

**AN INVESTIGATION INTO THE EFFECT OF
COMPACTION ON THE PERFORMANCE OF
COMPOSITE MATERIAL MADE FROM WATER
HYACINTH AND RICE STRAW**

A PROJECT REPORT

submitted by

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of

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In

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DECLARATION

I, Anandhu Krishnan G, hereby declare that, this seminar report entitled 'An Investigation into the effect of Compaction on the Performance of Composite Material made from Water Hyacinth and Rice Straw' is the bonafide work of mine carried out under the supervision of Dr. K A SHAFI, Professor in the department of mechanical engineering, TKM College of Engineering, Kollam. This submission represents my ideas in my own words and where ideas or words of others have been included; I have adequately and accurately cited and referenced the original sources. I also declare that I have adhered to the ethics of academic honesty and integrity and have not misrepresented or fabricated any data or idea or fact or source in my submission. I understand that any violation of the above will be a cause for disciplinary action by the institute and/or the University and can also evoke penal action from the sources which have thus not been properly cited or from whom proper permission has not been obtained. The content of this report is not being presented by any other student to this or any other University for the award of a degree.

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CERTIFICATE

Certified that this report entitled '**An Investigation into the effect of Compaction on the Performance of Composite Material made from Water Hyacinth and Rice Straw**' submitted by '**Anandhu Krishnan G, TKM20MECI02** to the APJ Abdul Kalam Technological University in partial fulfilment of the requirements for the award of the Degree of Master of Technology in Computer Integrated Manufacturing, Department of Mechanical Engineering is a bonafide record of the project presented by him, under my guidance and supervision. This report in any form has not been submitted to any other University or Institute for any purpose.

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ABSTRACT

The conversion of biomass waste resources into value-added products is gaining popularity on a wide range all over the world. Thermal insulation materials derived from agricultural and aquatic waste are becoming more attractive in the building industry to reduce heat loss or gain through the house envelope because of their sustainability and lower environmental impact. This study compared the effect of compaction during preparation on the physical, mechanical, and thermal characteristics of a composite material made from water hyacinth and rice. The primary raw materials used for the production of composite materials are the aquatic floating weed water hyacinth, rice straw, and a suitable binder. The pre-treatment of raw water hyacinth includes drying, crushing, and grinding. Dried rice straw preferably of 1 cm length is used. The raw materials are mixed to obtain a homogeneous mixture in the required proportions. Then, blended the binder into the homogeneous mixture and mixed thoroughly. Prepared a mould of standard dimensions. Poured the mixture into the mould and compacted the mould by applying a constant load. Repeated the procedure for various weight ratios of water hyacinth and rice straw. Finally, prepared thermal insulation materials with different compaction loads. Conducted experimental investigations to determine the properties such as; apparent density, porosity, water absorption, flexural strength, compressive strength, and thermal conductivity. Then compared the optimal properties for the studied insulation materials with that of the commercially available conventional insulations and other bio based insulation materials.

Keywords: Thermal insulation; density; porosity; water absorption; Thickness of swelling; flexural strength; compressive strength; thermal conductivity

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ABBREVIATIONS

WA	Water Absorption
MDI	Methylene Diphenyldiisocyanate
OPC	Ordinary Portland cement
WHP	Water hyacinth petiole
TS	Thickness of swelling
RS	Rice straw
IS	Indian standard
MOR	Modulus of Rupture
PP	Polypropylene
PET	Polyester

NOTATIONS

M	Mass (gm.)
V	Volume (m ³)
M _{sat}	Saturated Weight
M _d	Dry Weight
Q	Heat transfer
t	Time(s)
k	Thermal Conductivity (W/m K)
T ₁	Surface Temperature (k)
x	Thickness (mm)
F	Load (N)
L	Length (mm)
b	Width(mm)
d	Thickness(mm)

CHAPTER 1

INTRODUCTION

1.1 GENERAL BACKGROUND

Numerous researchers have recently concentrated on energy conservation in houses and buildings. Buildings' appropriate insulation plays a critical role in maintaining comfortable thermal conditions for a long time. Installing effective thermal insulation in residential buildings saves 50-60 % of their energy usage. Thus, one of the most significant actions to take to improve the energy efficiency of homes is thermal insulation. Building thermal insulation has been accomplished using synthetic materials. However, insulating materials made of synthetic elements, like fibre glass, can lead to lung cancer [1]. As a result, numerous studies on manufacturing renewable and environmentally beneficial thermal insulating materials manufactured from natural fibres have been studied.

Natural fiber-based materials made from renewable raw material sources are currently gaining popularity. They exhibit excellent acoustic and heat insulation qualities, frequently more significant and more advantageous than synthetic fibres, due to their low mass density and cell structure. Natural fibre insulation offers the advantage of being a renewable source and having low heat conductivity. Another benefit is that it is a renewable resource and doesn't significantly harm the environment. All future construction will adhere to the passive home standard, and all current structures will undergo renovations to satisfy the low-energy building standard [2]. Generally, current development trends closely follow the ideals of sustainable development. People are becoming increasingly concerned about the depletion of energy and raw material resources and excessive air pollution. Recyclability and non-toxic materials are given far more importance.

Natural fibres hold significant possibilities and potential for usage as eco-friendly raw materials, particularly in thermal insulation. Natural fibres also have a low environmental impact and are biodegradable. They have lower environmental impacts and higher fibre content compared to glass fibre. Natural fibre composites are likely to be more environmentally friendly than glass fibre composites in the majority of cases [3]. Both performance and price are competitive on the market for insulating materials. Natural insulating products are now a niche market.

Free-floating, flowered water hyacinth is an invasive aquatic plant native to South America's Amazon Basin. Since the 1800s, it has mostly spread to the tropics and subtropics. In the United States since 1984, Africa since the early 1900s, Asia since 1902, and Europe since the 1930s, water hyacinth has been considered an invasive aquatic plant. Asexual and sexual reproduction is both possible in water hyacinths. In contrast to asexual reproduction, which involves budding through vegetative reproduction systems, sexual reproduction involves the development of seeds through flowers. Within 5 to 15 days, the invasive plant doubles in size. Favorable conditions for the optimum growth of water hyacinth are nutrient-rich water, temperature ranges from 28°C to 30°C, pH value between 6.5 and 8.5, salinity < 2%, 20 mg/L N, 3 mg/L P, and 53 mg/L K [4].

The environment, human health, and economic growth are all significantly impacted by water hyacinths. Some of the social effects are a lack of clean water, an increase in the prevalence of water-borne diseases, community migration, interpersonal conflict, and difficulties accessing water sources. In addition, it reduces the quality and quantity of fish. Water hyacinth also blocks waterways, hampers water transportation, obstructs tunnels and turbines, reduces hydropower output, obstructs irrigation canals, and devalues lake aesthetic value and tourism. The most significant environmental effects are water quality reduction, water loss from increased evapotranspiration, flooding, siltation, and aquatic life decline. Water hyacinths reduce dissolved oxygen, phosphorus, and nitrogen.

1.1.1 Problems Induced by Water Hyacinth

Water hyacinth poses a serious threat to the social advantages that people might gain from an ecosystem.

- It increases the lake's evapotranspiration, which has a substantial impact on the hydrology of the lake.
- It fosters the development of snails and mosquitoes that spread diseases like malaria and bilharzia.
- In major water bodies where the invasive water hyacinth weed is present, the mat of this weed affects recreational and tourism facilities as well as transportation, irrigation, and electricity infrastructures.

- Water hyacinth completely covers lakes and wetlands, out-competing native aquatic species and reducing oxygen levels for fish.
- Large water hyacinth infestations can obstruct river transportation and fishing, harm bridges, and clog dams.
- The invasion of water hyacinth can have an impact on the quality of the water.



Fig.1.1: Photograph of Water hyacinth



Fig.1.2: Problem induced by water hyacinth in the water bodies

1.1.2 Control Methods of Water Hyacinth

Physical, chemical, and biological treatments are frequently used worldwide to eradicate or control water hyacinths. The physical approach involves either manual removal by hands and hand tools or direct harvesting, cutting, or removing the plant using machines. To eliminate or slow weed growth, chemicals (herbicides and

pesticides), either conventional or nonconventional, can be administered directly or indirectly to the afflicted areas. Arthropods and diseases are applied to the affected areas as part of biological approaches. Arthropods feed on the water hyacinth's leaves, but infections cause the plant to become ill and eventually succumb to bacterial decomposition. The weevil, pathogen, bacteria, fungus, and virus groups are the most prevalent and efficient arthropods [5]. Although the most advisable are preventive control methods, integrating control methods is advised.

1.2 PROBLEM STATEMENT

Polymer-based synthetic materials, including polystyrene and mineral or glass wool, are expensive, require a lot of energy to manufacture, and generate a lot of waste when used. Every year, India produces over 350 million tonnes of agricultural waste, most of which are burned in the atmosphere, producing greenhouse gases. Water hyacinth is an invasive floating plant found in water bodies worldwide. In Kerala, invasive aquatic weeds like water hyacinth (WH) are simultaneously causing severe economic and environmental problems. Recycling these wastes into environmentally friendly, energy-efficient construction materials is a practical solution to the pollution problem and resource conservation for the upcoming generation. By properly utilizing these agricultural and aquatic resources, we can address issues with pollution, landfilling, and the high cost of building materials. This study looks at the development and performance evaluation of novel bio-insulating materials based on rice straw and water hyacinth fibres to solve this issue.

1.3 OBJECTIVES

The primary objectives of this thesis are:

- Water hyacinth and rice straw will be used to create composite thermal insulation panel boards.
- To test the developed board for apparent density, true density, water absorption, porosity, thickness of swelling, flexural strength, compressive strength, and thermal conductivity.
- To look into the impact of optimal compact load on panel boards.
- To compare the apparent density, true density, water absorption, porosity, thickness of swelling, flexural strength, compressive strength, and thermal

conductivity of the developed board to that of commercially available thermal insulation materials.

1.4 SCOPE OF WORK

The performance of a new thermal insulating material made of water hyacinth, rice straw, and epoxy resin is investigated in this study. The main goal of this project is to develop a sustainable thermal insulating material out of rice straw and water hyacinth. To assess the performance of these materials, experiments were carried out under controlled conditions. To evaluate hygrothermal performance, thermal conductivity, apparent density, true density, water absorption, and porosity are used. Furthermore, flexural and compressive strength are used to assess mechanical properties.

1.5 THESIS OUTLINE

Chapter bifurcation, in brief, is as follows. Chapter 1 deals with background information on the approaches and studies related to the development and performance evaluation of sustainable thermal insulation materials from Water hyacinth and rice straw. Chapter 2 involves a detailed literature review of the past and recent studies associated with the various thermal insulation materials developed from renewable resources. Chapter 3 discusses the elaborated methodology for the development and performance evaluation of sustainable thermal insulation using water hyacinth and rice straw. This chapter briefs on the calculation of apparent density, water absorption rate, flexural strength, and thermal conductivity of thermal insulation material thus developed. In chapter 4, the test results of the experimental work are discussed. A comparative study with bio insulation materials conventionally using thermal insulation materials is also included in this chapter. In chapter 5, the report concludes by highlighting the main contributions of this thesis work and future works that can be applied to this area, and chapter 6 portrays the references used for this thesis work.

CHAPTER 2

LITERATURE SURVEY

The purpose of this chapter is to provide a literature survey of past research efforts, such as journals or articles related to the development and performance evaluation of thermal insulation materials from renewable resources. Moreover, a review of the properties such as apparent density, water absorption rate, porosity flexural strength, compressive strength, and thermal conductivity is also included in this chapter. The literature review also discusses current and previous research on thermal insulation from renewable resources.

2.1 LITERATURE REVIEW ON BIO BASED THERMAL INSULATION MATERIALS

Binici et al. [1] developed a new insulating material made from vermiculite, sunflower stalks, wheat stalks, and gypsum as an alternative to synthetic insulation products made from non-renewable plastic sources. The engineering, mechanical, and physical characteristics of the samples were evaluated, and the results were compared to those of competing products. The proposed compressed insulation material made of vermiculite, sunflower stalks, vermiculite, gypsum, and wheat stalks has a thermal conductivity coefficient of 0.063-0.334 W/mK, a compressive strength of approximately 0.363 MPa, and a density of 0.166-0.302 g/cm³.

Zach et al. [2] addressed the potential for changing and modifying hemp-based thermal insulating materials to reduce hygroscopicity and water absorption. According to the results of the trials, the hydrophobic treatments had a substantial impact on the absorbability of thermal-insulating materials made of hemp fibres. All treated samples displayed reduced short-term absorbability values when compared to the REF sample that wasn't treated. The lowest value of short-term absorbability was found to be 0.36 kg/m².

Korjenic et al. [3] developed insulating material from renewable resources using jute, hemp, and flax that has similar physical and mechanical qualities to that of frequently commonly used insulation materials. The investigation's main objective was to determine how changes in moisture content affected the speed at which other parameters changed. The testing findings show that using the proper combination of natural materials is perfectly comparable to using conventional materials. The

apparent density varies from 26.1 – 82.1 kg/m³, and thermal conductivity ranges from 0.0458 - 0.0393 W/mK.

Dersseh et al. [4] studied the properties and negative impacts of water hyacinth across Lake Tana. The weed significantly harms the aquatic ecology, socioeconomics, and hydrology. Even though hyacinth prevention techniques work best, integrated weed management solutions are advised once water bodies are contaminated. Ethiopia's largest freshwater lake, Lake Tana, plagued with water hyacinth from 2011. When the adjacent marshes and flood plains are excluded, it is estimated that the area in Lake Tana that is vulnerable to water hyacinth infestation is around 24,800 hectares, or roughly 6 m of the lake's depth.

Ruiz et al. [5] developed a new insulation construction material made of cement, and WH's petioles (WHP) were studied. There were methods for different WHP particle. Subsequently examined two other panels. The WHP content used in both panels varied, ranging from 40:60 (WHP: cement) to 100:0. The findings suggest that WHP-cement board can be utilized in place of traditional insulation. Their thermal conductivity ranged from 0.63 to 0.45 W/mK.

Hroudová et al. [6] examined how relative humidity affected the thermal insulation characteristics of hemp-based insulating material and how equilibrium moisture absorption was determined. The findings demonstrate that natural-fibrous material can be used in contemporary low-energy and passive buildings as long as it is not exposed to high relative humidity (above 60%) for an extended period of time without suffering any discernible harm to its ability to insulate against heat flow.

Ali et al. [7] examined whether binding palm tree surface fibres (DPSF) with corn starch could be used to make building thermal insulation samples. The sample's thermal conductivity (DPSF) was for various densities measured between 0.0475 and 0.0697 W/mK. The degradation of the fibres begins around 232 C when the sample loses just about 8.5% of its initial mass. The same continued until it lost about 62% of its weight at about 475 C, according to Thermogravimetric analysis (TGA and DTGA). The fibre diameter typically ranges from 12 to 580 μ m.

Grillet et al. [8] developed sodium lignosulfonate-modified bamboo fibre and bone glue-based bio-insulation fiber boards with low environmental impact. These materials' moisture buffer values range from 2.5 to 3.9 g/ (m².%RH), which is higher

than bamboo fibreboard without glue (1.7 g/(m².%RH)). These values fall into the "decent" category. Compared to other fiber insulating materials, the range of the water vapor diffusion resistance factor is 8 to 17. Additionally, it has the maximum thermal conductivity of any material at 0.088 (W/mK), which has density 538 kg/m³.

Grillet et al. [9] studied the effect of high-absorbing bio-glues based on a protein and lignin compound on moisture transfer and storage, as well as the thermal performance of bamboo particleboards. The results show that the thermal conductivity of the composites ranges from 0.101 to 0.201 W/mK, corresponding to their density. Because of their low compactness, fiberboards with larger fibres have lower thermal conductivity than particleboards.

Villena et al. [10] discussed the use of palm pruning waste as a natural binder in the production of particleboards. The raw material for the boards was Washingtonia palm rachis in five particle sizes, with the citric acid content set at 10% by weight in relation to the weight of the rachis particles. For 7 minutes, single-layer agglomerated panels were created using a pressure of 2.6 MPa and a temperature of 150 C. The density, thickness swelling, water absorption, modulus of rupture, internal bonding strength, and thermal conductivity properties of twenty panels were investigated. Better mechanical properties resulted from smaller particle size.

Kim et al. [11] investigated the applicability of biochar to buildings, researchers created composites out of biochar and natural inorganic clay (NIC). Following the preparation of the coconut shell, rice husk, and bamboo biochar, these were mixed into NIC in four different ratios to form a board. The thermal conductivities of the samples were 0.138, 0.101, and 0.155 W/mK, respectively. The thermal conductivity of pure bio composite is 0.308 W/mK, so these figures are 55.19%, 67.21%, and 49.68% lower.

Gaspar et al. [12] developed thermal insulation boards with rye straw, moss, reed, and liquid glass as a binder. Thermal conductivity and compression, and bending strength of the specimens were tested. The best results were obtained on panels of moss and straw with thermal conductivity of 0.044-0.046 W/mK with a density of 156-190 kg/m³ and compression strength between 0.20 and 0.21 MPa.

Moura et al. [13] developed buffing dust waste/polystyrene bundling insulating composite. This study shows that adding 10 % buffing dust to polystyrene

composites reduces the thermal conductivity of the insulation board by 13%. When compared to conventional bundling thermal insulation materials, all prepared composites have superior thermal conductivity of 0.044 - 0.056 W/mK, compression strength of 11.55-8.23 MPa, and flexural strength of 29.51-10.53 MPa.

Li et al. [14] investigated the effects of four variables on the mechanical, thermal, hydraulic, and microscopic morphology of bio insulation materials using wheat straw and geopolymer as the binder. The compressive strength of bio-insulation materials were 0.18 to 5.622 MPa, and their density ranges from 235 to 894.1 kg/m³. Their thermal conductivity ranges from 0.092 to 0.186 W/mK. Additionally, the figures for water and moisture absorption rates are 32-107% and 4-33%, respectively. It is advised to use wheat straw of 0.2 cm in length, a Wp/W ratio of 1, an S/S ratio of 0.124, and a H/S ratio of 0.0124. It has a thermal conductivity of 0.101 W/mK, density of 302.4 kg m⁻³, and a compressive strength of 1.2 MPa

Belayachi et al. [15] investigated how well a bio-composite made of cereal straw and mineral binders performed in heat transfer. The goal is to decrease the amount of mineral binder while keeping enough mechanical characteristics to assure self-bearing to decrease thermal conductivity. Three additions from a sustainable and biodegradable biomass source were used: haemoglobin, casein, and gelatine. The thermal conductivity value ranges from 0.054 to 0.16 W/mK. They also fit into the category of thermal insulation materials.

Philip et al. [16] examined the water hyacinth-based thermal insulating materials. The WH- cement panel board's thermal conductivity measurements were less than that of common woods and other building materials like particleboard, MDF, hardboard, and plywood. The thermal conductivity of the sample is determined to be 0.0765 W/mK. The density of the WH-cement thermal insulation boards is less than wood, according to the findings of the density measurements, suggesting that it may be used as a substitute material. It also has low densities compared to commercially accessible materials like particleboard, MDF, hardboard, and plywood.

Abedom et al. [17] studied the various mechanical and thermal insulating properties of composites made from bagasse fiber/bamboo charcoal for technical applications. This study used five hybrid composites with bagasse fibre and bamboo charcoal proportions of 100%/0%, 70%/30%, 50%/50%, 30%/70%, and 0%/100%

with 65% polyurethane foam are used. Their mechanical properties are examined following ASTM standards. The thermal conductivity values were obtained from 0.086 – 0.130 W/mK. The composite sample provides the best thermal insulation quality with a bagasse/bamboo ratio of 30/70, which is appropriate for vehicle interiors for a particular application involving heat absorption.

Panyakaew et al.[18] investigated the properties of binderless insulation boards made from bagasse using hot pressing at a pressure of 14.7 MPa. To investigate the effect of pressing temperature on the physical properties of the insulation boards, three temperature settings (1600C, 1800C, and 2000C) were used for pressing bagasse. The lowest TS value of binderless bagasse insulation board was 42.7% at a pressing temperature of 160 0C/7 min, which is higher than the maximum permissible level (10%) for insulation boards in JIS A 5905: 2003. Furthermore, results revealed low thermal conductivity values ranging from 0.049 to 0.055 W/mK for densities ranging from 250 to 350 kg/m³.

Agoudjil et al. [19] investigated thermo physical, chemical, and dielectric properties of date palm leaf base (petiole) and bunch. Six specimens were examined in order to determine the effect of palm date type and the contrast between materials based on petioles and bunch. The effect of fibre orientation on properties was also investigated. The highest performing material had a thermal conductivity of 0.072 W/mK.

Masri et al. [20] investigated the use of pruning residues from date palm tree leaves as reinforcement. For the production of Leaflets-Polystyrene Composite (LPC) material, three reinforcement particle sizes A (0.1-0.315 mm), B (0.315-0.5 mm), and C (0.5-1 mm) were used, as well as several combinations of reinforcement to matrix weight ratios (80:20, 75:25, and 70:30). The matrix was made of recycled expanded polystyrene (EPS) waste dissolved in gasoline. This matrix was mixed with date palm leaflet reinforcements before being poured into a mould and compacted under 10 bar pressure. The bulk density of the tested samples ranged from 542 to 824 kg/m³ and the thermal conductivity ranged from 0.11 to 0.16 W/mK.

Zhou et al. [21] investigated the properties of thermal insulation material made from cotton stalk fibres with no chemical additives using high-frequency hot pressing. The thermal conductivity of the samples tested ranged from 0.0585-

0.0815W/mK. Furthermore, higher density panel boards had relatively poor insulation properties. The test results also revealed that the moisture content (MC) of the fibre and the pressing time had no effect on thermal conductivity. Even though, increased fibre MC and pressing time resulted in a significant improvement in mechanical properties.

Abdullah et al. [22] investigated a new cement composite material reinforced with coconut fibre. This study looked into the use of coconut fibre as a partial replacement for sand in the production of cement composite material. The cement-to-sand ratio was set at 1:1, and the water-to-cement ratio was set at 0.55. Brown coconut fibre from matured coconuts contains more lignin, which can be used as binders, surface-active agents, and dispersants. The weight of the coconut fibre ranged from 0% to 15% by 3% increments. The modulus of rupture and compressive strength of the composites increased as the percentage of coconut fibre increased, reaching an optimum value of 9%. Increased coconut fibre content reduced mechanical properties due to decreased workability.

Lertwattanakul et al. [23] compared the physical, mechanical, and thermal properties of thermal insulation panel materials developed from coconut coir fibre and panel board made from OPC. Panel boards were made with 5, 10, and 15% OPC replacement by coconut fibre in that study. According to the results of the test, the strength properties of the fibre mixed samples were lower than the control mix. However, all of the samples met the ASTM standard's optimum range. All of the samples had lower bulk density (2100-1800kg/m³) and thermal conductivity (0.41-0.37 W/mK) than conventional materials such as wood, MDF, particle board, hardboard, and plywood. Water performance (4.67-9.66%), on the other hand, is superior to that of other bio-based materials.

Muthuraj et al. [24] evaluated the thermal insulation performance of rice husk composites with a biodegradable poly butylene adipate-co-terephthalate/poly lactic acid (PBAT/PLA) blend binder by hot pressing. The test results revealed that using 13.5 2% binder content, rice husk composite had a density of 378 13 kg/m³, thermal conductivity of 0.08, and lower water absorption of 40%. Because the thermal conductivities of the husks composites are less than 0.1 W/mK, it may be suitable for thermal insulation applications. Rice husk composites displayed semi-rigid behaviour with adequate flexural (1.2 MPa) and compressive properties (14 MPa).

Zhou et al. [25] developed thermal insulation boards using rice straw by high-frequency hot pressing. As an adhesive, methylene diphenyl diisocyanate (MDI) resin (100% solid) diluted with Acetone was used to bond the rice straw particles. To investigate the effect of high-frequency heating on panel properties, the moisture content (MC) of particles was adjusted to 10, 14, and 18%. The test results showed that increasing the moisture content (MC) from 10% to 14% increases the moment of resistance (MOR) and IB by approximately 40.12% and 7.61%, respectively. As a result, the time required for HF hot-pressing has been reduced. When particle MC was increased from 14 to 18%, both the MOR and the IB decreased. When the MC was increased from 10% to 18%, the TS of the board increased by about 50%, while thermal conductivity remained between 0.051 and 0.053 W/mK.

The literature study concludes that water hyacinth (WH), an invasive aquatic weed, poses serious economic and environmental problems in India. Recycling these aquatic wastes into durable, energy-efficient insulating material is a workable solution to the pollution issue and safeguarding natural resources for upcoming generations. The current study investigates the water hyacinth's potential for use in the manufacture of thermal insulation. The majority of research on thermal insulation panel boards focuses on materials including date palm leaflets, coconut husks, rice straws, bamboo fibre, sunflower stalks, and bamboo fibre. Also, investigations on composites of Water hyacinth with Epoxy resin have not yet been tried and tested effectively, especially under conditions prevailing in Kerala. The methodology to design the Water hyacinth – rice straw composite panel and different physical and mechanical properties are presented in the current work following reviewed literature. The current work also includes a comparative study of Water hyacinth – rice straw composite with agro-waste-based insulation materials and conventional thermal insulation materials.

CHAPTER 3

METHODOLOGY

This chapter introduces the research process for producing a thermal insulation material from rice straw and water hyacinth. The core aspects of this chapter are the methodology, materials, mould preparation, and testing methods of the developed thermal insulation materials. The experimental methods to determine the different physical, mechanical and thermal characteristics of the developed thermal insulation materials are presented in this chapter.

3.1 MATERIALS

A new organic thermal insulating material composed of water hyacinth and rice straw was considered in the present work as shown in the Fig.3.1. The primary raw material is Water hyacinth and rice straw, as its effective utilization as thermal insulation panel board was considered in the current study. The following factors were considered when selecting additive raw materials for developing composite thermal insulation panel boards.

- Availability in abundance
- Limited major alternative use
- Serious environmental issues

Epoxy was chosen as the binder for composition with water hyacinth and rice straw since prior research showed that epoxy has a superior binding property and a short curing period.

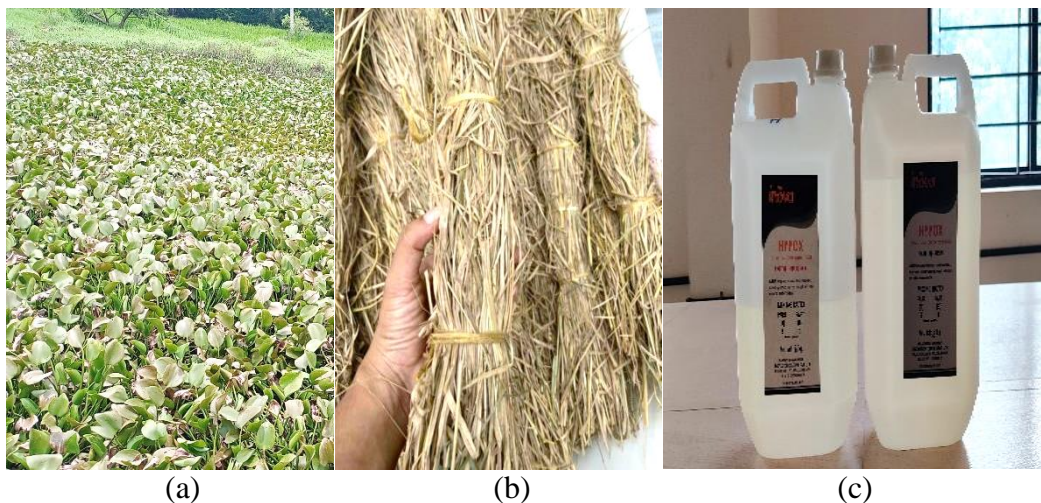


Fig. 3.1: Raw materials; a) Water hyacinth; b) Rice straw; c) Epoxy resin.

3.1.1 Raw Materials

(i) Water hyacinth

A perennial, herbaceous, free-floating aquatic plant, water hyacinth was first discovered in the South American Amazon Basin. German naturalist C. Von Martius found the species while researching the Brazilian flora in 1823. The plant has grown widely around the globe since the late 1800s. Most subtropical and tropical nations in Latin America, Africa, the Caribbean, Pacific, and Southeast Asia have experienced a rapid expansion of the invasive weed from the Amazon. By characterizing each of the water hyacinth's components, the morphology of the plant can be inferred. The broad, thick, glossy, and egg-shaped leaves are 10-15 cm wide. The plant grows up to 1m above the water's surface, but its typical height is between 20 and 30 cm. The stalks are bulbous, long, and spongy. The roots are purple-black, freely dangling, with lengthy treads 2.54 cm below the water's surface. The plant is always found in colonies since it cannot survive independently. The weed's petals contain dots that are both purple and yellow. In ideal circumstances, its biomass can reach up to 25 kg/m² or 400 tons/ha, 500,000 plants/ha, yielding up to 400 seeds per flower and 5000 seeds per plant. Both asexual and sexual reproduction is possible in water hyacinths (by vegetative means: budding and stolen production). Both reproduction methods offer a high potential for production in a short amount of time. Vegetative reproduction is the method used in uniparental reproduction. In around 200 days, 3,418,600 plants and 47 daughter clusters of leaves can be created through vegetative reproduction. In 60 days, three parent water hyacinth plants may create 3200 young plants; after 23 days, two parent plants can produce 30 offspring.

The production of seeds from the weed's blossoms with the help of insects is how it reproduces sexually. In just 26 days, a single water hyacinth plant can produce a flower. The ideal temperature range for water hyacinth growth is 28°C to 30°C. Because the invasive weed's root cannot take in enough nutrients from the water to support its overall and optimal growth, sunlight is crucial for photosynthesis. Salinity level of 2% or below is ideal for water hyacinth growth.

(ii) Rice Straw

With 43.85 million hectares under rice cultivation and productivity of 2290 kg/ha as of 2016, India is the world's second-largest rice producer. Punjab, Uttar Pradesh, and

Haryana, Tamil Nadu, and Sikkim, are the principal rice-growing states in India. Between 1950–1951 and 2015–2016, the area under rice cultivation rose noticeably by 145%, while rice production multiplied five times. About 23 million tonnes of rice crop residue are produced yearly, or 66.4% of all crop residue produced in the Indian subcontinent. IARI estimates that India burns 80% of its rice crop leftovers annually. This results in the burning of 26.89% of the world's rice harvest residue. Aside from harming people and animals, residue burning harms agricultural lands' biodiversity and soil fertility. The soil loses 5.4 kg of nitrogen, 2.2 Kg of phosphorous, 25.5 kg of potassium, and 1.3 kg of sulfur when one tonne of rice straw is burned. One centimeter of soil is heated by burning straw, raising the temperature to 33.8-42.2 °C¹⁰. This explains why organic carbon, nitrogen, and other nutrients that would have remained in the soil have been lost. This also eliminates the bacterial and fungal species necessary for rich soil. When taken straight from the field, rice straw has dry matter density ranges from 13 to 18 kg/m³. Chopped straws with lengths ranging from 2 to 10 mm can have a density of 50 - 120 kg/m³, depending on the equipment used.

(iii) Epoxy resin

The family of essential elements or dried end products known as epoxy includes epoxy resins. The collection of reactive prepolymers and polymers known as epoxy resins, commonly referred to as polyepoxides, includes epoxide groups. Epoxy is another name for the functional group made up of epoxides. An oxirane is a term given to an epoxide group by the IUPAC. The epoxy resin system comprises two parts: an "A" side and a "B" side. The epoxy curing agent, also referred to as the "hardener," is contained on the B side and is what causes the epoxy groups in the epoxy resin on the "A" side to react. Epoxy resins and curing agents interact to create stiff, thermoset materials. The epoxy resin shows the following properties:-

- High strength
- Low Shrinkage
- Excellent adhesion to various substrates
- Effective electrical insulation
- Chemical and solvent resistance
- Low toxicity
- Corrosion resistance

3.1.2 Sample collection and pre-treatment

(i) Water hyacinth

The water hyacinth was hand-picked from a pond in Kollam, Kerala. It is abundant in most water bodies in Kerala. The pre-treatment of water hyacinth collected were

- chopping leaves and roots
- drying in sunlight
- grinding to particle size
- storing in airtight containers

Water hyacinths were collected from streams and ponds near Kollam, Kerala and chopped off the leaves and roots of water hyacinth. The petioles were washed properly to remove the mud and other wastes as shown in Fig.3.2. The petioles were then sundried for 10 days to achieve a constant weight. After sun drying, they were milled into powder form and stored in air-tight containers. The particle size of the petioles chosen is 2.36 mm. Sieved the particles through a 2.36 mm sieve.



Fig. 3.2: Various stages of pre-treatment processes of Water hyacinth (Collection of Water hyacinth; Removal of leaves and roots; Petioles separated; Cleaning of Water hyacinth petioles; Drying the Water hyacinth in sunlight).



Fig. 3.3: Sieving and collection of crushed Water hyacinth petioles (particles passing through 2.36 mm IS Sieve)

(ii) Rice straw

Rice straw was cheaply available and was collected from the nearby shop. The pre-treatment of rice straw includes cleaning and chopping. The unwanted parts of the rice straw are removed after that; it is cut into small pieces and has a dimension of 1 cm shown in Fig 3.4.



Fig.3.4: Various stages of pre-treatment processes of rice straw

3.2 MOULD PREPARATION

Developed a mould with dimensions 30 x 25.5 x 2 cm for the preparation of the panel board shown in fig 3.5. A stopper is placed on the inner face of the mould To maintain a constant thickness for the panel board. The stopper has a dimension of 2cm

in width, and the welding process fixes it. After the welding process, the surface of the mould is ground so that a smooth surface is obtained.



Fig.3.5: Fabricated Mould for making the thermal insulation board

3.3 THERMAL INSULATION PANEL BOARD PRODUCTION

Developed composite panel boards with water hyacinth and rice straw-epoxy by applying 0.04 MPa compaction pressure. The general methodology used for developing thermal insulation panel boards is illustrated in Fig 3.6.

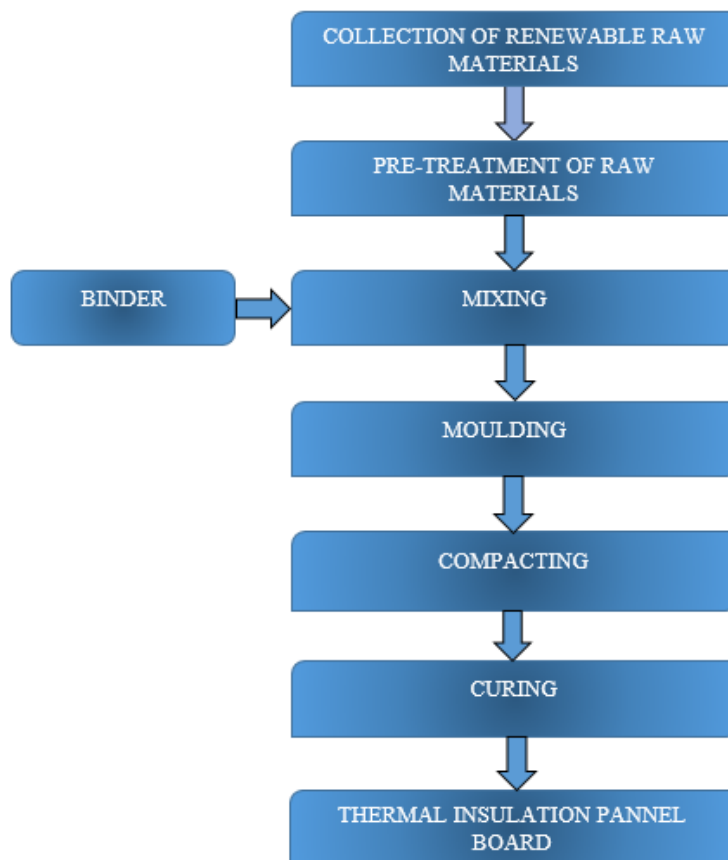


Fig. 3.6: General Methodology Block Diagram

The methods adopted for the manufacturing process of Water hyacinth and rice straw-epoxy panels are shown in Fig. 3.7.

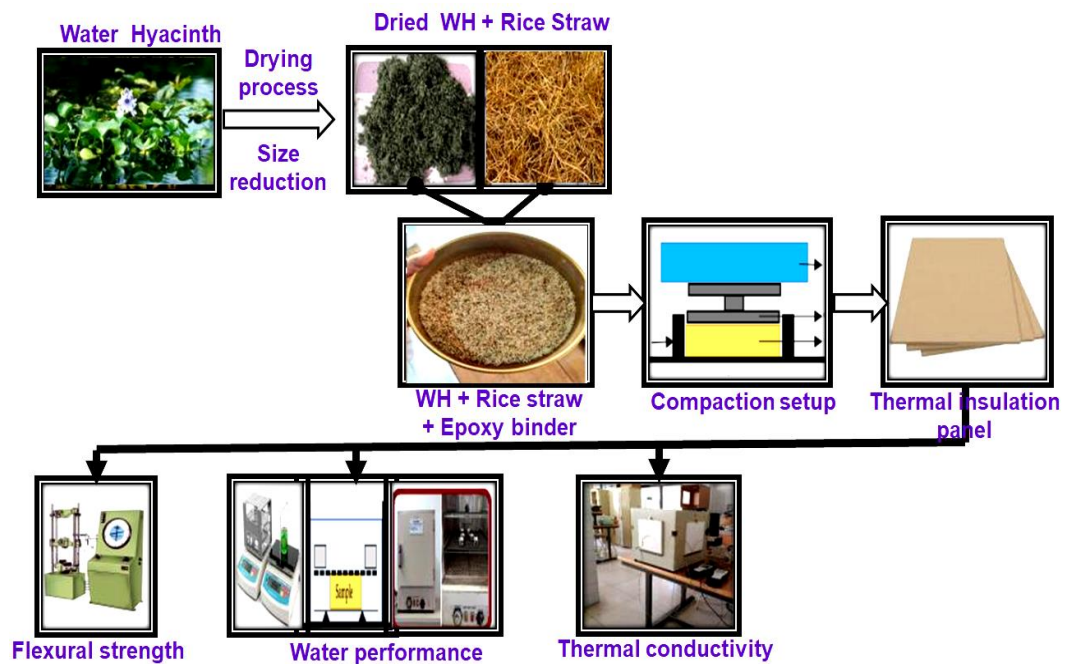


Fig. 3.7: Block diagram illustrating methodology and experimental design [16].

Water hyacinth particle passes through a 2.36 mm sieve, and rice straw having a dimension of 1cm length was used to make the panel. Water hyacinths and rice straws are the primary raw materials for developing thermal insulation panel boards. Collected water hyacinth from the local water bodies. Removed the roots and leaves of the water hyacinth. The petioles were then pre-treated by cleaning, drying, powdering, and drying. Petioles of WH are adequately washed and sun-dried for 15 days to achieve constant weight. Then it is crushed into 2.36mm particle size. Used a sieve of 2.36mm to sieve the particles. The pre-treatment of rice straws was done by chopping the unwanted parts. Then they were cut into 1cms in length. The binder used is epoxy resin since it has a low curing time. The epoxy resin consists of hardener and resin. The mixing proportion of resin and hardener is in the ratio of 1:2. The weight of raw materials (400g) and resin (800g) is kept constant. The mixing ratio of the raw materials and binder is 1:2, finalized by the trial and error method. First, the resin and hardener of the epoxy are mixed well in a ratio of 1:2 for 3 minutes. Then 400g of water hyacinth and rice straw are taken in a 1:2 ratio.

Then raw materials and resin are adequately mixed for 5 mins and poured into a mould. The mixture is spread uniformly in the mould using a plate. It is then

compressed at 3KN using UTM for 1day in a loaded condition. Then the sample is kept in sunlight for two days for curing. After curing, the samples were de-moulded. Conducted different tests to determine flexural strength, water performance, apparent density, and thermal conductivity of the developed panel boards (Fig. 3.8).



Fig. 3.8: Development of thermal insulation board

Different sample boards are developed by varying the Water hyacinth to rice straw ratio (WH: RS).the ratios are varied from 100:0 to 0:100 shown in table 3.1. Developed 11 different sample panel boards by varying the Water hyacinth to rice straw ratios, as shown in fig 3.9. After the curing period, these panel boards are subjected to various tests to determine their physical, mechanical, and thermal properties, such as apparent density, water absorption rate, flexural strength, and thermal conductivity.

Table 3.1: Details of mixing ratios of Water hyacinth and Rice straw

Sl No	Ratio (WH:RS)	Weight of raw materials	
		WH(gm.)	RS (gm.)
1	100:0	400	0
2	90:10	360	40
3	80:20	320	80
4	70:30	280	120
5	60:40	240	160
6	50:50	200	200
7	40:60	160	240
8	30:70	120	280
9	20:80	80	320
10	10:90	40	360
11	0:100	0	400

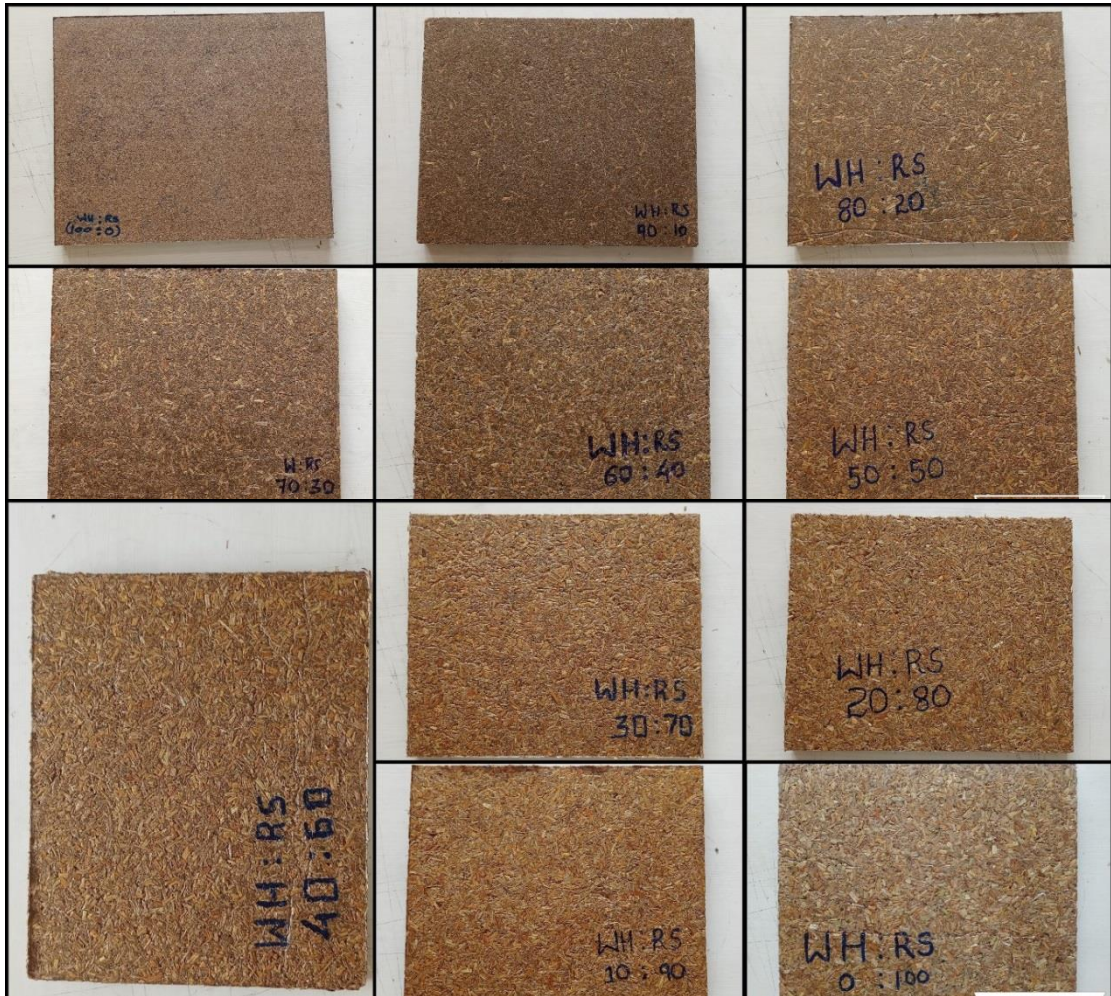


Fig .3.9: Photographs of the samples developed by varying mix proportions

The best composition was chosen based on the tests conducted for physical, mechanical and thermal properties. Another four samples of the same composition were developed by varying the compaction load at 2KN, 2.5 KN, 3.5 KN and 4 KN. The same tests were carried out for the newly made samples to determine the physical, mechanical and thermal properties.

3.4 TESTING METHODOLOGY

According to applicable requirements for insulation materials used in the building industry, the following test procedures were performed to research the behavior of bio based thermal insulating materials.

3.4.1 Apparent density

The apparent density is an important property that determines the thermal performance of thermal insulation materials. Using the gravimetric method,

determined the apparent density of test specimens dried at 105°C. Each proportion of thermal insulation panel board took four samples in dimensions 5x5x2cm. The average density values from each proportion have been calculated. The exact measurements of the test specimens, which were accurate to 0.1 mm, using a Vernier calliper were taken. Using a lab balance, calculated the weight with a 0.01 g precision. The apparent density of the samples was determined according to EN 1602.

$$\text{Apparent density (kg/m}^3\text{)} = \frac{M}{V} \quad (1)$$



Fig.3.10: Apparent Density Measurement

3.4.2 True density

True density is defined as the ratio of mass to volume of a sample, ignoring material pores (true volume). From each proportion of thermal insulation panel boards, four samples were taken in dimensions 5x5x2cm. Each sample was dried in an oven at 105°C for 24 hours to calculate its dry solid mass m_s . Using a lab balance, calculated the dry solid mass with a 0.01 g precision. The samples were then dipped in a test tube with water for 15 min. The volume of water displaced (true volume) after 15 min were noted.

$$\text{True density (kg/m}^3\text{)} = \frac{\text{initial mass}}{\text{true volume}} \quad (2)$$



Fig.3.11: Various stages of true density measurement

3.4.3 Porosity

Porosity is a crucial factor in the analysis of the microstructures of materials. In relation to the total volume of the material, it correlates to the volume of interstices that can absorb fluid. Porosity of a particular sample can be calculated in relation with apparent density and true density of the sample.

$$\text{Porosity (\%)} = \left(1 - \frac{\text{apparent density}}{\text{true density}}\right) \times 100 \quad (3)$$

3.4.4 Water Absorption (WA)

The water absorption rate was determined by total immersion (WA) following the European Standard 12087. From each proportion of thermal insulation panel boards, four samples were taken in dimensions 5x5x2cm and calculated the average water absorption values from each proportion. The samples were immersed in a container for 24 hrs with an iron rod to prevent the samples from floating.

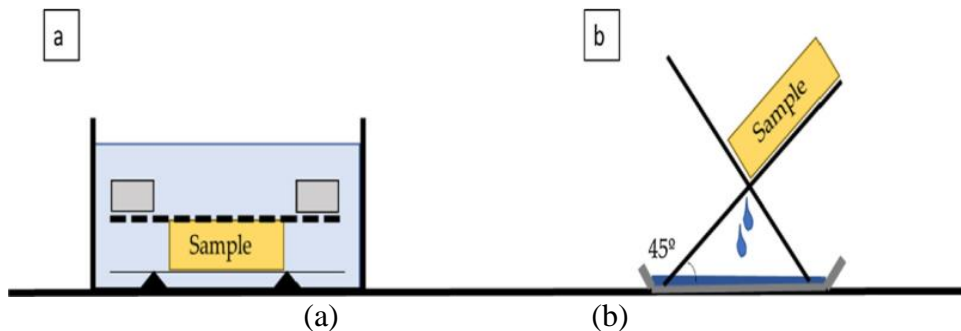


Fig. 3.12: Schematic diagram of the procedure of the water absorption test:

- a) Samples placed inside the beaker; b) Samples placed in an inclined surface.

After 24 hours, the specimens were taken and placed on a 45° inclined surface for 10 minutes to drain some of the water, and the weight of each sample was measured

using an electronic balance (M_{sat}). The samples were heated in an electric oven at 105°C until the mass of the sample was stable, at which point the dry weight (M_d) was determined.

$$WA (\%) = \left(\frac{M_{sat} - M_d}{M_d} \right) \times 100 \quad (4)$$



Fig.3.13: Various stages of water absorption testing

3.4.5 Thickness of Swelling

When considering the board's final installation, thickness swelling (TS) is important. According to European Standard 317, it is quantified as a percentage increase in the specimen's thickness following a 24-hour immersion in water.



Fig.3.14: samples immersed in water for measuring thickness of swelling

A digital micrometre with a 0.01 mm resolution was employed. At the start of the test, three reference points were marked on the board. Following the measurement of

the thickness (E_0) at the reference position, the samples were immersed in water, shown in Fig. 3.14. After the samples were submerged in water, they were left on an inclination (45°) for 10 minutes (Fig. 3.12), at which point board thickness at the reference position was measured (E_1)

$$\text{Thickness of Swelling, TS (\%)} = \left(\frac{E_1 - E_0}{E_0} \right) \times 100 \quad (5)$$

3.4.6 Flexural Strength

According to European Standard 12089, a three-point bending strength test was carried out on the samples to determine the flexural strength of the developed samples.



Fig. 3.15: 3 Point flexural Testing machine for flexural strength calculation.

The load cell used was 10 KN. Flexural strength value can be determined using the following equation.

$$\text{Flexural stress (N/mm}^2\text{)} = \frac{3FL}{2bd^2} \quad (6)$$

Where F is the load (N), b the width of the test piece (mm), L is the span (mm), and d is the thickness of the test piece (mm). The specimen with dimension 20 x 3 x 2 cm is used to determine the flexural strength with a span length 150mm. A three-point bending test is used for this test. The specimen is marked with a length of 10cm from the middle to both sides, so the total load is applied on this 150cm span length. Load is applied to the centre, and support is given at the marked ends. The remaining portions are held as freely. After that, the load is gradually applied to the

material. When the material breaks, the load value is noted, and as a result, flexural strength is evaluated.

3.4.7 Compressive strength

Using a 600 KN universal testing machine, the compression properties of the newly made fibre board samples were assessed and tested in accordance with ASTM D1037-12. The specimen's dimensions are 50 x 40 x 20 mm, and it was uniformly compressed until it fractured. Area (A) of the contact surface was measured prior to compression. Initial Length (L₁) and Final length (L₂) of the sample after compression were noted using digital micrometre with a 0.01 mm resolution. The load (P) is noted at the time of fracture.



Fig. 3.16: Compressive strength measurement using UTM.

$$\text{Strain } \varepsilon = \frac{L_1 - L_2}{L_1} \quad (7)$$

$$\text{Actual area } A_c = \frac{A}{1 - \varepsilon} \quad (8)$$

$$\text{Compressive strength } \sigma \text{ (MPa)} = \frac{P}{A_c} \quad (9)$$

3.4.8 Thermal Conductivity

Calculated the thermal conductivity of the samples using a thermal conductivity measurement apparatus (Fig. 3.15), which is available in the sophisticated instrument facility, NIT Trichy Tamil Nadu, India. KD2 pro is the apparatus used for the determination of thermal conductivity. KD2 pro is a battery-operated, menu-driven

device that can analyze the material's thermal properties. It consists of a handheld controller and a sensor kit, and these sensors can be inserted into any material. A single needle sensor can be used to determine the thermal conductivity and thermal resistivity of the materials. The controller has an operating temperature of 0 to 50°C, and the sensor has an operating temperature of -50 to 150°C. In this work, KS 1 type sensor is used. This sensor has a dimension of 10 cm long and a 2.43 cm diameter. The sensor heats the sample significantly, which allows it to measure thermal conductivity. KS 1 sensor is used for measuring the thermal conductivity of insulating materials.



Fig. 3.17: Measurement Thermal Conductivity using KD2 pro

For measuring the thermal conductivity using KD2 pro, the specimen has the dimension of 10 x 2 x 2 cm. A hole of size 3 mm is developed from the top to bottom surface vertically so that the probe can be inserted inside the specimen. The probe heats the sample and transfers heat radially through the material. The probe first heats the material somewhat in the range of 45°C, gradually reducing the temperature to room temperature. As a result, we will get the thermal conductivity of the specimen. Approximately 10 minutes is required to obtain the result.

CHAPTER 4

RESULTS AND DISCUSSION

Rice and wheat straws are the two most common agricultural straws produced in Kerala. Large-scale growth of the water hyacinth, an invasive aquatic plant, is also observed in Kerala's water bodies. Due to its low density, fibrous properties, low thermal conductivity, non-toxicity, and pollution-free aspects, construction materials made from renewable resources, such as agricultural straws and water hyacinth, have a better future in Kerala. This study developed a novel thermal insulation material made of water hyacinth and rice straws using low compaction technology and epoxy resin as a binder. The mechanical and physical properties were evaluated to determine the panels' performance. This section discusses the findings of tests done to ascertain apparent density, true density, porosity, water absorption rate, thermal conductivity, compressive strength, and flexural strength. The resulting values of physical, mechanical, and thermal properties of test specimen sets are presented in Table 4.1.

Table 4.1: Physical property values of developed samples for varying mix proportion

Sl. No	Mixing Proportion (WH:RS)	Apparent Density (kg/m ³)	True density (kg/m ³)	Porosity (%)	Water Absorption (%)	Thickness of swelling (mm)
1	100:0	919.57	925.41	0.63	13.88	2.24
2	90:10	774.91	788.65	1.74	17.31	1.54
3	80:20	871.19	884.00	1.45	16.96	1.39
4	70:30	787.08	800.57	1.69	17.15	2.41
5	60:40	681.45	743.84	8.39	42.45	1.93
6	50:50	862.49	875.63	1.50	17.09	2.98
7	40:60	721.54	739.14	2.38	17.81	2.46
8	30:70	781.43	795.12	1.72	18.08	3.07
9	20:80	685.89	733.93	6.55	28.93	1.91
10	10:90	859.57	873.96	1.65	17.02	2.73
11	0:100	793.39	808.12	1.82	17.44	1.16

Table 4.2: Mechanical and Thermal Property values of developed samples for varying mix proportion

Sl. No	Mixing Proportion (WH:RS)	Flexural strength (MPa)	Compressive strength (MPa)	Thermal conductivity (W/mK)
1	100:0	0.21	9.88	0.088
2	90:10	0.44	8.31	0.091
3	80:20	0.64	9.86	0.115
4	70:30	0.61	9.70	0.117
5	60:40	0.53	6.21	0.069
6	50:50	0.38	7.75	0.113
7	40:60	0.33	7.47	0.081
8	30:70	0.53	7.84	0.113
9	20:80	0.78	7.34	0.101
10	10:90	1.08	12.16	0.078
11	0:100	1.10	11.20	0.091

The test results for physical, mechanical and thermal properties showed good values for the composition 60:40(WH: RS). Another four samples of the same composition were developed by varying the compaction load at 2KN, 2.5 KN, 3.5 KN and 4 KN. The same tests were carried out for the newly made samples to determine the physical, mechanical and thermal properties. The effect of compaction load on the proportion 60:40(WH: RS) is shown in Table 4.3 and Table 4.4.

Table 4.3:- Physical property values of the developed samples varying compaction load for the composition 60:40 (WH: RS)

Sl. No	Compaction load (KN)	Apparent Density (kg/m ³)	True density (kg/m ³)	Porosity (%)	Water Absorption (%)	Thickness of swelling (mm)
1	2	624.72	708.37	11.80	64.26	2.01
2	2.5	656.14	734.52	10.67	56.18	1.97
3	3	681.45	743.84	8.39	42.45	1.93
3	3.5	704.83	756.71	6.85	38.73	1.84
4	4	712.54	755.67	5.70	31.84	1.92

Table 4.4:- Mechanical and thermal property values of the developed samples varying compaction load for the composition 60:40(WH: RS)

Sl. No	Compaction load (KN)	Flexural strength (MPa)	Compressive strength (MPa)	Thermal conductivity (W/mK)
1	2	0.30	5.96	0.063
2	2.5	0.36	6.07	0.070
3	3	0.53	6.21	0.069
4	3.5	0.55	6.42	0.082
5	4	0.67	6.56	0.108

The test results for the effect of compaction load didn't show any better mechanical properties with thermal conductivity values. The mechanical strength tends to decrease with thermal conductivity values. Mix proportion 60:40(WH: RS) with 3KN compaction load is chosen for further comparative study.

4.1 APPARENT DENSITY

The apparent densities of samples prepared using Water hyacinth, rice straw, and epoxy is calculated based on mass by volume relationship. Four samples of the same ratio are tested, and the result obtained is the average of all the values measured. The values obtained are 681.45 to 919.57 kg/m³, shown in Table 4.1.

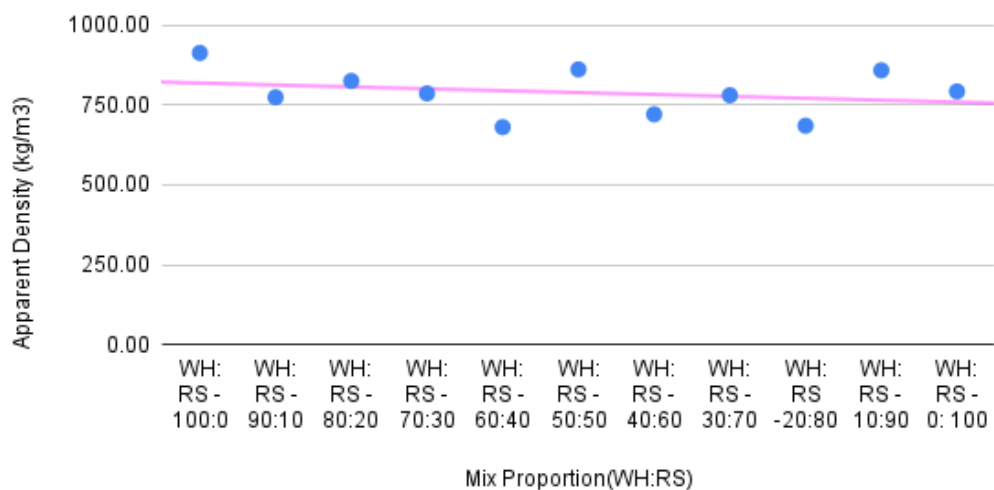


Fig. 4.1: Variation of apparent density with mix proportion

The variation of apparent density with mix proportion (WH: RS) is illustrated in Fig.4.1. The average value obtained is 794.41 kg/m³. The lowest density value obtained is

681.45 kg/m³ with a composition ratio of 60:40 (WH: RS). The highest value obtained is 919.57 kg/m³ for the sample panel board developed with a composition ratio of 100:0(WH: RS). Comparison of the apparent density values of developed samples with other insulation materials from renewable raw materials and commercial insulation materials are shown in Table 4.5.

Table 4.5:-Apparent density of developed samples with other insulation materials from renewable raw materials and commercial insulation materials.

Source material	Apparent density (kg/m ³)	Reference
WH+RS(60:40)	681.45	Present work
WH (P-Panel)	467	[5]
Rice straw	250	[25]
Sunflower stalk	166-340	[1]
Wheat straw	302	[24]
Cotton stalk	300	[21]
Coconut fibre(OPC)	1955	[22]
Coconut husk	300	[18]
Coconut coir	1960	[23]
Wheat husk	448	[24]
Bagasse	300	[18]
Date palm	265	[19]
Oil palm fibre	1996.67	[23]
Date palm	683	[20]
Corn stalk	280	[1]
Wood	540	[20]
MDF	1045	[20]
Plywood	490	[20]
Particle board	690	[20]
Hardboard	890	[20]

The samples developed in this work are compared with other bio-based thermal insulation materials and conventionally used thermal insulation materials. Other bio-

based insulation materials include Water hyacinth (P-panels) composite, rice straw – MDI composite, sunflower and wheat stalk, coconut fibre, oil palm fibre, corn stalk, date palm fibre, bagasse, wheat husk, coconut coir, cotton stalk. Conventionally used thermal insulation materials such as wood, MDF, plywood, particleboard, hardboard are also used in this comparison.

Some of the bio-based thermal insulation materials show relatively less bulk densities as that of samples developed in this work. The materials such as Water hyacinth(P-panel) (470kg/m^3) [5], sunflower stalk (300kg/m^3)[1], wheat straw (302kg/m^3) [24], cotton stalk (300kg/m^3) [21], bagasse (300kg/m^3) [18], coconut husk (300kg/m^3)[18], rice husk (378kg/m^3) [24], and corn stalk (280kg/m^3) [1]shows relatively lower bulk density. Samples developed in this work shows very low densities while comparing with some of the other bio-based thermal insulation materials such as coconut fiber – OPC composite (1955kg/m^3) [22], oil palm fibre (1996.67kg/m^3) [23], coconut coir (1960kg/m^3) [23], coconut fibre (958kg/m^3) [1]. The samples developed in this work shows lower bulk density than the commercially available insulation materials such as plywood (490kg/m^3)[20], MDF (1090kg/m^3)[20], particleboard (690kg/m^3)[20], hardboard (890kg/m^3) [20].

4.2 TRUE DENSITY

The true densities of samples prepared using Water hyacinth, rice straw, and epoxy is calculated based on the mass to true volume of the sample. Four samples of the same ratio are tested, and the result obtained is the average of all the values measured. The true density values obtained ranged from $733.93 - 925.41 \text{ kg/m}^3$ and are shown in Table 4.1.

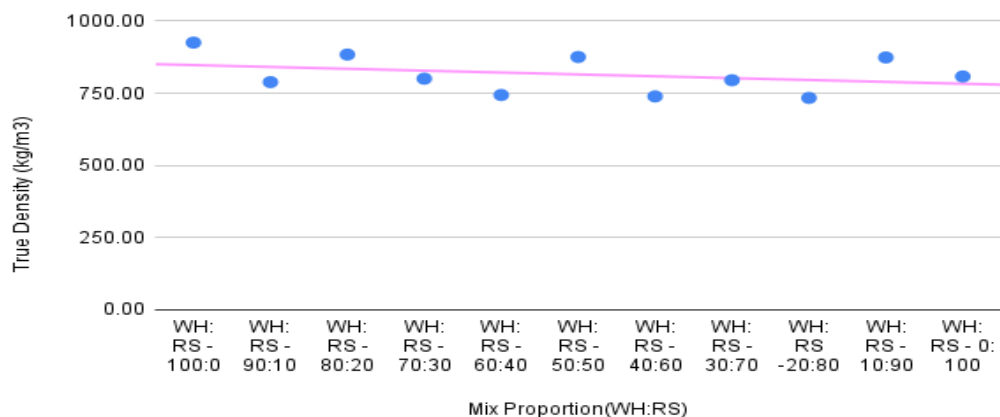


Fig. 4.2: Variation of true density with mix proportion.

The lowest value of the density obtained is 733.93 kg/m³ with a composition ratio of 20:80 (WH: RS), and the highest value obtained is 925.41 kg/m³ for the sample panel board developed with a composition ratio of 100:0 (WH: RS). The variation of true density with mix proportion (WH: RS) is illustrated in Fig.4.2

4.3 POROSITY

The porosity of the insulation panels is calculated with the samples' apparent density and true density.

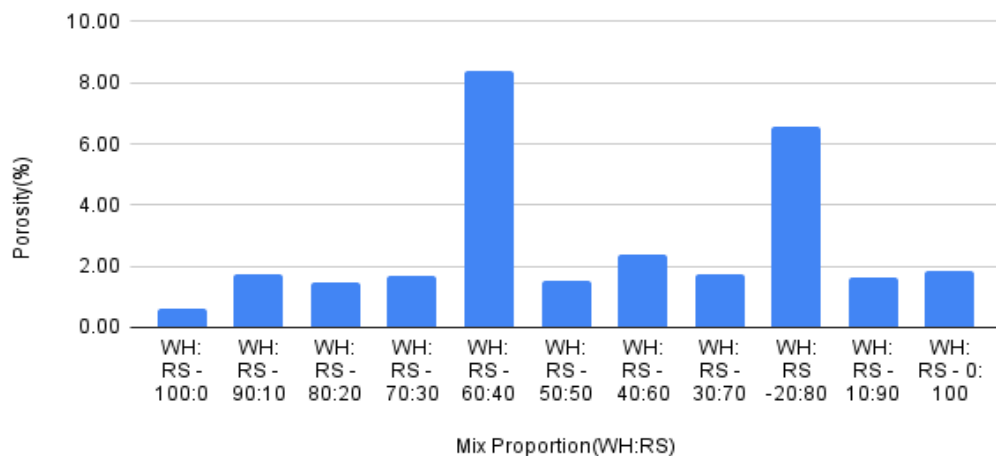


Fig. 4.3: Variation of porosity with mix proportion

The porosity of the samples ranged from 0.63% - 8.39% and is shown in Table 4.1. The highest porosity obtained is 8.39% for the composition 60:40 (WH: RS), which has the lowest apparent density. The lowest porosity value obtained is 0.63% for the composition made of water hyacinth alone. The variation of porosity with mix proportion (WH: RS) is illustrated in Fig.4.3.

4.4 WATER ABSORPTION

The water absorption rate of the natural fibre composite materials depends on the fibre size, surface area, cellulose and hemicellulose content, porosity, and density of the composites. Water absorption increases with the porosity of the samples. The samples developed in this work show a water absorption rate in the range of 13.88 – 42.45% after being immersed in water for 24hrs and are shown in Table 4.1. The result shows that the maximum water absorption rate is obtained for the samples developed with composition 60:40, i.e., 42.45%, and the lowest value observed for the sample developed from the water hyacinth alone, i.e., 13.88%.

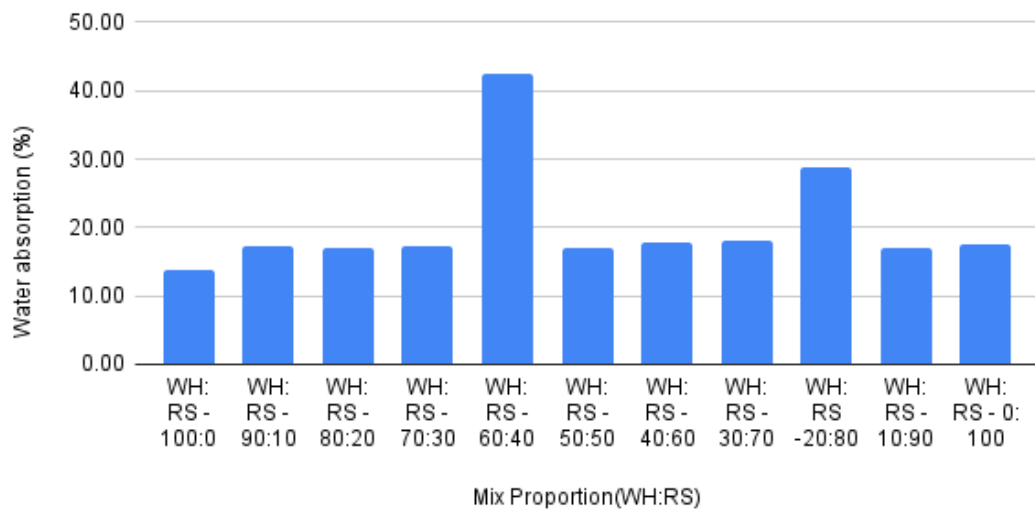


Fig. 4.4: Variation of water absorption with mix proportion

Table 4.6:-Water absorption rate of developed samples with other insulation materials from renewable raw materials and commercial insulation materials.

Source material	Water absorption (%)	Reference
WH+RS(60:40)	42.45	Present work
WH (P-Panel)	318.67	[5]
Sunflower stalk	75	[1]
Wheat straw	32-107	[24]
Coconut fibre(OPC)	2.33	[22]
Coconut coir	7.19	[23]
Wheat husk	55.5	[24]
Oil palm fibre	4.29	[23]
Corn stalk	28.12	[1]

The variation of water absorption with mix proportion (WH: RS) is illustrated in Fig.4.4. Comparison of the apparent density values of developed samples with other insulation materials from renewable raw materials and commercial insulation materials are shown in Table 4.6. The samples developed in this work has low water absorption(13.88 – 42.45%) rate compared to some of the other bio-based thermal insulation materials such as Water hyacinth P-panel (318.67%)[5], sunflower stalk (75%)[1], wheat straw (32-107%)[24], wheat husk (55.5%)[24], corn

stalk(28.12%)[1] shown in Table 4.6. While comparing with the above-mentioned bio-based insulation materials, the samples developed in this work show lower water absorption rate.

4.5 THICKNESS OF SWELLING

The change in length calculates the thickness of swelling for the insulation panels before and after immersing in water for 24 Hrs. The values obtained ranged from 1.39 -3.07% and are shown in Table 4.1. The result shows that the maximum thickness of swelling is obtained for the samples developed with composition 30:70(WH: RS), i.e., 3.07%, and the lowest value observed for the sample developed with rice straw alone, i.e., 1.16%. The maximum allowed TS value is 15% for a good thermal insulation material and the developed samples fall within the range. The variation of thickness of swelling with mix proportion (WH: RS) is illustrated in Fig.4.5.

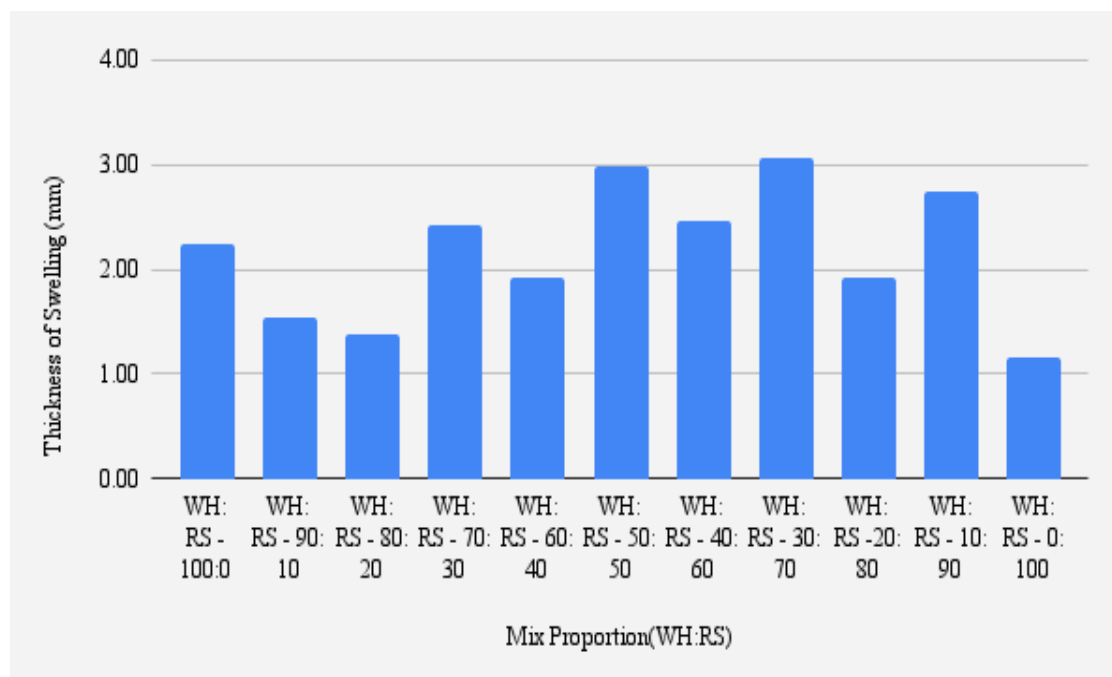


Fig. 4.5: Variation of thickness of swelling with mix proportion.

The samples developed in this work has very low thickness of swelling (1.39 -3.07%) rate compared to some of the other bio-based thermal insulation materials such as Date palm(32.0%)[10], Canary Islands palm(38.2%)[10], Oil palm(20.0%)[10], Tobacco straw(22.0%)[10], Cotton stalks(24.0%)[10], Sunflower stalk(25.0%), Cotton carpel(26.0%), Wheatgrass(41.7%), Washingtonian palm(19.6%) shown in Table 4.7

Table 4.7:-Rate of thickness of swelling of developed samples with other insulation materials from renewable raw materials.

Source material	Thickness of Swelling (%)	Reference
WH+RS(60:40)	1.93	Present work
Date palm	32.0	[10]
Canary Islands palm	38.2	[10]
Oil palm	20.0	[10]
Tobacco straw	22.0	[10]
Cotton stalks	24.0	[10]
Sunflower stalk	25.0	[10]
Cotton carpel	26.0	[10]
Wheatgrass	41.7	[10]
Washingtonian palm	19.6	[10]

4.6 FLEXURAL STRENGTH

The flexural values of the developed samples range from 0.21 to 1.10 MPa, as shown in Table 4.2. The result reveals that the lowest flexural strength is observed at the composition 100:0 (WH: RS), and the maximum value is observed at the composition 0:100 (WH: RS).

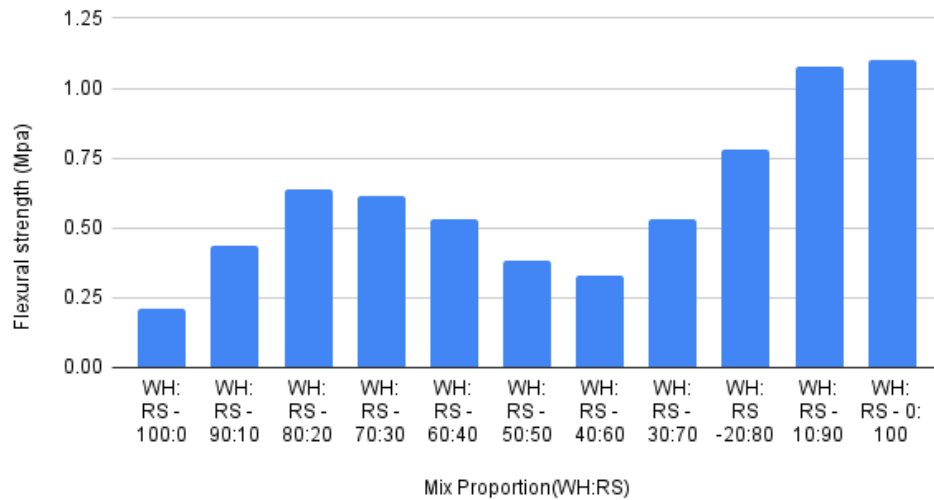


Fig .4.6: Variation of Flexural strength with mix proportion

The variation of flexural strength with mix proportion (WH: RS) is illustrated in Fig.4.6. According to Indian standard IS 3129-1985, the thermal insulation materials should have a minimum flexural strength of 1.5 MPa. The flexural values of the

developed samples range from 0.21 to 1.10 MPa which is below the required standard.

Table 4.8:-Flexural strength of developed samples with other insulation materials from renewable raw materials

Source material	Flexural strength (MPa)	Reference
WH+RS(60:40)	0.53	Present work
WH (P-Panel)	0.42	[5]
Rice straw	0.56	[25]
Sunflower stalk	0.075	[1]
Wheat straw	5.622	[24]
Cotton stalk	0.5	[21]
Coconut fibre(OPC)	15.23	[22]
Coconut husk	0.40	[18]
Coconut coir	8.83	[23]
Wheat husk	0.76	[24]
Bagasse	0.43	[18]
Oil palm fibre	7.89	[23]
Date palm	0.88	[20]
Corn stalk	0.13	[1]
MDF	1.3-2.5	[20]

According to Indian standard IS 3129-1985, the thermal insulation materials should have a minimum flexural strength of 1.5 MPa. The flexural values of the developed samples range from 0.21 to 1.10 MPa which is below the required standard. The samples developed in this work has good flexural strength compared to other bio-based thermal insulation materials such as Water hyacinth (P-panels) composite(0.42 MPa), sunflower stalk(0.075 MPa), coconut fibre(0.5 MPa), corn stalk(0.13MPa), bagasse(0.43 MPa), cotton stalk(0.5 MPa). But the developed samples has low flexural strength compared to other insulation panel boards such as wheat husk(0.76 MPa), coconut coir(8.83 MPa), oil palm fibre(7.89 MPa), rice straw composite(0.56 MPa), date palm fibre(0.88 MPa), wheat stalk(5.662 MPa), MDF(1.3-2.5 MPa) shown in Table 4.8.

4.7 COMPRESSIVE STRENGTH

The flexural values of the developed samples range from 6.21 to 12.16 MPa, as shown in Table 4.2. The highest value recorded for compressive strength is 12.16MPa for the composition 10:90 (WH: RS). The lowest compressive strength recorded is 0.30 for the composition 60:40(WH: RS). The variation of compressive strength with mix proportion (WH: RS) is illustrated in Fig.4.7.

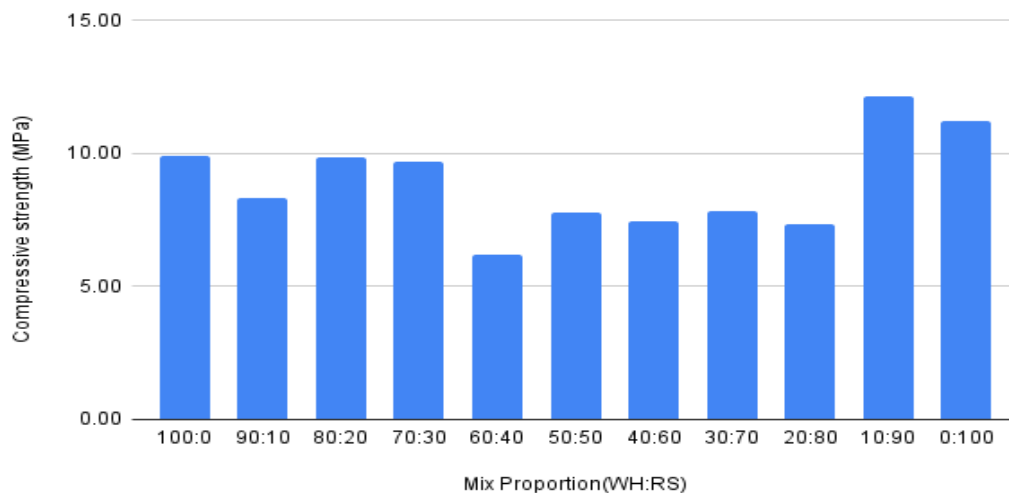


Fig .4.7: Variation of Compressive strength with mix proportion.

4.8 THERMAL CONDUCTIVITY

Thermal conductivity is the amount of steady-state heat flux transferred through a unit thickness material with a unit area induced by unit temperature difference across the cross-section.

Thermal conductivity is the effectiveness of the material in conducting heat. If the thermal conductivity value becomes very low, the material has a very high insulating property. The thermal conductivity of the samples developed in this work ranges from 0.069 to 0.117W/mK, as shown in Table 4.2. The variation of thermal conductivity with mix proportion (WH: RS) is illustrated in Fig.4.8. According to the TS805EN601 standard, materials having thermal conductivity value 0.1W/m K are considered insulating materials. The samples developed having the thermal conductivity in the range of 0.069 to 0.117W/mK and an average thermal conductivity value of 0.096W/mK. The lowest thermal conductivity value noted was 0.069 W/mk for the composition 60:40 (WH: RS) which is below the required standard value. The samples developed is compared with other bio-based insulating materials such as Water hyacinth-cement composite, rice straw –MDI composite, sunflower and wheat

stalk, coconut fibre, oil palm fibre, corn stalk, date palm fibre, bagasse, rye straw, wheat husk, coconut coir, cotton stalk and conventionally used thermal insulation materials such as wood, MDF, plywood, particleboard, hardboard whose values are shown in Table 4.2. Thermal conductivity of the samples developed in this work shows relatively similar values of rice straw (0.052W/m K)[25], Water hyacinth cement composite (0.062W/m K)[5], coconut husk (0.057W/m K)[18], bagasse (0.052 W/m K)[18]. Also the Water hyacinth-rice straw thermal insulation material possess very good thermal insulation property than other bio-based material such as sunflower stalk (0.095W/m K)[1], wheat straw (0.092W/m K)[24], coconut coir (0.386W/m K)[23],coconut fibre (0.254W/m K)[1], wheat husk (0.1 W/m K)[24], oil palm fibre (0.323 W/m K)[23], date palm(0.135W/m K)[19], corn stalk (0.075W/m K)[1]. It is also observed that the Water hyacinth-rice straw thermal insulation material has very good thermal insulation property while comparing with commercially available insulation materials such as wood(0.151W/m K)[20], MDF (0.19W/m K)[20], plywood (0.083W/m K)[20], particleboard (0.097W/m K)[20], hardboard (0.126W/m K)[20]. It is also observed that the Water hyacinth-rice straw thermal insulation material has very good thermal insulation property while comparing with commercially available insulation materials such as wood(0.151W/m K)[12], MDF (0.19W/m K)[12], plywood (0.083W/m K)[12], particleboard (0.097W/m K)[12], hardboard (0.126W/m K)[12]. The thermal conductivity values of all the samples are lower than that of conventional woods and other conventional materials such as MDF, particleboard, plywood, and hardboard.

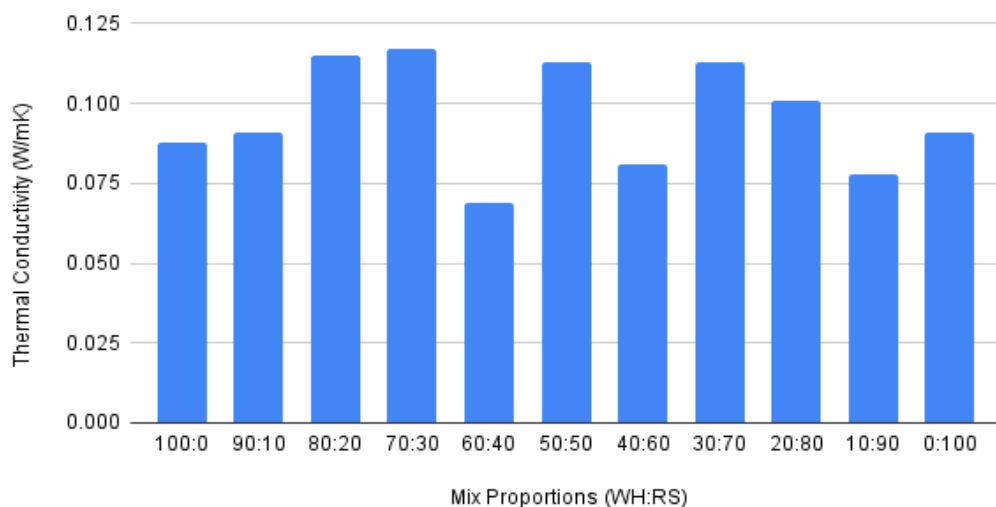


Fig.4.8: Variation of Thermal conductivity with mix proportion

Table 4.9:-Thermal conductivity values of developed samples with other insulation materials from renewable raw materials

Source material	Thermal conductivity (W/m k)	Reference
WH+RS(60:40)	0.069	Present work
WH (P-Panel)	0.062	[5]
Rice straw	0.051	[25]
Sunflower stalk	0.095	[1]
Wheat straw	0.092	[24]
Cotton stalk	0.07	[21]
Coconut husk	0.057	[18]
Coconut coir	0.386	[23]
Wheat husk	0.1	[24]
Bagasse	0.052	[18]
Date palm	0.083	[19]
Oil palm fibre	0.323	[23]
Date palm	0.135	[20]
Corn stalk	0.075	[1]
Wood	0.151	[20]
MDF	0.19	[20]
Plywood	0.083	[20]
Particle board	0.097	[20]
Hardboard	0.126	[20]

The material with thermal conductivity below 0.1W/mK can be used as insulating material. Therefore Water hyacinth-rice straw composite can be effectively used as insulating material.

CHAPTER 5

CONCLUSION

5.1 SUMMARY

The demand for natural resources based on eco-friendly building materials for sustainable constructions has risen. Renewable resources' high energy efficiency, applications, and reusability have all contributed to this. Kerala produces a lot of agricultural straw, mostly rice straw. Furthermore, an invasive aquatic plant known as water hyacinth has been observed growing on a large scale in Kerala's water bodies. Building materials made from natural resources, such as agricultural straws and water hyacinth, will undoubtedly have a brighter future in Kerala, thanks to their low density, fibrous characteristics, low thermal conductivity, non-toxicity, and pollution-free properties. In this study, a novel thermal insulation material was created from water hyacinth and rice straws using a low compaction technology and Epoxy resin as a binder. Mechanical and physical tests were performed on the panels to determine their properties. As a result, the findings can be summarised as follows:

- The apparent density of the developed samples ranged from 681.45 kg/m³ to 919.57 kg/m³. The lowest apparent density was found to be 681.45 kg/m³ for the mix proportion 60:40 (WH: RS) which showed good thermal property.
- The true density of the developed samples ranged from 733.93kg/m³ to 925.41kg/m³. The lowest value of the density obtained is 733.93 kg/m³ with a composition ratio of 20:80 (WH: RS)
- All the samples showed good porosity range (0.63-8.39%) and water absorption range (13.88 - 42.25%) and is excellent compared to commercially available insulation panels.
- Thickness of swelling ranged from 1.16 to 3.07%, which is very low as compared to other insulation panels made from natural fibres. The maximum allowable thickness of swelling for a good insulation material is 15%.
- The result reveals that the lowest flexural strength is observed at the composition 40:60 (WH: RS) and the maximum value is observed at the composition 0:100 (WH: RS).

- All samples showed good compressive strength, the lowest compressive strength was obtained for 6.21MPa for the composition 60:40(WH: RS) and the maximum value (12.16MPa) was observed at a composition of 10:90 (WH: RS).
- All samples showed low thermal conductivity, the lowest thermal conductivity was observed for samples developed in the composition 60:40(WH: RS) and the maximum value was observed at a composition of 70:30 (WH: RS) with an average thermal conductivity value of 0.096W/mK.

In conclusion, self-supporting WHP-cement boards could be used as an alternative to thermal insulation material. This material improves building energy efficiency in areas where WH is a persistent problem. Because the WH pest is a problem in the majority of tropical countries around the world, the simple manufacturing procedure promotes sustainable development and replication in different development contexts. The optimal percentage (WH: RS) was determined to be 60:40 at compaction load of 3KN, indicating good physical, flexural strength, and thermal resistance.

5.2SCOPE FOR FURTHER WORK

This study can be extended to the following areas;

- Studies can be made with some other dangerous and invasive aquatic weeds.
- Durability of the board can be increased by pre-treating the raw materials in any chemical solutions.
- Thermal insulation panel board from WH can be developed and analysed using other binders.
- Compaction periods can be varied and can analyse its impacts on the board properties.
- Tertiary composite can be developed using WH in combination with other natural fibres.

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