal roofs can endure up to 50 years or more with good maintenance and are resistant to damage from wind, hail, and fire. They may be fitted on most roofing structures without the need for extra support because they are lightweight.

Furthermore, in Figure 2.7 shows the metal roof tile. Koumbem et al. (2021) reported that the results show that, for the same geometric parameters, the earth roof terrace and earth tile roof improve thermal comfort by lowering the interior temperature by 5 °C and 4.6 °C, respectively, in comparison to a corrugated metal roof.

Figure 2. 7: Metal roof tile Koumbem et al. (2021)

2.2.6 Polycarbonate roof

A type of thermoplastic material known as polycarbonate is used to create polycarbonate roofing. Lightweight and strong polycarbonate roofing is a popular choice for both residential and commercial construction projects. Because of its great impact resistance, polycarbonate roofing is renowned for being resistant to damage from hail, wind, and other sorts of severe weather. Additionally, it is UV-resistant, so exposure to sunlight won't cause it to age or turn yellow over time.

Polycarbonate roofing is available in a variety of colors and styles, including clear, opaque, and tinted. It can be installed in a variety of roofing configurations, including flat and pitched roofs. Moreover, Polycarbonate as shown in Figure 2.8 is the best transparent or semi transparent roofing material because it is a very durable material with 200 times the impact resistance of glass while weighing half as much (Molkens et al., 2021).

As a result, it can withstand a wide range of climates and environmental impacts. It can also be carried, moved, handled, and installed with ease because of how light it is. Injuries on the job site may be decreased because it is also less prone to fracture or break during installation than heavier roofing materials.

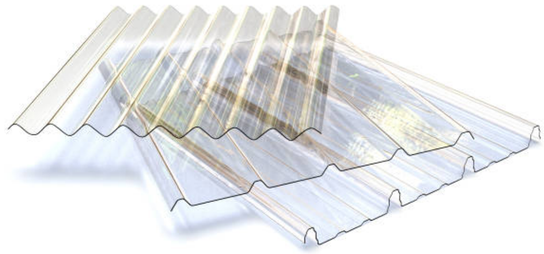


Figure 2.8: Polycarbonate roof (Molkens et al., 2021).

2.3 Introduction of Kenaf

Kenaf is also known as Hibiscus Cannabinus L. It is a plant in Malvaceae family with Hibiscus gene. Kenaf plants are largely unbranched and able to grow up to 5 to 6 meters tall and the diameter of stem is approximately 25 to 35 millimeters (Khiari et al., 2020). In Figure 2.9, the physical appearance of kenaf plants was shown. Kenaf is one of the plants that can produce natural fibers that are mostly obtained from bast and core. Kenaf compromised with 35 to 40 % of bast fiber while 60 to 65 % of core fiber by weight of the kenaf's stalk (Lim et al., 2018). Bast fibers, also called phloem fibers, they are present in inner bark. Bast fibers are much longer compared to core fibers. Core fibers are obtained from the ligneous core. Kenaf plant has a wide range of adaptation to climates and soils opposed to other fiber plants in commercial production. For example, jute, hemp, flax, wool and so on. It only takes 150 days to harvest. The development of high-performance engineering products made from natural resources is increasing worldwide due to renewable and environmental issues. Therefore, kenaf plants have been extensively exploited all over the world.

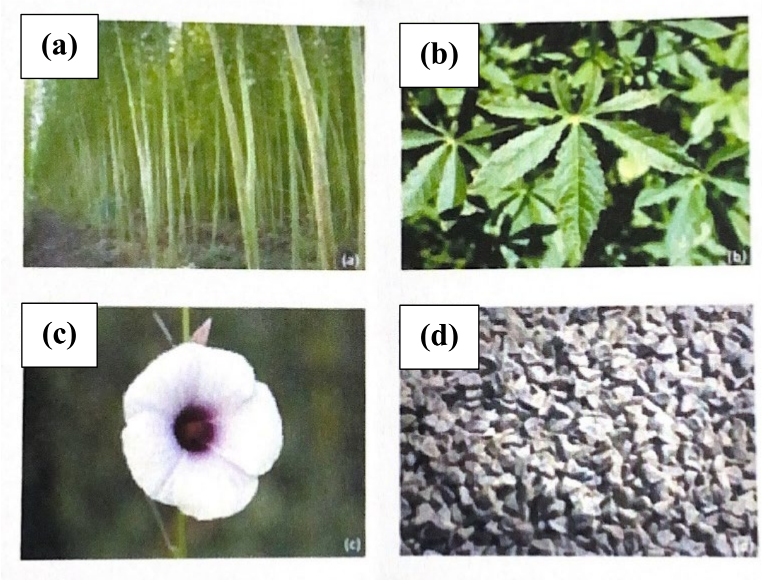


Figure 2. 9: Kenaf plants (a) stem (b) leaves (c) flower (d) seed (Yan et al., 2022)

2.3.1 Kenaf core

Kenaf core refers to the inner woody part of the kenaf plant stem that remains after the fibrous outer part is removed. The kenaf core is also known as the hurds or shives, and it makes up about 30-40% of the plant's total biomass. The kenaf core is composed of cellulose, hemicellulose, and lignin, and it has several potential uses Besides, it has rigid open cell structures, and it is not easy to compact. However, the applications of kenaf core are still little in the industry but it will have a high potential for developing if there are more studies are carrying out. Currently, most of the use of kenaf core materials are as absorbents especially in animal bedding material or paper products as it is excellent in water absorption. Unlike other filling materials, kenaf core is biodegradable at the same time provides perfect water absorption and low dust content (Alias et al., 2019).

Preparation of kenaf core fraction from Lips et al research in 2009, they were performed by dry fractionating with a stack of vibrating DIN 4188 sieves while kenaf pith was manually separated from core particles. As from the result, Lips et al. observed that large kenaf particles have a higher absorbency than the medium and small particles. They stated that the large kenaf particles originate mainly from the bottom part of the stem and that contains only 1 to 2% of pith material. It is obvious that despite the high absorption capacity, differences in amount of pith cannot be the only cause of the higher absorption of the fraction with the large core particles. They believed that internal structure of pores and water transport vessels of the large particles or a different chemical composition must be the reason for the higher water absorption. However, in this research that covered with gypsum-based ceiling application, large kenaf core size are not preferable as it will decrease the performance of composite due to the reinforcement dislocation interactions. Figure 2.10 demonstrated different kenaf core size and kenaf pith that used for experimenting from the research of Lips et al., 2009.

Figure 2.10 : Different kenaf core size and kenaf pith (Lips et al ., 2009)

2.3.2 Application of kenaf

Kenaf is edible, it can be consumed as human food and livestock feed (Giwa Ibrahim et al..2019). In some countries, the citizens take kenaf leaves and young shoot of kenaf as home dish. Kenaf seeds also yield an edible vegetable oil (Cheng et al., 2016). The kenaf seed oil is also used for cosmetics, industrial lubricants and for biofuel production.

According to previous study from Rafidah et al. (2017), they mentioned both kenaf fibers, bast fibers and core fibers can use for pulp and paper. They believed that the bast fibers has higher mechanical performance than core fibers. This is because of the longer the fibers able to provide more strength to support writing or drawing application as well as packaging and print. From the research, even though the kenaf based paper making process is much economic and easier but the quality of final paper product showed higher than conventional tree paper.

Moreover, kenaf has potential for bioplastic and bio-composite industry due to the fiber can be used as reinforcing fiber in composite (Venkategowda et al., 2021). Compared to glass fiber, kenaf based materials are cheaper and environmentally friendly in spite of that mechanical performance of kenaf based composite products show a huge improvement.

2.4 Application of Composite in Current Roof Material

In the current state of the industry, the technological advances the industry have become, with the development and research in producing better product by combining variety of material with composite. By mixing the composite with the current material it can improve the performance of such material in term of application by enhancing the mechanical, chemical and thermal property. Composites are increasingly being used in current roof materials due to their superior properties over traditional materials.

Some research and development have been done in improving the current material of roof by mixing it with other composite material. Based on the study that has been done by Chakartnarodom et al. (2020), they have mixed the basalt fire with texture-cement roof tiles. Texture-cement roof tiles are often used on traditional home, hotel or resort because of its beautiful appearance whereas basalt is a type of volcanic rock. The result shows that the roof material that was reinforced by this fiber produces a good outcome where it passes the requirement to be used as a roof tile. On top of that, this fiber can be a replacement to the uses of current fiber that was used in the mixture before. This replacement can be the reason for the reduction of the material cost. Figure 2.13 shows the reduction of cost if the matrix material is reinforced with the composite material. In addition, the matrix material can be used less if the combination has more composite material. This is because in shaping tiles it has a certain value of volume. Through mixture, matrix material should be use lesser to make spaces for the volume of the composite material.

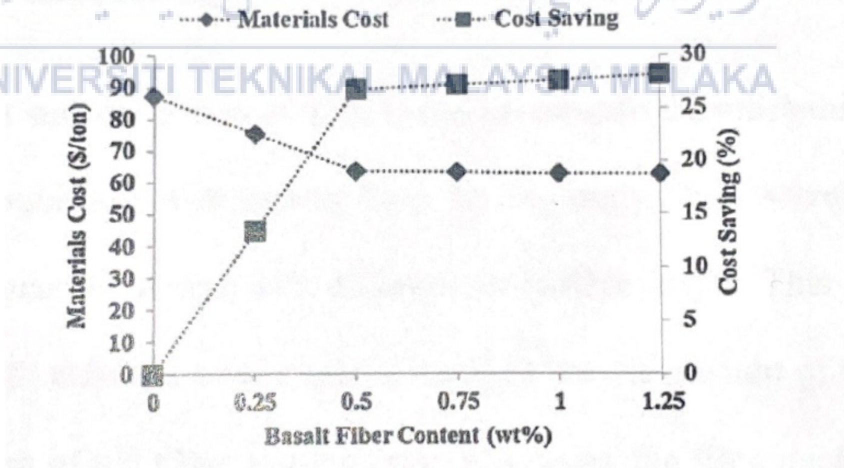


Figure 2.11 : Cost of raw materials and cost saving using basalt fiber (Chakartnarodom et al., 2020)

Recently Zhou (2021) has done a study on the mixture of concrete reinforce with steel fiber. The purpose for this study is to explore the influence of composite material on cement. Testing is done to evaluate the capabilities of fiber mixture with matrix material and if it increases the overall properties of the matrix material. To obtain the best possible result, several samples were made with different combinations that have different value of substance ratio. In Figure 2.14 shows reinforcing concrete with steel fiber does exhibit some enhancement for the matrix material but it is not a substantial improvement. In general, if the mixture contains more steel fiber and less water, the strength of the concrete increases. Furthermore, the author indicates if unsuitable length fiber steel is used, the fiber has high tendency to get clutter when stirring.

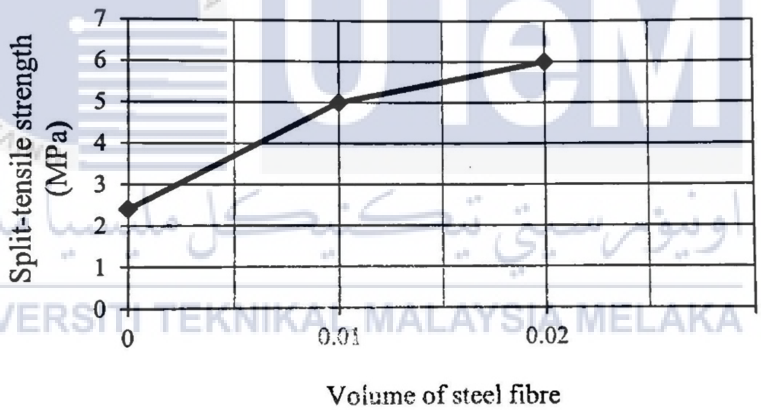


Figure 2.12 : Split-tensile strength vs. Volume of steel fiber from (Zhou,2021)

In a different study, Bao et al. (2021) has investigated the mechanical properties of clay soil that were reinforced with carbon fiber. In this study, there were several samples that have different quantity in ratio with different set of fiber length. This study discovered that mixing fiber with clay soil does improve strength, but the amount of improvement dictated by the length of the fiber. Furthermore, increasing the fiber content enhances the material's compressive strength but decreases the optimal moisture content and the fiber has higher tendency to get clustered in the mixture. Therefore, the optimal uses of the fiber content are crucial in preventing composite clustering and to achieve even fiber dispersion. Figure 2.15 shows the highest improvement is produce when clay soil is mix with 3 % of 6 mm carbon fiber.

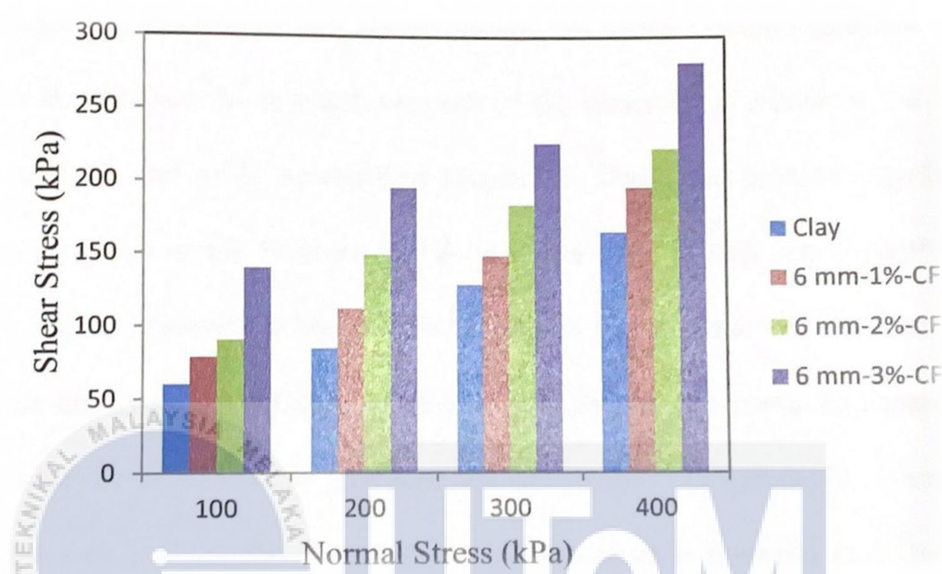


Figure 2.13 : Shear strength of the effect in different content of fiber at different pressure from (Bao et al., 2021)

The study by EsmaeilpourShirvani et al. (2019) examines the effect of reinforcing sand-clay mixture with kenaf fiber. Various samples were produced to determine the best ratio of materials that will produce the best result. The result shows that when kenaf fiber is mixed with clay-sand, the end product's shear strength and internal friction seem to be increases, but the main material's characteristics appear to be unaffected. Furthermore, Figure 2.16 shows the finished product becomes more robust if more fiber is added to the mix compared to when the clay content is higher than the kenaf fiber.

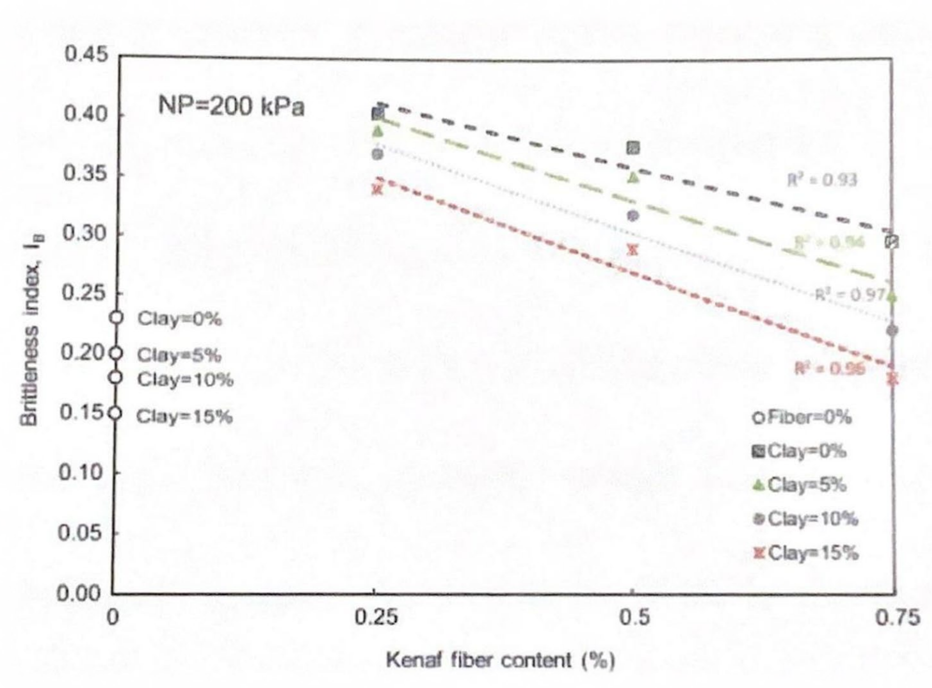


Figure 2.14 : The effect of kenaf fiber to clay content in brittleness (EsmaeilpourShirvani et al ., 2019)

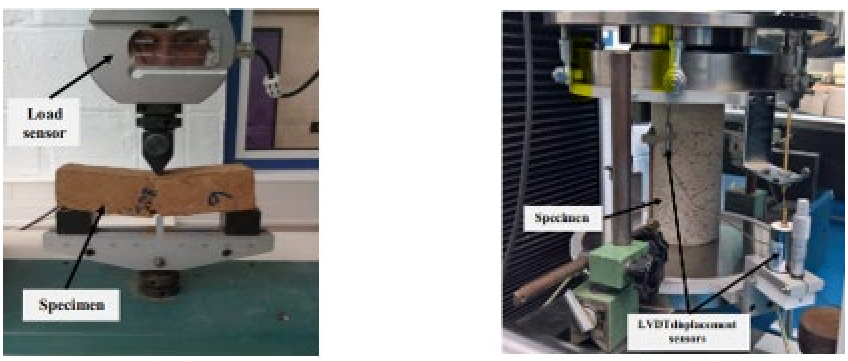
To summarize, the studies that are mentioned have similar overall findings which is, all of the fiber do enhance the strength on each of the material. It increases ductility, compressive strength and other mechanical properties. They also pointed out that if the fibers have more ratios in the mixture it will improve the material significantly but the fiber will have higher tendency to be clustered when the mixture are stirred. The reason for creating various samples with different ratio of matrix material to composite material is to examine which of the combinations produces the best result. Unfortunately, there was no attempt was made to explore the potential of other composite material (KC) which can bring other type of improvement to the current roof material.

2.5 Testing

Testing is an important part of this research since it serves as an evaluation to determine whether the material or product in question can be employed in a commercial setting. The following types of testing were selected for this investigation: flexural testing, heat testing, tensile testing, and water absorption testing.

2.5.1 Testing of mechanical properties

When choosing a material for a roof, mechanical efficiency is an extremely important factor to take into account because roofs are expected to withstand severe weather. In addition, individuals may frequently climb up onto the roof in order to install antenna dishes or repair tiles that are cracked. Because of this, testing is required in order to determine whether the material is strong enough to be used as a material for roofing. In comprehensive study of Omrani et al. (2020), the testing were conducted followed the regulation of European Standard EN 196-1 to explore the specimen compressive and fleural strength. Figure 2.17 shows the equipment that were used to determine the compressive strength are the SHIMADZU AG-IC that have maximum capacity of 250 kN and a constant rate of 4 mm/min while the flexural testing uses TINIUS OLSEN H5OKS with load capacity of 50 kN and 0.4 mm/min loading rate.



(a) (b)

Figure 2. 15 : Mechanical testing (a) flexural, (b) compressive (Omrani et al ., 2020)

2.5.2 Heat testing

Heat testing on roofing materials is conducted to evaluate their performance and durability under high temperatures. This testing helps determine the materials' ability to withstand heat exposure, prevent heat transfer into the building, and maintain their structural integrity. According to De Silva et al ., (2017), the best way to measure a specimen's thermal efficiency is to expose it to direct sunlight. Since the main purpose of this experiment is to only examine the output of the surfaces, polystyrene was used to cover the side of the specimen. Aside from that, saw dust is used to fill the gap between the polystyrene sheets to ensure no air is trapped. To measure the temperature of the specimen, digital thermometer is connected to the thermocouple which was place on the bottom of the specimen surfaces. Schedule observation and recording of the temperature are done every 30 minutes from 8 am to 6 pm. Figure 2.18 shows the setup to measure the thermal performance of the material.

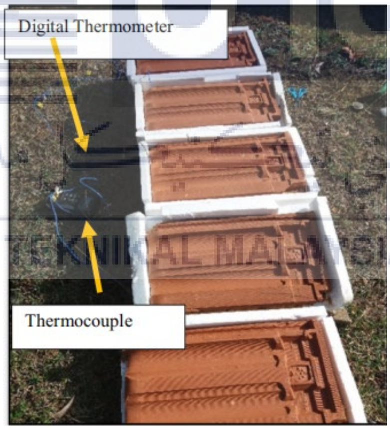


Figure 2. 16 : Thermal performance testing set up (De Silva et al ., 2017)

2.5.3 Water absorption test

The water absorption test is used to evaluate the durability and long-term performance of roofing materials in wet environments as well as their resistance to water infiltration. The test aids in determining the material's water resistance, which is crucial in determining if it is suitable for roofing applications. A study by Bamigboye et al. (2019) said that the highest levels of water absorption amongst the composites were 10% PET (2.94%) while the lowest was at 30% PET (0.15%). This implies that 30% PET has the least affinity for water with absorption rate of 0.15% and relatively the soundest while 0% PET with 6.02% is the least on the soundness scale.Composite values were all lower than that of the reference tile 0% PET (6.02%). Amongst the plastic binder compositions, water absorption values decreased steadily down to 100% PET of which 20-100% of PET fell between the range of 2% specified by the standard. This simply showed that increase in plastic content led to corresponding decrease in water absorption up to 100% PET .

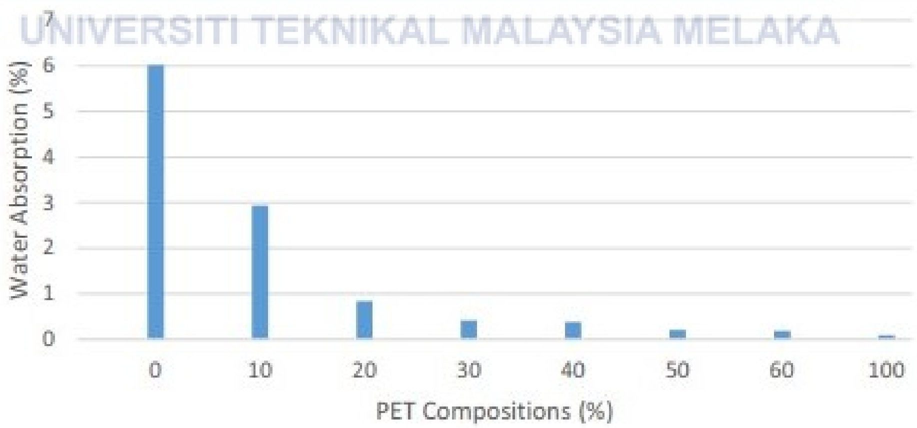


Figure 2. 17 : Water absorption values in % for different tile compositions Bamigboye et al. (2019)

2.6 Summary

Roofs are essential for protecting buildings from weather elements and maintaining a comfortable indoor climate. Different regions and climates have influenced the design and materials used for roofs. In hot climates, green roofs are common, using environmentally friendly materials that are easy to collect. However, traditional materials like wood have disadvantages such as flammability, weakness, and rot.

A roof's main purpose is to shield a building from the elements, including rain, snow, wind, sunlight, and severe temperatures. An attractive roof can also improve ventilation, energy efficiency, and aesthetics. There are many different types of roofs, each having their own advantages, such as gable, hipped, hip and valley, hipped with Dutch gables, and skillion roofs.

Roofing materials have a significant impact on the performance and durability of roofs. Clay, asphalt, concrete, asbestos (which is now banned in many countries due to health dangers), metal, and polycarbonate are all common roofing materials. Clay roofs are long-lasting, energy-efficient, and visually appealing. Asphalt roofs are inexpensive, simple to build, and can last for decades. Concrete roofs are durable, fire-resistant, and customizable. Metal roofs are long-lasting, lightweight, and resistant to extreme weather. Polycarbonate roofs are impact and UV resistant, as well as simple to handle and install.

Kenaf, also known as hibiscus cannabinus, is a plant that produces natural fibers from its bast and core. Kenaf fibers are used in various applications. The kenaf core refers to the woody inner part of the plant stem. Kenaf plants are adaptable to different climates and soils, making them widely used as a renewable resource.

Overall, choosing the best solution for a given climate, durability, energy efficiency, and aesthetic preferences requires understanding the many types of roofs and roofing materials

CHAPTER 3

METHODOLOGY

This chapter will discuss the planning procedure and methodology employed in this study to make sure that all of the research objectives are met. The methods used to complete the research will be covered in this methodology. The process includes material preparation, fabrication, and associated experimental testing .This technique's goal is to ensure that the experiment's methods and progress are on track for this study, and that the preparation plan is followed to achieve the desired results.

3.1 Introduction

Figure 3.1 depicts the investigation flow for this study, which will use Kenaf Core as a reinforcing composite that will be applied to polyester to manufacture roof tiles. Both of these materials are combined to make a mixture which each of the mixture will have a distinct ratio value. The fabrication procedure will next be carried out, with the roof tiles being manufactured using the hand layup method. It will be allowed to dry for several days in order to remove the moisture trapped within the sample. If the samples' quality is confirmed to be satisfactory, they will be subjected to a series of tests, including tensile, flexural, heat test , and water absorption. Finally, all of the findings are analyzed, and the research can be concluded.

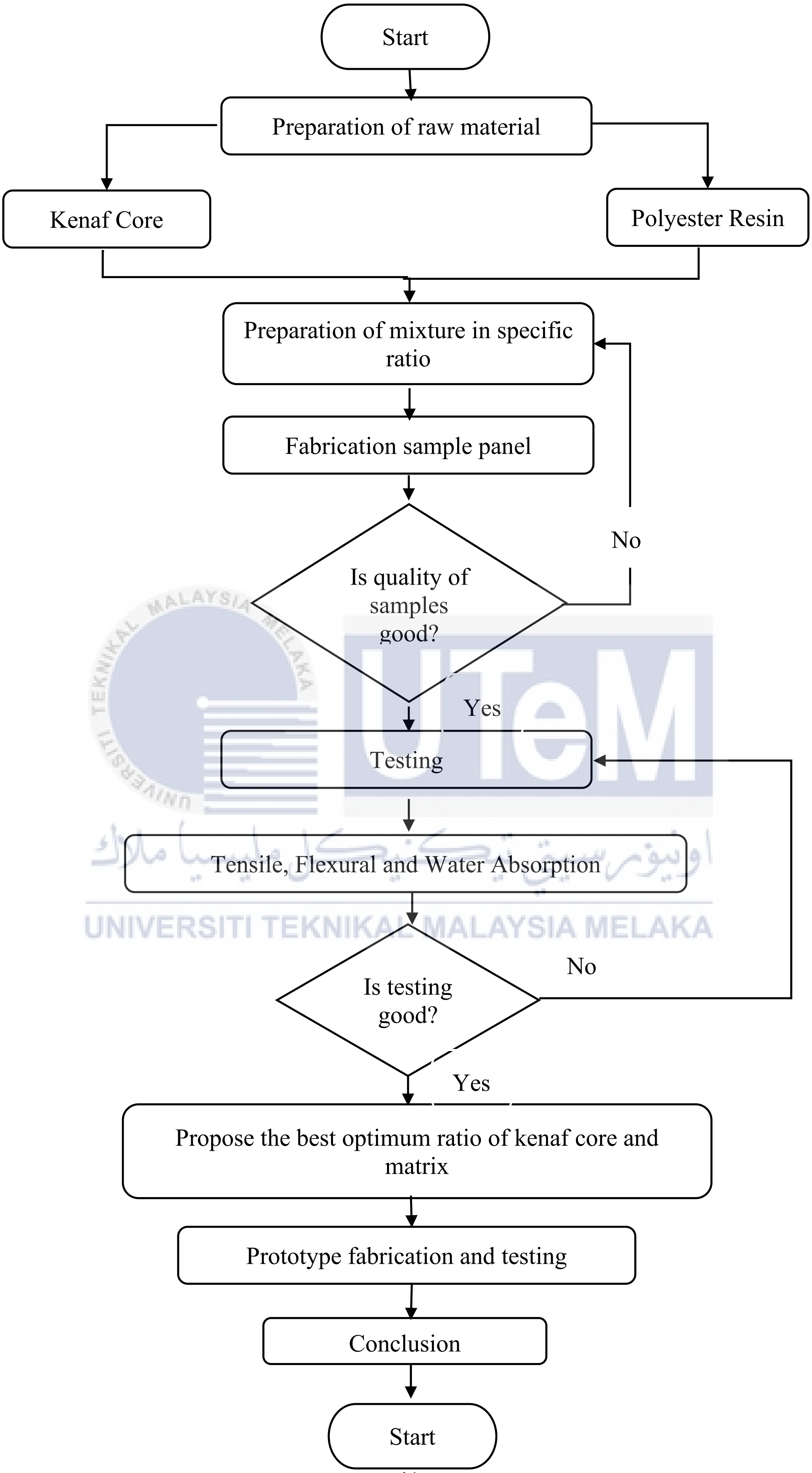


Figure 3. 1 Research flow cart

3.2 Preparation of Raw Materials

The materials are carefully chosen and prepared prior to the tests. The choice of materials is important since it affects how well the product turns out. This preparation aims to ensure that enough matrix which is kenaf core material is ready before the fabrication process is started. In addition, the study's basic materials included matrix, kenaf core . The kenaf core acts as a reinforcing agent and the polyester acts as the matrix component in the manufacture of roof tiles. To comply with the standards, the size and amount of the materials are precisely measured. Additionally, the manufacturing method that will be used in this study is based on earlier research and is suggested as a result of that research.

3.2.1 Polyester as matrix material

Polyester is the main component or matrix material in this study. Polyester composites are widely utilized, in part due to their affordability. This material finds extensive use in the construction of yachts, automobiles, tanks and piping, and artificial stone. They are a popular option in construction applications because of their mechanical performance to cost ratio. However, the utilization of peroxide as a catalyst for polymerization and styrene as an agent for crosslinking in these resins can negatively impact human health, causing eye and skin irritation or even brain damage. Polyester resins are considered to have a greater environmental impact than epoxy and vinyl ester resins (Maxineasa & Taranu, 2018).

Polyester resins are widely utilised in engineering applications because to their low cost, however their use in high-performance composites is limited. They may be designed to have a variety of qualities, ranging from flexible and malleable to hard and brittle (Maxineasa & Taranu, 2018). Polyesters, while being inexpensive, having low thickness and fast solidifying time, exhibit lower mechanical properties compared to other thermosetting materials. They also have limited resistance to weathering and a notable inclination to shrink. The use of a thermoplastic component can help to reduce volumetric shrinkage. These resins may be designed to cure at room or increased temperatures, allowing for greater processing flexibility (Maxineasa & Taranu, 2018).The cost of the polyester resin will be RM70.00 for five kilogram as shown in Figure 3.2.

Figure 3. 2 : Polyester resin and harderner

3.2.2 Kenaf core composite

For this study, the use of KC as a reinforcing material was carried out. As was indicated before, KC possesses additional characteristics that have been uncovered by experts. These characteristics include a strong capacity to absorb fluids and superior thermal insulation. There is little doubt that kenaf fiber performs more effectively than other types of fiber, but it also carries a higher price tag. As was said before, kenaf plants have a bast or fiber content of approximately 30%, while the remaining 70% is composed of the core. As a direct consequence of this, a greater quantity of KC was created as a byproduct of the harvesting of the kenaf plant than was the fiber. reducing its cost by sacrificing some of its mechanical capabilities in order to do so. For the purpose of this research, KC is utilized as a material for reinforcement. In the course of this research, KC of several sizes was used so that the researchers could determine which variety of KC worked best when coupled with clay. Figure 3.3 shows the physical appearance of KC for all the size while Table 3.1 depicts three different varieties of shredded KC including the price. These products were supplied by the Lembaga Kenaf dan Tembakau Negara (LKTN).Table 3.3 shows the physical and chemical properties of KC.

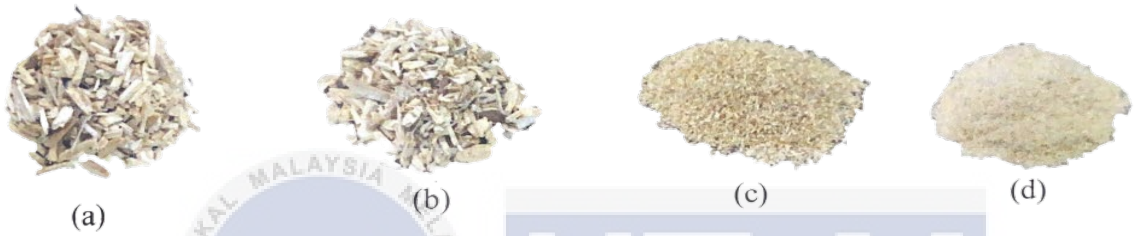


Figure 3. 3 :Variation of kenaf core size (a) 20 mm; (b) 10 mm; (c) 20 mesh; (d) 40 mesh

Table 3.1: Price of kenaf core based on mesh size

Mesh size	Quantity (kg)	Price (RM)
20 mm	10.0	8.50
10 mm	10.0	9.00
20 mesh	10.0	11.00
40 mesh	10.0	20.00

Table 3.2: Chemical composition and physical properties of kenaf core (Nayeri et al., 2013)

Microfibril size / Chemical content	Core
Fibril length, L (mm)	0.75
Fibril width, W (mm)	19.23
L/W	39
Lumen diameter (lm)	32
Cell wall thickness (lm) Cellulose (%)	1.5
Lignin (%)	19.2
Hemicellulose (%)	29.7
Ash content (%)	1.9
Holocellulose	87.2
α - Cellulose	49.0

3.3 Preparation of Mixture

Samples must be created before the experiment is carried out. There are steps that must be completed before the fabrication process in order to manufacture the sample. The importance of this stage is further underscored by the fact that when testing is done, the results will be seen as fair because every sample was subjected to the same parameter and had the same composition across all types.

The kenaf core was carefully weigh using the digital scale to ensure the ecaxt kenaf core that will be needed is corectly weigh.The polyester resin than weigh with the ratio of 1:3 from the kenaf core weight. Than the harderner gonna be weigh 1.8% to tthe weight of the polyester resin.After kenaf core ,polyester resin and harderner it will be mix togeteher until all of the kenaf core was coated with polyester resin .

Table 3.4 shows the sample code for kenaf core and polyester resin with the different size of kenaf core. The reason why the composition of the material is for each sample are because the purpose of this research is to propose the best size of kenaf core with polyester to produce the roofing material or roof tile.

Table 3.3: Sample Code of Composite Material

Sample Code	Kenaf Core Size
C1	40 Mesh (0.42 mm)
C2	20 Mesh (0.84 mm)
C3	<3mm (1-2 mm)
C4	<10mm (9- 5 mm)
C5	<20mm (19 – 10 mm)

3.4 Manufacturing of Sample

In this study, the mould of the specimen as shown in figure 3.4 is fabricate in the dimension of 250 mm x 150 mm by using laser cut machine.The mixture of kenaf core and polyester resin gonna be put inside the mould. After that as the cold press using the hydraulic press for 1 tonne will be applied.To make it easier to demold after hardening, silicon spray is put to the surface of the mold. After that the sample will be dried for 24 hours at a temperature of approximately 28 °C or at a room temperature under the shade. The sample will dry quickly if it is heated to a high temperature. The samples will be placed on shelves in shade to prevent drying out too quickly. If the tile dries too quickly, it could become distorted or deformed.

Figure 3.4 : Mold of fabrication process

3.5 Testing

Testing is an important part of this research since it serves as an evaluation to determine whether the material or product in question can be employed in a commercial setting. The following types of testing were selected for this investigation: flexural testing, heat testing, tensile testing, and water absorption testing. This examination will be carried out in accordance with the standard that has been determined to be ASTM. Following the rules that have been established will lead to the greatest possible results, and using the information that has been gathered will allow for analysis and discussion to take place. The sample that has the dimensions of an industrial roof tile will be used in some of the testing that will be done.Table 3.6 shows the testing standard that will be used.

Table 3.4: Testing standard

Testing	Testing Standard
Tensile Test	ASTM D638
Flexural Test	ASTM D790
Compression Test	ASTM C1358
Impact Charpy Test	ASTM D6110
Heat Test	ASTM C1470
Water Leaking Test	ASTM D570
Swelling Test	ASTM D570

3.5.1 Tensile test

Tensile testing is an important way to evaluate roofing materials because it tells us a lot about their mechanical properties, strength, and how well they work when they are stretched. It can be used to find out how strong roofing materials are under strain and how much force a material can take before it breaks or changes shape permanently. This knowledge is very important for figuring out if a material can stand up to wind forces or structural stresses without breaking. As part of the standard test technique for determining the tensile strength of laminated composite specimens established by ASTM D3039, the specimen will be rotated under a torsion force. The specimen will be drawn with a crosshead speed of 2 mm/min, which is based on the standard ASTM D638. This will continue until the specimen fails. The stress-strain curve is determined through the experiment, and its results will be discussed and analyzed later.The dimension of the specimen is shown in the Figure 3.5.

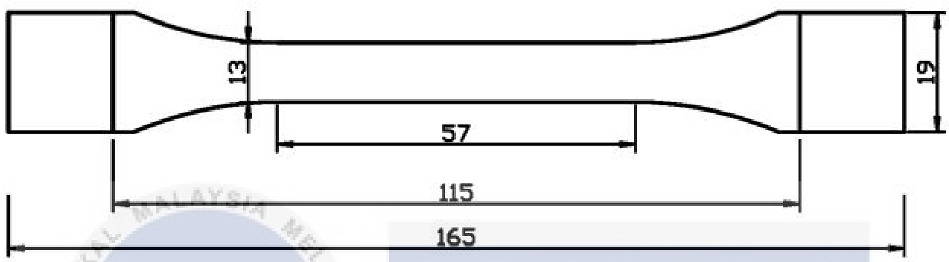


Figure 3. 5 Dimension of tensile testing

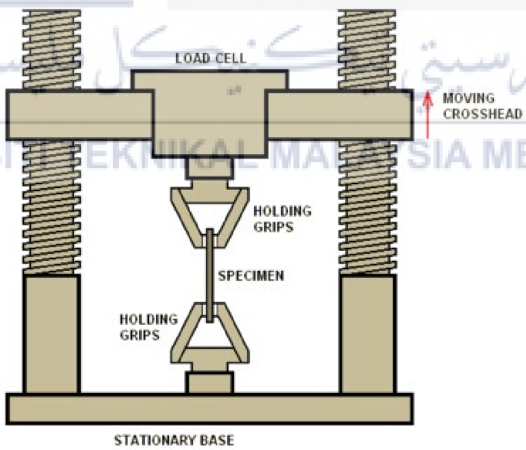


Figure 3. 6 : Tensile testing set-up

3.5.2 Flexural test

Due to the fact that the roofing material must be able to withstand a substantial amount of load or impact, flexural is an important consideration in this research. In order to carry out this test in compliance with the regulations of ASTM C1341, the sample being placed between two supports and a force being applied to the center of the sample, causing the samples to bend. The outcomes of this test will serve as the basis for calculating the sample's modulus of rupture. The machine that will be tested will be put through its paces on the Flexural Strength Machine, which can be found in the material testing laboratory at UTeM. The dimension of the specimen is shown in the figure 3.7. The machine has a loading rate of 2 mm/min and can support up to 100 kN of force when it is under load as shown in Figure 3.8

Figure 3. 7 Dimension Of Flexural Testing Specimen

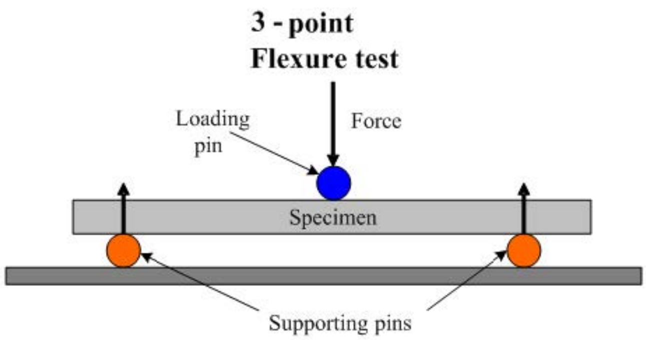


Figure 3. 8 : Diagram of flexural test

3.5.3 Compression test

The Compression testing on composite materials performs several critical purposes in determining their mechanical behavior and structural integrity. In terms of strength evaluation, this test can aid in determining the composite material's final compressive strength. This is the maximum compressive stress that the material can withstand before failing. This test is also used to ensure that the manufactured composite materials fulfil specified criteria and have uniform mechanical properties. The test identifies the manner and pattern of failure by compressing a composite material until failure, providing insights into the material's structural weaknesses and failure mechanisms. This test helps assess how a composite material will withstand compressive loads over time, contributing to predictions of its long-term durability. In order to carry out this test in compliance with the regulations of ASTM C1358, the sample will be brought into two compression platens together to compress the sample. Applied force and crosshead displacement data are collected in real time and the test continues until the sample fails or the tester chooses to end the test.

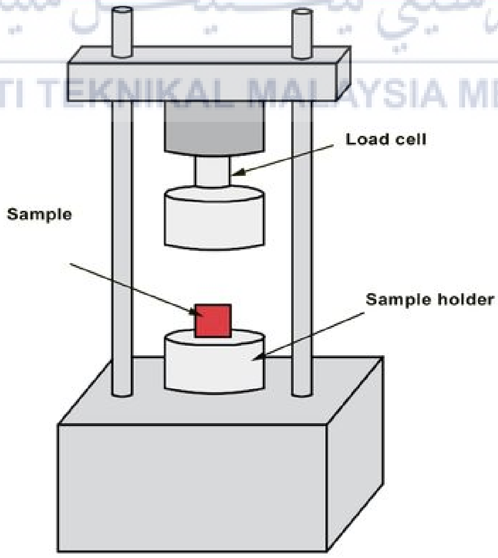


Figure 3. 9 Diagram of compression test

3.5.4 Charpy impact test

Impact testing is a form of mechanical testing used to evaluate a material's resistance to transient, high-energy loads as well as its ability to withstand force before breaking. The sample specimen of impact test are follow ASTM D6110 method testing. A standardised specimen is tested by striking it with a pendulum or falling weight at a predetermined pace. For a standard pendulum impact test, a pendulum is raised to a predetermined height while the specimen is secured in place horizontally. The pendulum swings down and strikes the specimen after being released. As a result of the impact force, the specimen deforms and eventually fractures. During the impact, numerous factors are measured, including the energy received by the specimen, the maximum force exerted, and the degree of deformation.

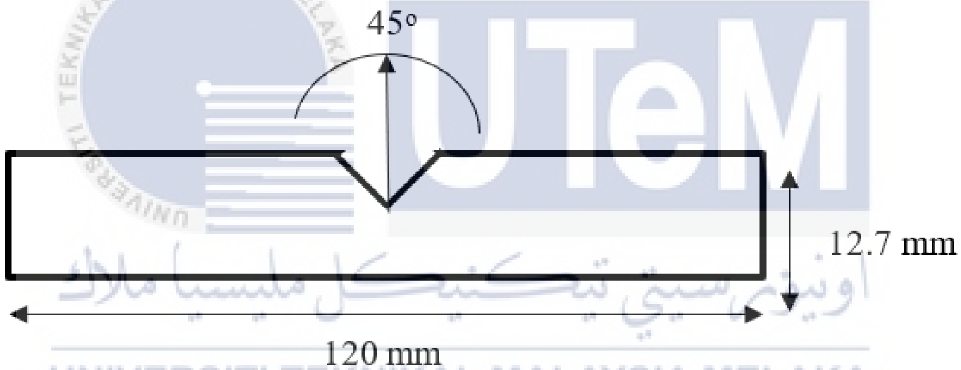


Figure 3. 10 Dimension for charpy impact test

Figure 3. 11 : The Eurotech charpy impact tester

3.5.5 Heat testing

The thermal efficiency of the material that will be used for the roof is essential given that it will be positioned on the top of the house. Since it is common knowledge that roofs are subjected to the sun for longer periods of time, the use of materials that have a great thermal performance and are long-lasting is required. As a direct consequence of this, the primary purpose of this test is to ascertain and evaluate the thermal efficiency of the sample output of the surfaces. The bottom half of the samples will be covered with polystyrenes, as illustrated in Figure 3.6, while the top half of the samples will be left exposed to the heat sourec and will have a thermocouple fastened to the surface. This technique is carried out in accordance with the requirements of standard ASTM C1470, and UTeM will be responsible for providing both the digital thermometer and the temperature sensor, which will be a thermocouple.

Figure 3. 12 : Heat testing set-up

3.5.6 Water absorption test

The test evaluates the roofing material's capacity to resist water penetration and absorb moisture. It specifies the amount of water that a substance can absorb during a given time period. This information is critical in establishing the material's resistance to water damage, which can jeopardise structural integrity and performance.To eveluate the water penetration and moisture absorption there will be two test that will be conducted.The first test will be the water penetration test where square container with a hole on the bottom gonna be placed on top of a sample that has been cut into 100mm x 100mm dimensions as shown in Figure 3.13. To make sure that no water was going to leak at the gap between the container and the sample, the container was fixed onto the sample with the help of epoxy. The weight of the sample with container filled with was water then recorded .The second test was the swelling test, it was performed by the specimen that been cut into 30mm x 30mm size and then submerged into the water as shown in figure 3.14.The test will be perform in the period of 30 days where the data of the thickness and the weigh of the sample will be taken on each 10 days.

Figure 3. 13 : Water penetration test set-up

Figure 3. 14 Swelling Test Set-up

3.6 Fabrication of prototype

After all of the testing is completed and the best KC: Polyester has been determined, it is time to fabricate a real roof tile using the industrial design roof tile while using the same fabrication method with different design of mould as shown in figure 3.15. The design of the roof tile is the singgora tile as shown in Figure 3.9. The purpose of this activity is to examine and determine whether the product can be utilized commercially on public buildings.

Figure 3. 15 Mold for prototype

Figure 3. 16 : Prototype of Roof Tile

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Fabrication and characteristics of composite

In this study, the important aspect is on the detailed construction process and consequent properties of composite panels, specifically five separate samples labelled C1, C2, C3, C4, and C5. The fabrication process necessitates a detailed examination of critical variables to quantify their impact on the mechanical properties and physical characteristics of the composite. The reinforcement material that introduces the kenaf core, with the goal of determining the best combination for providing increased strength in composite panels. Each specimen is coded, as detailed in table 4.1, allowing for a systematic examination of the link between fabrication factors and composite panel properties. This method provides a thorough examination of the interactions between various fabrication configurations, providing useful insights to produce durable composite materials for roofing material.

Table 4. 1 Sample Code

Sample Code	Kenaf Core Size
C1	40 Mesh (0.42 mm)
C2	20 Mesh (0.84 mm)
C3	<3mm (1-2 mm)
C4	<10mm (9- 5 mm)
C5	<20mm (19 – 10 mm)

4.2 Mechanical Testing

This chapter focuses on presenting the findings and participating in a detailed discussion of the mechanical tests' conclusions. Tensile testing revealed the material's axial strength, flexural testing revealed its bending behavior, compression testing reveals the material compression strength and impact testing revealed its resistance to rapid force. The meticulously acquired experimental results from these experiments form the basis for a thorough assessment of the mechanical performance and prospective uses of the polyester epoxy embedded with kenaf core.

4.2.1 Tensile test analysis

This test determines a material's tensile strength and modulus of elasticity. This test measures both the force required to break the specimen and the specimen's extension. To determine the tensile strength of a material, ultimate tensile strength (UTS) data must be employed. After the sample was subjected to stress until it split, force was measured. The tensile load is displayed against the change in length, or displacement, of the material. The load is then translated to stress, and the displacement to strain. To produce the composite specimen for testing, the ASTM D-3039 standard is applied.

The overall tensile strength of the material is the greatest strain that can be maintained and is considered the maximum stress imposed in the test sample by the original cross section of the specimen. While the modulus of elasticity or elastic force characterizes a material's properties while it is stressed, deformed, and then returns to its original shape after the stress is removed. Figures 4.1 demonstrate the variance in tensile strength and elasticity for five sample (C1-C5).

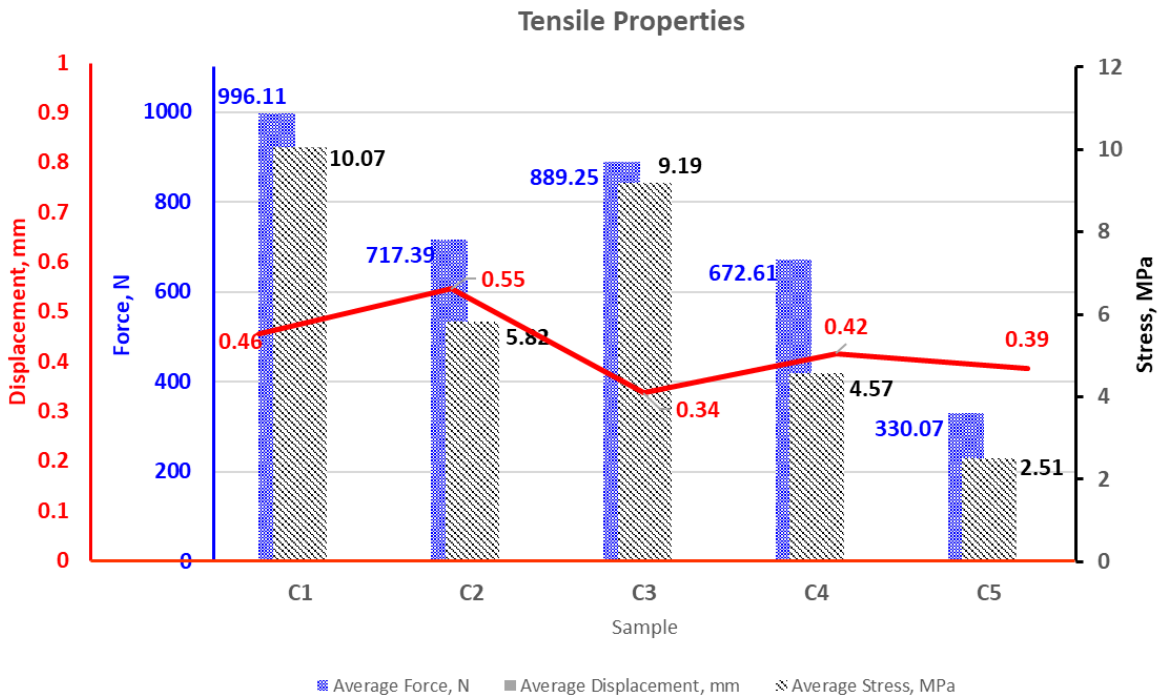


Figure 4. 1 Tensile properties

In this research, five samples of polyester resin embedded with kenaf core were utilized namely C1, C2,C3,C4 and C5. Each sample represents a variation in the size of kenaf core. Figure 4.1 visually illustrates the maximum force values for tensile strength obtained from the combination of kenaf core and polyester resin. This figure serves as a graphical representation of the tensile strength performance across the different sizes of kenaf core, providing a clear insight into the influence of various sizes of kenaf core on the composite material's mechanical properties.

The analysis of the graph indicates that among the different sizes of kenaf core used as reinforcement, C1 exhibits the highest force value at 996.11 N, while C5 shows the lowest force value at 330.07 N, representing a decrease of 666.04 N. The analysis of the displacement graph reveals that C2 exhibits the highest value at 0.55mm, while C3 shows the lowest value at 0.34 mm. The displacement data on the graph appears scattered, lacking a discernible trend or pattern, suggesting a degree of variability in the observed values Based on the stress graph analysis, it can be shown that C1 has the highest stress value which is 10.07 MPa among the different sizes of kenaf core employed as reinforcement, while C5 has the lowest stress value of 2.51 MPa, indicating a decrease of 7.56 MPa.

As the mesh size increases from C1 to C5, the tensile testing graph shows a constant downward trend, indicating a link between sample size and tensile strength. This decrease is consistent with the idea that bigger mesh sizes may impair the material's capacity to sustain tensile pressures, presumably due to more voids and lower material density. A major exception is sample C2, which has a lower tensile strength than both the preceding C1 and following C3 samples. This unexpected outcome necessitates serious consideration.

Variations in material composition, inconsistencies in the production process, or unique properties of the C2 sample could all contribute to this anomaly. Further analysis is required to comprehend the exact conditions surrounding sample C2 and decide if the deviation is due to experimental error or a special attribute of that mesh size. This anomaly emphasizes the significance of scrutinizing individual data points and taking into account any outliers within the dataset.

While the general trend shows that tensile strength decreases with bigger mesh sizes, the appearance of anomalies such as C2 highlights the complexities of material behavior. It emphasizes the importance of a sophisticated understanding of the interaction between mesh size and mechanical properties, taking into consideration the complexities that influence material performance. Overall, this tensile testing graph provides useful insights into the link between mesh size and tensile strength, recommending a detailed investigation of individual samples for a more complete comprehension of the data. The failure mode of the the sample is shown in Figure 4.2 prove that a bigger kenaf core size have a weaker relationship between kenaf core and polyester resin

Figure 4. 2 The failure mode of kenaf core mix with polyester resin

4.2.2 Flexural test analysis

The flexural performance of the samples was evaluated in this part utilizing the Universal Testing Machine (UTM), as shown in Figure 4.3. The samples used for testing were 12.7 mm x 127 mm in size. The data was rigorously recorded, and graphs were created to aid in the analysis and comparison of flexural performance across five different size of sample. The ASTM D790 standard was followed during the testing, with the crosshead speed set at 2 mm/min. Furthermore, the bottom support was set at a height of 60 mm. This standardized testing method assures consistency and reliability in analyzing the flexural properties of composite samples, providing significant insights into their mechanical behavior under bending stresses.

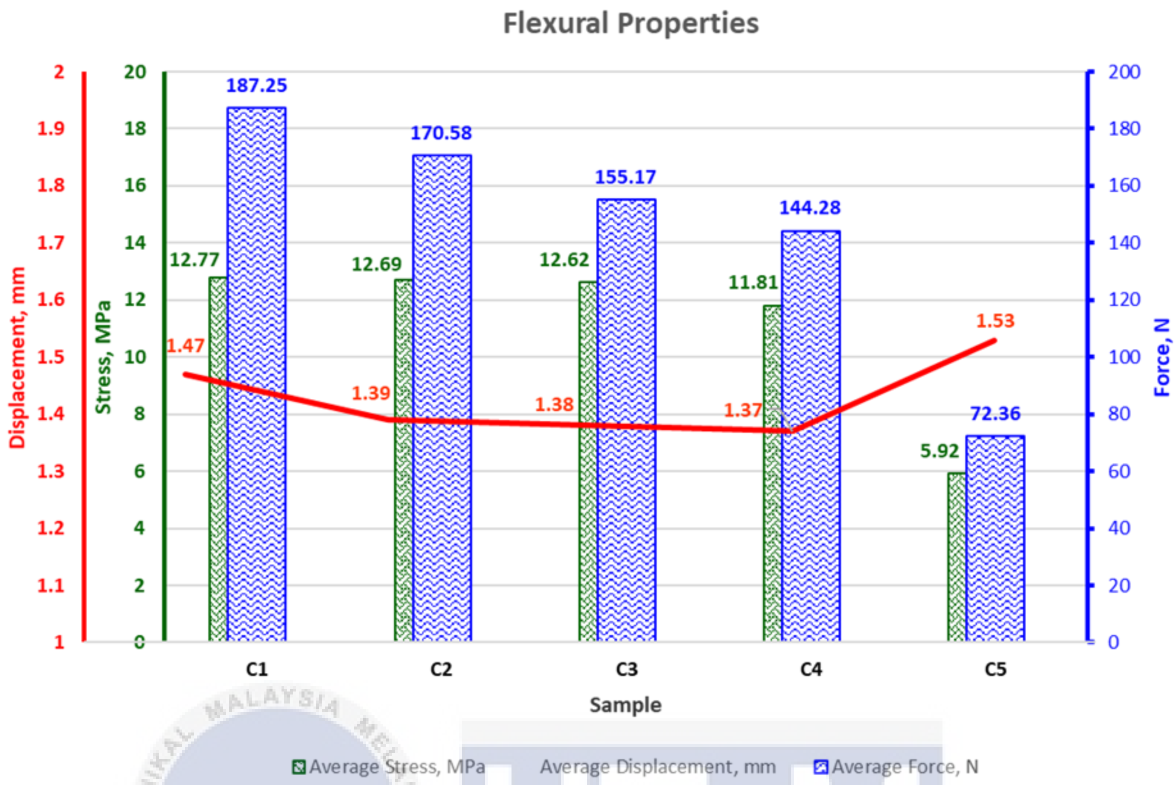


Figure 4. 3 Flexural properties

According to the graph, C1 has the maximum stress value of 12.77 N among the different sizes of kenaf core employed as reinforcement, while C5 has the lowest stress value of 5.92 N. The displacement graph analysis reveals that C1 also has the maximum value at 1.53 mm, while C3 has the lowest value at 0.34 mm. The displacement data on the graph show no clear trend or pattern, indicating some fluctuation in the recorded values. According to the results of the force graph analysis, C1 has the maximum force value of 187.25 N among the various sizes of kenaf core used as reinforcement, while C5 has the lowest force value of 72.23 N, showing a decrease of 114.89 N.

The flexural testing graph displays a consistent and discernible trend as the mesh size increases from C1 to C5.The observed decrease in the measured value as mesh size increases shows a relationship between sample size and flexural strength. This tendency is consistent with the hypothesis that increasing mesh sizes will result in lower flexural strength. The steady decline in flexural strength could be due to bigger voids and lower material density in larger meshes. The structural integrity of the material may be affected as the mesh size rises, resulting in a reduced ability to bear flexural loads.

The data's evident pattern enhances our understanding of how mesh size affects the material's flexural capabilities. The consistency of the decline across numerous samples give support to the hypothesis that increasing mesh size is associated with a decrease in flexural strength within the measured range. It is important to note that the observed trend is based on the tested mesh size range, and extrapolating beyond this range may necessitate more testing and analysis. Furthermore, real-world applications and external circumstances should be considered when interpreting these findings to ensure their practical applicability. Overall, the provided graph adds to our understanding of material behaviors in flexural applications by providing significant insights into the link between mesh size and flexural strength.Figure 4.4 show the failure mode of the flexural testing that show the sample with the smaller size of core (C1-C3) have a cleaner breaking point than sample with bigger kenaf core size (C4 & C5) that prove the bigger kenaf core size have a weaker relationship between kenaf core and polyester resin than the smaller one.

Figure 4. 4 The failure mode of kenaf core mix with polyester resin

4.2.3 Compression test anlysis

The compression load of the samples was evaluated in this part also utilizing the Universal Testing Machine (UTM). Mechanical properties of composite materials can be altered by giving a load to the composite materials. Compression testing involves a sample of the composite material wil be bring into two compression platens together to compress the sample. Applied force and crosshead displacement data are collected in real time and the test continues until the sample fails or the tester chooses to end the test. In this test the specimen was cut into 100mm x 100mm for every sample. The sample was compress 60 % of it thickness with cross head speed of 2 mm/min. The graph force vs displacement was taken as shown in Figure 4.5 .

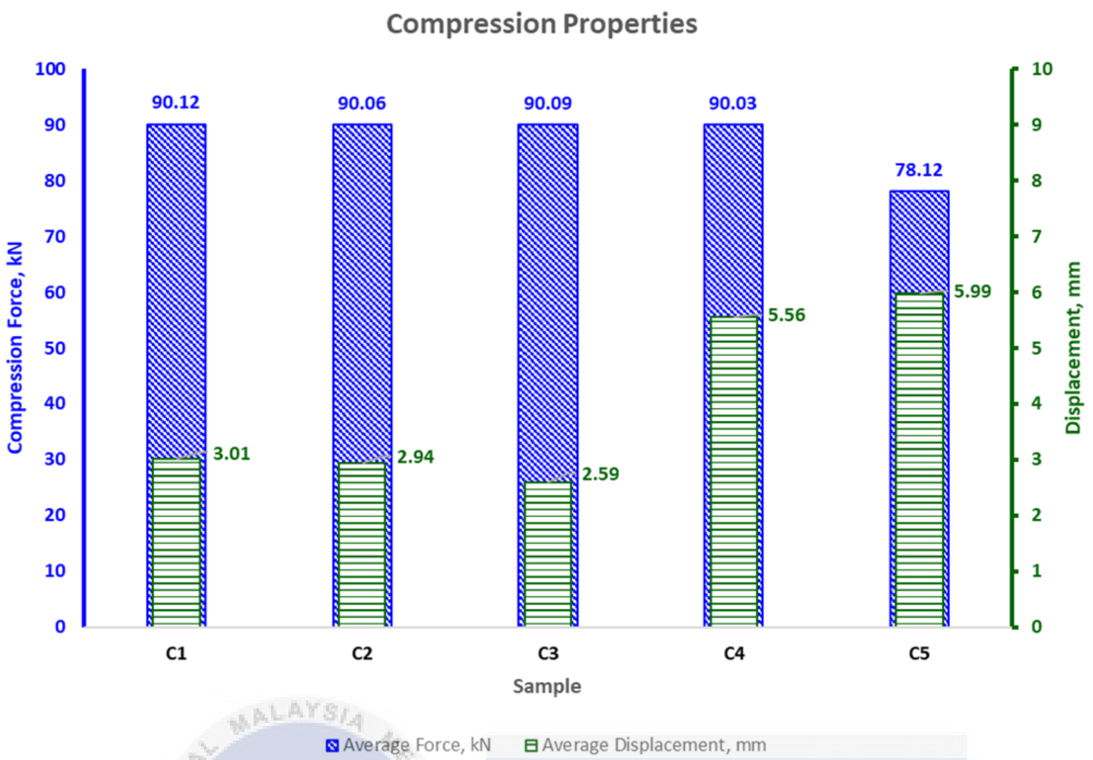


Figure 4. 5 Compression properties

According to the graph, the compression characteristics values for the five composite samples C1, C2, C3, C4, and C5 is shown. The graph displayed the displacement and compression force data. It was found that sample C5 had the lowest compression force value, measuring 78.12 kN, while sample C1 had the greatest value, measuring 90.12 kN. Additionally, sample C5 was found to have the most displacement value measured at 5.99 mm, while sample C3 had the lowest displacement detected at 2.59 mm. After the testing was over, every sample reappeared in the proper shape and without any cracks.

As the mesh size grows from C1 to C5, the compression testing graph shows a clear and consistent decreasing trend. This pattern indicates a connection in which smaller mesh sizes have stronger compression strength than bigger mesh sizes. The findings reflect the notion that finer meshes give superior structural support due to enhanced particle interlocking. The decrease in compression strength seen can be due to the greater porosity and lower material density associated with increasing mesh sizes. Larger empty gaps in the mesh structure may contribute to a lower resistance to compressive forces.

The trend's systematic character increases the credibility of the results, implying a high association between mesh size and compression strength. This knowledge can be useful in applications where compression resistance is important, such as construction materials or industrial filtering systems. The graph's evident trend establishes a platform for predictive modelling or mesh size optimization based on specific compression strength needs. However, other elements that may influence the material's performance, such as the type of material, production procedures, and ambient conditions, must be considered. In conclusion, the compression testing findings show a consistent link between mesh size and compression strength, providing useful information into the material's behaviors under compressive stresses.

4.2.4 Charpy impact test analysis

The pendulum charpy test was performed on kenaf core reinforced composite samples in accordance with ASTM D6110 standards. Each sample was precisely prepared for testing, measuring 10 mm x 55 mm in actual thickness with a notch. The Charpy test, represented in Figure 4.6, included applying an impact load of 8.8 kg using the Eurotech Charpy-Izod impact tester.

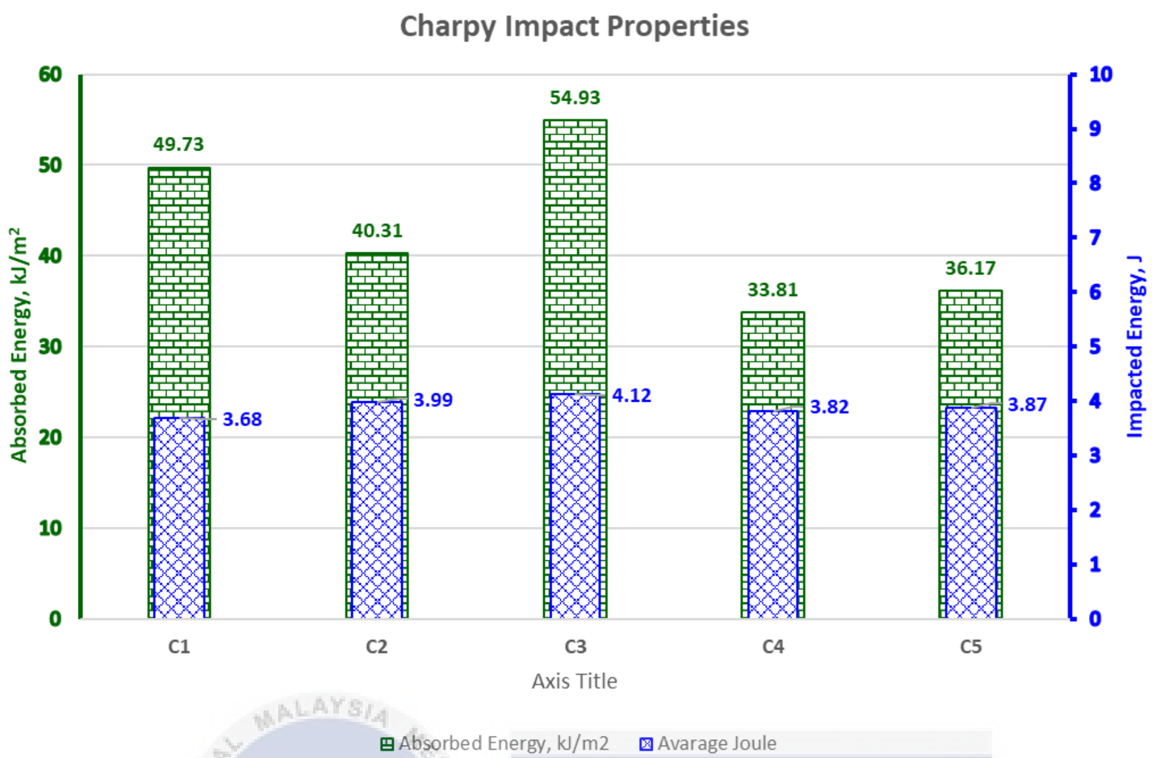


Figure 4. 6 Charpy impact properties

The absorb energy values for each of the five composite samples which is C1, C2 , C3, C4 and C5.The data of the absorbed energy and impacted energy was shown in the graph. It was discovered that C3 had more absorb energy than any other sample. The highest absorption energy measured is 54.93 kJ/ m. In comparison, C4 has the lowest absorb energy which is 3.68 kJ/ m². All the sample break into two pieces after been hit with pendulum's tremendous impact force because the specimens absorb the energy as shown in Figure 4.7. The impacted energy graph also showed that sample C3 come on top with the highest impacted energy measured of 4.12 J while sample C1 come with the lowest impacted energy which is 3.68 J.

The Charpy impact testing graph depicts an unusual scenario with five different mesh sizes for every sample which is C1,C2,C3,C4 and C5 and a randomly distributed distribution of data points. This dispersed pattern indicates that there is no clear trend or systematic relationship between mesh size and Charpy impact strength. The scattered results could be attributable to a variety of variables, including material heterogeneity, differences in sample preparation, or the influence of additional factors not considered by the mesh size alone. The Charpy impact test assesses a material's resistance to abrupt stress, and the dispersion suggests that mesh size alone may not be the most important predictor of impact strength in this context.

Understanding data scatter is critical for accurate interpretation. It could imply the presence of other relevant elements that should be looked into further. Material composition, contaminants, or the individual manufacturing process could all have a major impact on the recorded data points. In practice, this dispersed data suggests that selecting a precise mesh size may not be the only factor affecting the material's Charpy impact resistance. A thorough examination of various material attributes and manufacturing conditions is required.

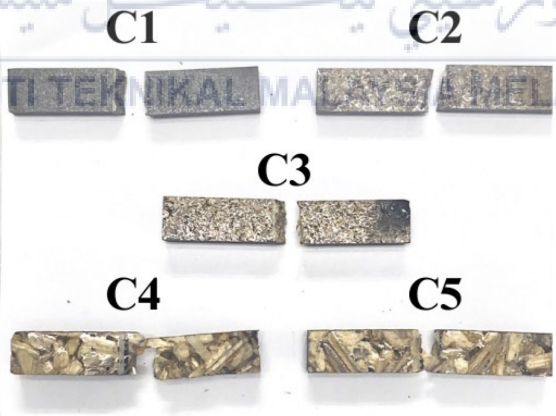


Figure 4. 7 The failure mode of kenaf core mix with polyester resin

4.3 Physical Testing

The purpose of conducting the physical test is intended to assess how the material interacts with environmental factors. Heat testing is required to evaluate the material's reactivity to elevated temperatures as well as its performance under heat-related circumstances. This testing helps to understand how the material performs when exposed to high temperatures, which is important for applications where heat resistance is required. Heat testing reveals information on a material's thermal stability, structural integrity, and propensity for deformation or degradation at high temperatures. Leaking test and swelling tests aid in determining the material's resistance to water absorption, which is critical for preventing degradation, mold growth, and structural compromise over time. Furthermore, swelling tests disclose how much the material expands when exposed to moisture, offering information into its dimensional stability. These evaluations are critical in ensuring that the composite material maintains structural integrity and performance under changing weather conditions, eventually adding to the roofing system's longevity and dependability.

4.3.1 Heat test analysis

The heat transmission testing is a critical aspect of evaluating the thermal performance of roofing materials, particularly those composed of composite materials. This testing is carried out following the ASTM C1470 standard. The sample was cut into 100mm x 150mm using bend saw. The test was conducted by placing the specimen on a hot plate that has a steady temperature of 70 degree Celsius for 30 minutes. After 30 minutes the reading is taken on the surface of the sample using an infrared thermometer. The surrounding temperature of the sample is also being taken after 30 minutes. The data taken is shown in the table and graph.

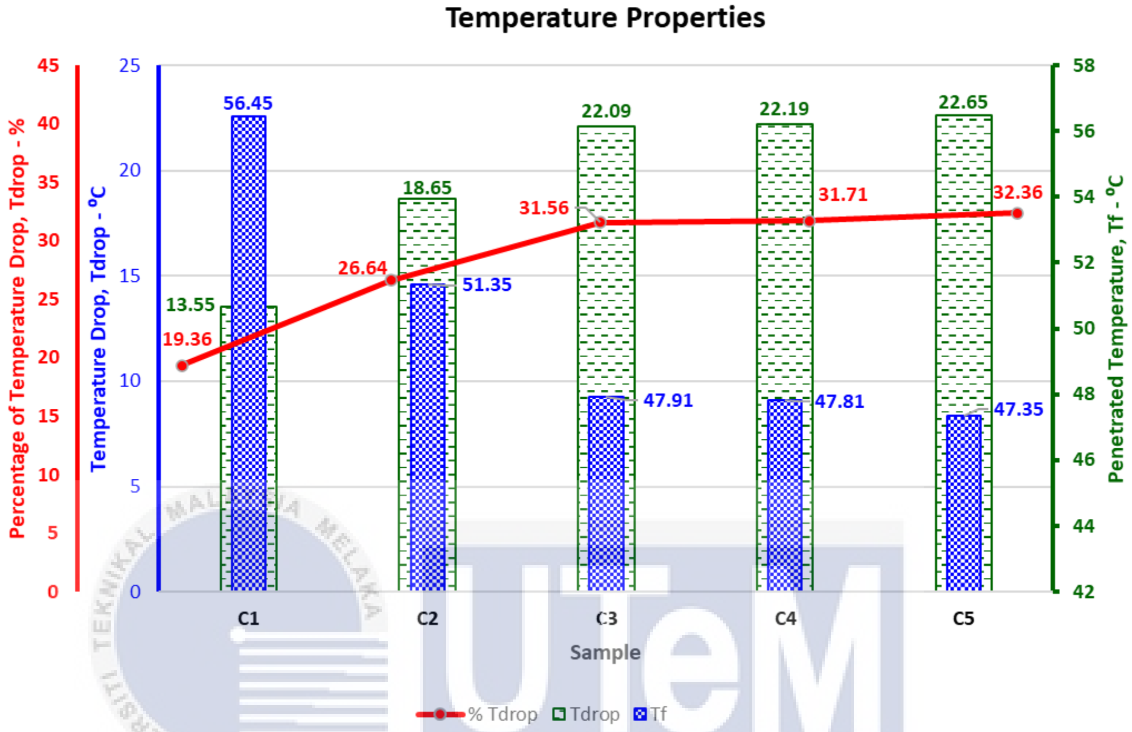


Figure 4. 8 Temperature properties

As the mesh size increases, the percentage of temperature drop graph shows a steady upward trend, starting from sample C1 with the lowest percentage value of 19.36 % and sample C5 with the highest value of 32.36 % suggesting a good association between mesh size and temperature reduction. This is consistent with the hypothesis that improved heat dissipation is encouraged by larger mesh sizes. This positive association implies that a more significant temperature drop is facilitated by greater mesh sizes. A larger mesh size probably improves ventilation by facilitating better heat dissipation and air movement. This discovery has important ramifications, especially for applications like roofing materials where efficient temperature control is essential. The temperature drop that progressively slopes downward as mesh sizes rise is consistent with the hypothesis that better air circulation is facilitated by more open mesh.

The temperature drop graph reveals a consistent and noticeable decline trend as the mesh size increases across the five samples. Because of the inverse relationship between sample size and temperature reduction, higher mesh sizes appear to be more effective in promoting heat dissipation. The tendency is most noticeable in the comparison between C1 and C5, with C5 having the greatest temperature decline form 70 c to 47.35 c and C1 has the lowest temperature drop from 70 c to just 56.45 c. This could be attributable to the bigger apertures in C5, which allow for better ventilation and airflow, facilitating more effective heat dissipation. The findings emphasize the relevance of mesh size in temperature regulation, providing practical insights for applications where temperature control is crucial, such as building materials or industrial processes.

Across the five different samples, the penetration temperature graph shows a definite rising trend as the mesh size rises. This pattern implies a direct relationship between mesh size and temperature penetration properties. Larger mesh sizes, as represented by C5, have greater penetration temperatures than smaller mesh sizes, such as C1. This observation is consistent with the idea that larger mesh sizes allow for more airflow, potentially leading to higher temperature penetration. This finding also suggests that the degree of temperature penetration in these samples is directly influenced by the mesh size, underscoring the significance of mesh design in controlling the properties of heat transfer in composite materials. More research should investigate maximizing mesh designs for certain uses while taking structural integrity and thermal efficiency into account.

4.3.2 Leaking test analysis

The leaking test is used to assess their resistance to water penetration, as well as the long-term performance and durability of roofing materials in wet environments.The test helps determine the material's water resistance, which is important in assessing if it is suitable for roofing application. This test was conducted following the ASTM D570 Standard.The data has been taken every day for 7 days to look at how much water has penetrated the sample. Figure 4.9 shows the data that has been recorded.

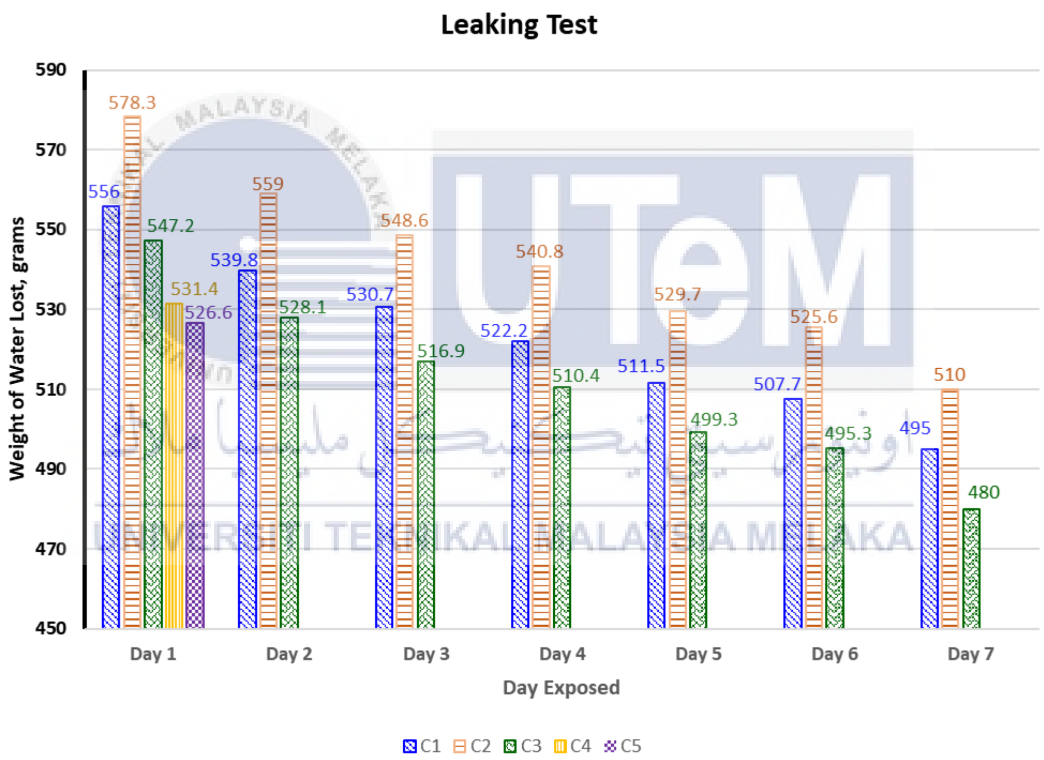


Figure 4. 9 Weight of water lost versus day exposed

The data shows that samples C1, C2, and C3 showed various degrees of water loss, it is critical to investigate the significance of these findings. Sample C1, with the lowest water loss of 10.97 %, demonstrates greater resistance to water penetration. This implies that a particular mesh size, probably greater in this case, is effective at preventing leaks. Samples

C2, with 11.81 % water loss, and C3, with 12.28 % water loss, have somewhat higher permeability but still pass the test. This suggests a key mesh size range that provides a reasonable mix of structural integrity and water resistance. The success of these samples emphasizes the significance of determining the right mesh size for roofing materials.

However, the failure of samples C4 and C5 raises an important point. These samples, with a smaller mesh size, were unable to sustain the water pressure used during testing. This emphasizes that reducing the mesh size below a specific threshold may damage the material's ability to keep water out. The relationship between mesh size and water loss emphasizes the importance of thorough design. While a smaller mesh may appear to be the obvious choice for improved watertightness, there is a delicate balance to be struck. A mesh that is too fine, as seen in C4 and C5, may result in a weakened structure that cannot effectively withstand water penetration.

This observation highlights the importance of optimizing mesh size in the design of roofing materials. While decreasing mesh sizes may improve watertightness, there appears to be a tipping point beyond which additional reductions severely impair performance. This research emphasizes the need of balancing mesh size in roofing materials to obtain optimal waterproofing qualities. The optimization procedure considers not just the immediate result of a leaking test, but also the roofing material's long-term durability and functionality in real-world situations.

4.3.3 Swelling test analysis

Swelling test is used to determine how much a material expands or swells when exposed to moisture. This test is critical for determining the dimensional stability of the roofing material, particularly when it comes into contact with water or variations in humidity. This test also follow ASTM D570 standard. The sample that has been cut into 30mmx 30mm dimension is submerged into water for 21 Days. Before submerging the thickness and weight of the sample without the water content will be weigh. After that the thickness and the weight of the sample will be recorded every 7 days.

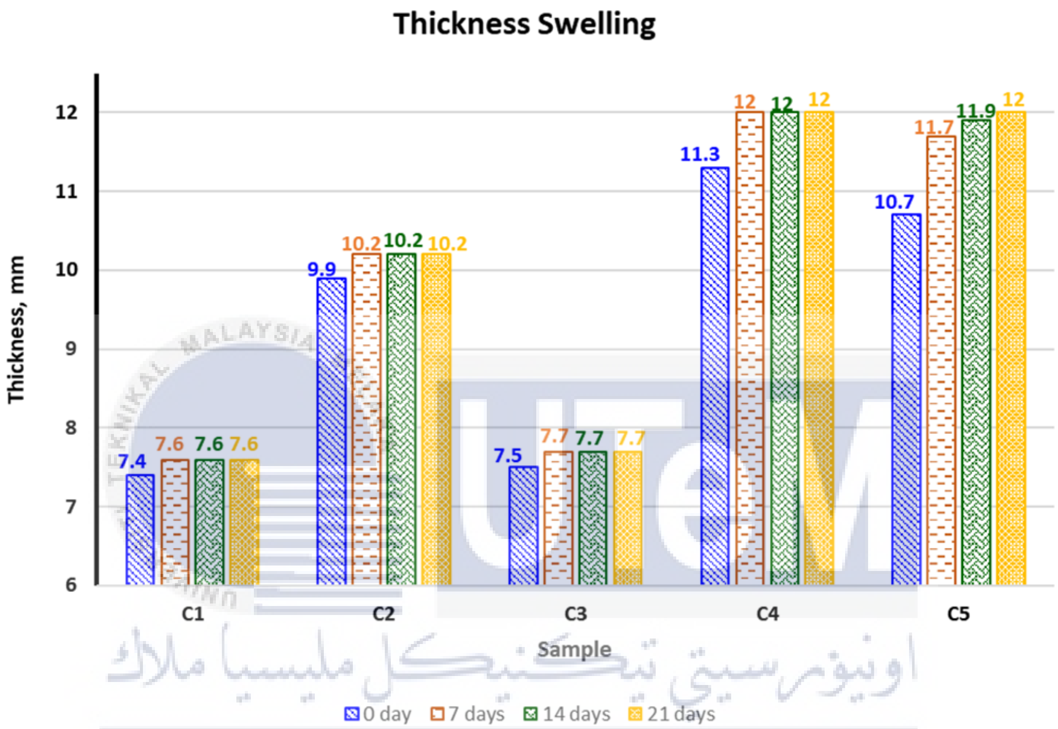


Figure 4. 10 Thickness swelling

The result indicates that throughout the course of the 21-day testing period, the swelling test findings' observed trends offer important insights into the water absorption traits and dimensional stability of samples C1 through C5. Samples C1, C2, and C3 exhibit a commendable resistance to swelling, as evidenced by their small and steady increases in thickness values, which range from 0.2 mm to 0.3 mm during the first 7 days and remain stable for the full 21 days, indicating a strong resistance to swelling followed by stabilization. This behavior implies that these samples resist the dimensional changes caused by water and retain their structural integrity.

However, Sample C4 shows a more noticeable initial thickness rise (value of 0.7), indicating a larger vulnerability to swelling in the first week. But after that, the sample stabilizes, suggesting that there may be a saturation point. Among the most notable is Sample C5, which has a unique swelling pattern that is defined by a significant initial thickness rise (10 mm) during the first seven days. A dynamic response to water absorption and desorption is suggested by the stabilization that followed from days 7 to 14 and the slight increase that occurred from days 14 to 21.

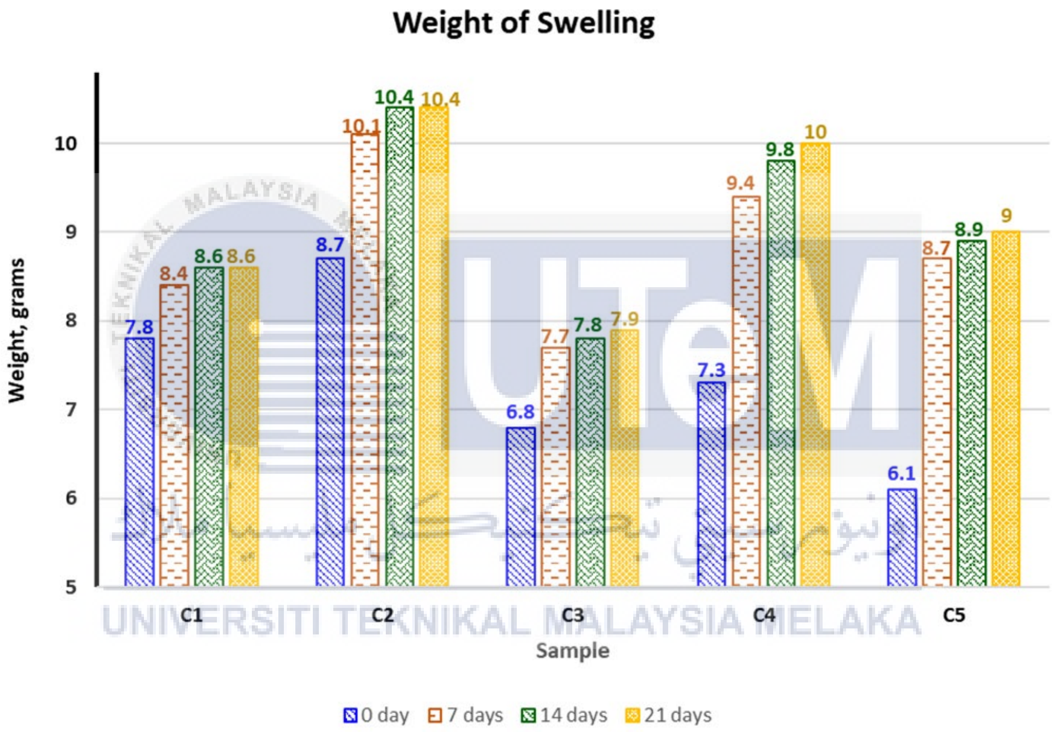


Figure 4. 11 Weight swelling

The trends seen in the weight of swelling test findings provide important information on how various core sizes affect the properties of composite materials meant for roofing applications in terms of water absorption. Sample C1's weight increased gradually by 0.6 g during the first 7 days before stabilizing, which raises the possibility that more controlled water absorption could be achieved with a smaller mesh size. On the other hand, the lower increase after the higher initial gain of 1.4 g in C2 suggests a possible variation in the reaction to water absorption, which could be impacted by a bigger core size. Sample C3 moderate gains and C4 sustained increase parallel have the same patterns as seen in C2. Greater water absorption may be facilitated by larger core sizes, as evidenced by the maximum weight gain of 2.6 g during the first 7 days in C5, which shows the most noticeable effect.

These results highlight the complex link between water absorption and mesh size, which may have consequences for the performance and structural integrity of roofing materials. Achieving the delicate balance between managing water-related concerns in composite materials and meeting structural requirements becomes dependent on the controlled optimization of mesh sizes. Subsequent research endeavors may explore these correlations more thoroughly, providing invaluable insights into customizing mesh dimensions according to distinct roofing material uses and environmental circumstances.

4.4 Performance Summary

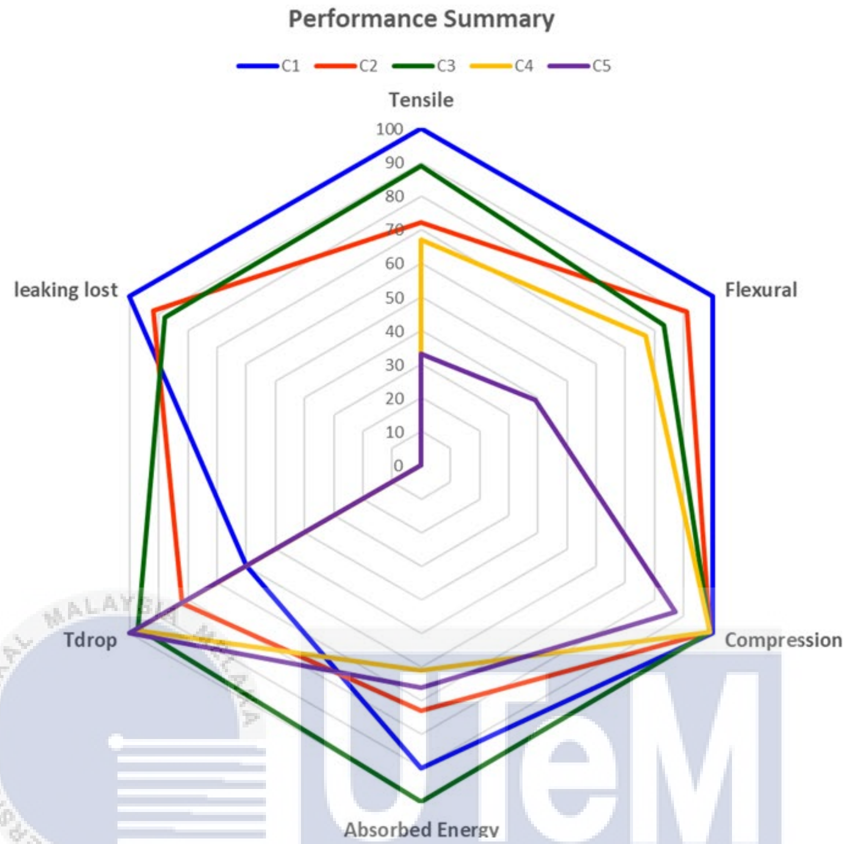


Figure 4. 12 Performance summary

The results in Figure 4.12 showed that from four mechanical properties testing, tensile test, flexural test, compression test and Charpy impact test provide a comprehensive evaluation of the strength, impact absorption, compression ability and durability of the tested samples. These samples, featuring polyester resin embedded with different sizes of kenaf core (C1-C5), exhibit varying levels of effectiveness in enhancing material properties. Notably, the analysis of the tensile test highlights the positive performance of all the samples except for sample C5, showcasing sample C1 with the highest force of 996.11 N, ultimate strength of 10.07 MPa, and a displacement of 0.46 mm. In the flexural test, again sample C1 to sample C4 showcasing a great performance with C1 stands out with the highest values, recording a force of 187.25 N, flexural strength of 12.77 MPa , and displacement of 1.47

mm while sample C5 showing the lowest values recording a force of 72.36 N and flexural strength of 5.92 MPa .The compression test reveals how well the polyester resin embedded kenaf core can withstand compression with sample C1 to C4 showing a great value range 90.03 kN to 90.12 kN further emphasizes a great performance in mechanical properties. In terms of absorbed impact and absorbed energy that been recorded from Charpy impact test, sample C3 show the highest impact absorption of 4.12 J and highest energy absorption of 54.93 kJ/m2 .

Beside the four mechanical testing that has been performed, to ensure that the polyester resin embedded with kenaf core will be a suitable material for a roofing material three physical testing, heat test, water penetration test and swelling test going to provide an evaluation in term of how well this sample can handle the nature in term of water and heat. Specifically heat testing ,sample C5 shows the highest values of temperature drop of 32.36 % followed by sample C4 with 31.71% and sample C3 with 31.56 % while sample C1 with the lowest value of percentage temperature drop of 19.36 % . Analyzing data on water absorption and swelling reveals that show an obvious pattern that suggests that kenaf core size may influence the material's interaction with water. For leaking test, sample C4 an C5 that have a bigger kenaf core size fail the test immediately while sample C1 to C5 with smaller kenaf core size only have a minimal percentage of water leaking range from 10.97 % to 12.28 %.The swelling test also show the same pattern where the thickness and weigh of sample C4 and C5 with bigger kenaf core have the highest value of added thickness and weigh ,where the thickness is 0.7 mm for sample C4 and 1.3 mm for sample C5 in 21 days period. In term of weigh sample C4 have an increase of 2.7 g and sample C5 have an increase of 2.9 g in 21 days period.

From the performance summary, the sample size that will be the most suitable for the application of roofing material is sample C3 with the kenaf core size of 3 mm.Sample

C3 showed the most balanced performance in mechanical testing and physical testing. Selecting sample C3 value as the benchmark for performance comparison to ensure a balance between outstanding results and constant behavior. According to the results of the four mechanical testing, sample C3 consistently was in the top three of the highest values in all parameters evaluated. The second high values obtained in force and ultimate strength for tensile stress, third highest values for the flexural strength, the highest value for impact absorption and energy absorption show that sample C3 is the most effective of the other four sample. In real-world applications that have been tested in physical test the consistent performance of samples C3 implies that a moderate core size may provide an appropriate combination of structural integrity and water interaction. The performance summary demonstrates that, while core size influences mechanical and physical features, a comprehensive understanding of the material's behavior under diverse conditions is critical for making informed roofing material selection selections. The emphasis on the sample benchmark ensures that performance evaluations are based on dependability and feasibility.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

This study provides an overview of the potential applications of kenaf core in construction materials (roof) utilizing a basic hand layup cold press technique. This research study was inspired by the utilization of lightweight and low-cost materials to create a new potential of advanced composite.

The first objective of this research is to fabricate natural composite panel using kenaf core mixed with polyester resin at specific ratios size through simple manufacturing methods which is in this study is hand layup cold press techniques is successfully accomplished with some highlight's such as the following:

a) The hand layup cold press technique with a hydraulic press at 1 ton pressure was successfully offered as a new prospect of natural composites for the manufacture of new roofing material using kenaf core mixed with polyester resin. The natural composite matrix ratio is 1:3, where it offers the most uniform distribution of kenaf core throughout the resin matrix, resulting in a well-bonded and homogenous composite structure.

b) The use of mold in this study also help to provide the uniform dimension for the panel of composite produced .With five different size of kenaf core,C1 ,C2 ,C3,C4 and C5 been used ,the use of mold in this process help to produce all of the panel with the same dimension in order to make sure data that been collected by the testing that will be done can be use.

The second objective of this research is to investigate the mechanical and physical properties of the kenaf core mixed with polyester resin composite panel is achieved. The important points of significant findings that reflected in the achievement of the second objective are summarized as follows:

a) Sample C1, C2 and C3 which have the smaller kenaf core size is performing well throughout all the four mechanical testing. In tensile testing sample C1 shows the highest value of force at 996.11 N and stress value of 10.07 MPa. For flexural testing, once again sample C1 shows the highest force value at 187.25 N and ultimate stress value of 12.77 MPa. In compression testing, sample C1 to C4 recorded a value that close to each other sample C1 still in the first place with the compression force value of 90.12 kN.

b) The result in physical properties testing show that in term of heat testing sample C3 to C5 is doing better than sample C1 and C2 where the percentage drop different between sample C3 to C5 only shows a value of 0.8 % while the difference between sample C1 and C3 is more than 10%.The leaking test and swelling test show the same trend as the mechanical testing where sample C1,C2 and C3 showing a better performance than sample C4 and C5 which have a bigger kenaf core size. Sample C4 and C5 fail the leaking test miserably while sample C1 to C3 showing a great result with values less than 13% of water lost. In swelling test, sample C1 to C3 show commendable swelling resistance that showed by the steady increases in thickness values, which range from 0.2 mm to 0.3 mm during the first 7 days and remain stable for the full 21 days, indicating a strong resistance to swelling followed by stabilization.

c) Result from both mechanical and physical properties highlight the complex link between mechanical properties and physical properties with the kenaf core size. The controlled optimization of core sizes is required to achieve the delicate balance between managing great material properties and commendable physical properties in composite panel.

In addition, the third objective is to propose the best ratio size based on mechanical & physical performance for new roofing material. The following conclusion for this objective is as follows:

a) Despite sample C1 with kenaf core size of 40 mesh (0.42mm) showing a great performance in mechanical testing, the physical properties testing showed the reason why kenaf core size of 40 mesh cannot be proposed as the new roofing material.

b) Sample C3 with kenaf core size of <3mm (1-2mm) showed the most accomplish balance in both mechanical and physical performance that proceed to be the best sized of kenaf core to be the new roofing material.

c) The chosen size not only fulfils but also exceeds the established standards for an excellent roofing material, assuring longevity, robustness, and optimal functionality in a variety of environmental circumstances.

5.2 Recommendations

There are several recommendations that could be suggested to further improve this research. The following recommendation is proposed :

a) Investigating an appropriate coating method to enhance the material's moisture characteristics is rooted in the recognition of the vital role that moisture resistance plays in the longevity and performance of roofing materials.

b) Study the potential application for kenaf core mix with polyester resin for other building material such as floor tile or wall tile.

c) Add another reinforcement material such as woven glass fiber to make it become hybrid composite and help to improve the mechanical properties of the roofing material.

d) Investigate the natural composite material resistance to external conditions such as UV light and temperature variations. Exposure to simulated sunlight over time could be used to test UV radiation resistance. Temperature fluctuation tests could entail exposing the material to a range of temperatures to assess its response and potential changes in attributes.

5.3 Green Element

The creation of a kenaf core-based roofing material promotes sustainability in building operations. Kenaf, chosen for its rapid renewability and minimal resource requirements, provides an environmentally beneficial alternative to traditional materials, with the goal of reducing reliance on non-renewable resources. The study lays a major emphasis on reducing the carbon footprint associated with the production of energy-intensive roofing materials. The initiative aims to drastically reduce greenhouse gas emissions by using kenaf core, a renewable resource, and developing eco-friendly production methods. Furthermore, the emphasis is on energy efficiency, recognizing the critical role that roofing plays in a building's total energy performance. By incorporating thermal insulating qualities and supporting appropriate ventilation, the new material promises to improve energy efficiency. This dual strategy not only improves indoor comfort but also lowers energy consumption for heating and cooling, resulting in a more sustainable built environment. In summary, the study combines sustainable material choices, carbon footprint reduction, and energy efficiency, with the goal of propelling the building sector towards eco-friendly roofing solutions by using the inherent benefits of kenaf core.

5.4 Sustainable Element

The incorporation of kenaf core in the development of roofing materials incorporates crucial sustainable characteristics. Kenaf, a fast renewable resource that requires fewer resources such as water and fertilizers than traditional materials, reduces the ecological footprint associated with roofing production dramatically. This emphasizes a commitment to sustainable construction processes and promotes responsibility for the environment. Aside from being environmentally friendly, kenaf core contributes to long-term benefits in roofing materials. Its thermal and acoustic qualities improve energy efficiency and occupant comfort. As a result, temperature management is improved, heating and cooling requirements are lowered, and energy consumption is reduced, reducing the carbon footprint and greenhouse gas emissions. Furthermore, the moisture resistance of the kenaf core increases the durability and lifespan of the roofing material, lowering the frequency of replacements and associated waste generation. In essence, the research and development of kenaf core-based roofing materials is guided by sustainable principles, promoting resource efficiency, energy conservation, and long-term environmental benefits.

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APPENDICES

APPENDIX A Gant Chart

Gant Chart for PSM 1																	
No	Task project	Plan/Actual	Week														
			1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	Registration of PSM title	Plan														
		Actual														
2	Briefing of PSM and project explanation by supervisor	Plan														
		Actual														
3	Drafting and writing of Chapter 2 Literature Review	Plan														
		Actual														
4	Presentation of draft Chapter 2 with supervisor	Plan														
		Actual														
5	Submission of Chapter 2	Plan														
		Actual														
6	Briefing of Chapter 3 with supervisor	Plan														
		Actual														
7	Writing of Chapter 3	Plan														
		Actual														
8	Submission of Chapter 3	Plan														
		Actual														

9	Discussion of Chapter 1 with supervisor	Plan														
		Actual														
10	Draft and writing of Chapter 1	Plan														
		Actual														
11	Submission of Chapter 1	Plan														
		Actual														
12	Writing Chapter 4 expected result and conclusion, abstract	Plan														
		Actual														
13	Submission of report PSM 1 first draft	Plan														
		Actual														
14	Last correction of the report	Plan														
		Actual														
15	Submission of report to supervisor and panels	Plan														
		Actual														
16	Preparation slide and presentation PSM 1	Plan														
		Actual														

Gantt Chart for PSM 2

No	Task Project	Plan/Actual	Week													
			1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	Discussion planning task with supervisor	Plan														
		Actual														
2	Raw material preparation and equipment	Plan														
		Actual														
3	Fabrication process	Plan														
		Actual														
4	Cutting process and testing process	Plan														
		Actual														
5	Analysis of the data	Plan														
		Actual														
6	Writing of Chapter 4	Plan														
		Actual														
7	Submission of Chapter 4	Plan														
		Actual														
8		Plan														

	Writing of Chapter 5	Actual														
9	Submission of Chapter 5	Plan														
		Actual														
10	Submission first draft report PSM 2	Plan														
		Actual														
11	Submission second draft report PSM 2	Plan														
		Actual														
12	Preparation for presentation of PSM 2	Plan														
		Actual														

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