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USE OF COIR FIBRE-REINFORCED NATURAL RUBBER COMPOSITES FOR ROOFING INSULATION: A REVIEW

W. S. A. Sudarshana[1*], L. K. T. Srimal[2], and R. Gallage[3]
[1]Institute of Technology University of Moratuwa, Sri Lanka
[2,3]University of Ruhuna, Sri Lanka
asankas@itum.mrt.ac.lk[1*], srimal@mme.ruh.ac.lk[2], rgallage@mme.ruh.ac.lk[2]

ABSTRACT: In a building, most energy is consumed for the heating, ventilation, and air conditioning (HVAC) process. In this process, the thermal comfort in the building is maintained in a way that is comfortable for the people inside the building. The roof of a building plays a critical role in the building's overall energy efficiency and thermal comfort. Compared to walls, the roof is directly exposed to the sun, making it a major source of heat gain. Therefore, adding an insulation layer to the roof can help control a percentage of the heat entering the building and reduce the energy spent on HVAC systems. As a solution, researchers have been searching for sustainable insulation materials. These materials are becoming popular because they are biodegradable, non-toxic, and have significantly low embodied energy during manufacturing. These types of sustainable insulation materials are typically produced by using lignocellulose fiber. Coir fiber is one of the lignocellulose fibers derived from coconut husk and is a renewable, abundant, and environmentally friendly raw material for manufacturing composites. Polymeric composites reinforced with natural fibers such as coir fiber have been developed in recent years and exhibit significant potential for various engineering applications due to their sustainability, low cost, low weight, low thermal conductivity and mechanical strength. However, adding a binder material such as natural rubber to the coir fiber is essential to create the final material. Then, the final composite material will be fully biodegradable. This research work provides an overview of current information on coir fiber and coir fiber reinforced natural rubber composites. The manufacturing of various matrices reinforced with coir fiber and the physical, mechanical, and thermal properties of these composites have been studied by several researchers and included in this review. With the help of these details, a research gap has been identified to optimize the porosity of the natural rubber composite with coir fiber reinforcement to preserve its strength and mechanical properties while minimizing thermal characteristics.

Keywords: coir fiber, composite material, natural rubber, roofing insulation, thermal conductivity

1. INTRODUCTION

One of the main problems the future construction field may encounter is increasing energy consumption, especially in every phase, from design to demolishing. At present, one-third of the energy generated worldwide is used for buildings, with the highest percentage of this energy for Heating, Ventilation, and Air-Conditioning (HVAC) systems. Countries near the equator, such as Sri Lanka, typically receive much solar radiation. Therefore, most heat transfer happens through the building envelope, while the roof becomes the central part (Mintorogo et al., 2015). Thus, the building's indoor heat can be mainly reduced by insulating the roof using some material and reducing the cost of the HVAC systems. It is essential to use modern, sustainable, and environmentally friendly thermal insulation materials to reduce the buildings' carbon footprint (Walbrück et al., 2021). Many thermal insulation material types are available in the European market: 60% of them are mineral and inorganic, such as glass, stone, and wool; 30% of the materials are organic foam materials, such as expanded polystyrene, extruded polystyrene, and polyurethane. Only 10% are combined (wool, gypsum foam) and technologically advanced materials such as nano-cellular-foams or transparent materials (Pavel & Blagoeva, 2018).

A composite material is created using two or more material types, and the characteristics of the final product are always different from the individual materials used (Mahmud et al., 2023). When the coir fiber is used as a reinforcement material, the final material has better mechanical, physical, and thermal properties (Chamath et al., 2022, 2023). Coir fiber has some unique characteristics, such as resistance to seawater, microbial attack, and high impact (Mahmud et al., 2023). Besides, low thermal conductivity or high thermal insulating properties are important (Chamath, 2022). Composites made using natural rubber and coir fiber have become more popular. This natural coir/rubber composite has an exceptional property called *biodegradability* (Rachmawati &

Widiarini, 2021). This is important because non-biodegradable materials such as plastic have become a disaster for the environment. These plastic materials create numerous problems, such as blocking drainages, polluting oceans, reducing the strength and quality of soil, and causing greenhouse effect. Therefore, all materials used must be biodegradable to become an environmentally friendly composite. These biodegradable materials can be degraded using biological components such as bacteria and fungi (Gross & Kalra, 2002). If a composite material contains one or more bio or natural components, it is called a *bio-composite*. A bio-composite can be fully degradable or partially degradable, according to the materials it contains. For example, coir fiber-reinforced natural rubber bio-composite can be named a fully degradable bio-composite because both materials are biodegradable. Roof thermal insulation was noted many years ago because nearly 60% of the heat energy transferring happens across the roof of the building (Sadineni et al., 2011). Roof insulation reduces room temperature and saves much energy. When using an air-conditioner to reduce room temperature and increase thermal comfort, the energy spending for air-conditioner could be decreased by installing a roof thermal insulation. Thermal insulation can also be a transmitting barrier. It can be named as a radiant-transmitting barrier by adding a material such as aluminum foil from behind the roof thermal insulator. Therefore, the infrared radiation is reflected by a roof thermal insulator. Polystyrene, fiberglass, and rock wool/mineral wool are the most used roof thermal insulators in the Middle East and Asian countries. A roof with a polystyrene or polyurethane insulation layer can reduce over 50% of the heat load compared to a roof with no thermal insulation material installed (Sadineni et al., 2011). This review aims to find coir fiber reinforced natural rubber composite insulation materials that can address the growing demand for energy-efficient and environmentally friendly building solutions. By exploring the use of natural fibers like coir and their composites, this paper provides an analysis of their potential as viable alternatives to traditional insulation materials.

2. LITERATURE REVIEW

2.1 Properties of coir fiber

It is imperative to discuss how the coir fiber properties affect roofing insulation applications. Coir fiber has an excellent strength-to-weight ratio, which means they are lightweight and strong. Therefore, coir fiber has become an efficient and effective reinforcement material. Moisture resistance is another outstanding property of coir fiber. This property is very useful in roofing insulation applications because it helps prevent water damage and leakages (Chamath et al., 2022, 2023), thus reducing energy consumption by regulating the temperature. Another critical feature of coir fiber for roofing insulation applications is resistance to microbial attacks. Microbial degradation is minimized when the roof is insulated using coir mats made from coir fiber. In addition, roofing insulation promotes long term durability and performance. Besides these properties, coir fiber is an eco-friendly and sustainable material. Therefore, coir fiber contributes to a building’s overall environmental sustainability. This discourages the use of non-renewable materials for thermal insulation. Harmful chemicals are not used when producing coir mats using coir fiber-reinforced natural rubber, and the manufacturing process is not harmful either. This non-toxic and environmentally friendly process is vital, especially in roofing applications. However, when manufacturing coir mats for roofing insulation, it is essential to modify the mats’ surface to make them chemically moisture resistant. This modification can be done by applying an appropriate coating or doing some treatments while enhancing the moisture resistance (Chamath et al., 2020). Therefore, introducing coir fiber for roofing materials gives excellent physical and mechanical properties with more environmental benefits. Coir fiber is obtained from the coconut husks and shells, which are usually considered waste products of coconut cultivation. Therefore, coir fiber made of these by-products reduces waste and helps in creating more sustainable and eco-friendly constructions. Coir fiber is more cost-effective than other traditional reinforcement materials.

2.2 Coir fiber reinforced natural rubber composites

When a porous composite material such as coir fiber reinforced natural rubber composites is exposed to a thermal gradient, heat transfer happens through vibrational conduction in the solid phase, conduction by colliding gas molecules in the pore phase and radiation, either through a partially transparent solid phase or across large pores. For pore sizes smaller than 5 mm (about 0.2 in), convection heat transfer can be ignored for the material under consideration in this investigation. Therefore, the thermal conductivity of coir fiber-reinforced natural rubber composites, commonly used in roofing insulation applications, can be significantly reduced by incorporating porous materials. This is achieved by increasing the material porosity and using longer coir fibers. With longer coir fibers, the material has a prominent presence of air-filled cavities, which reduces the overall thermal conductivity. The porosity of the natural rubber composite with coir fiber reinforcement must be optimized to preserve its strength and mechanical properties while minimizing thermal characteristics. This balance can be established by conducting experiments and testing to measure the thermal conductivity and mechanical properties of the coir fiber-reinforced natural rubber composite with different fiber lengths. A detailed investigation into the porosity optimization of the composite is essential to achieve the desired mechanical strength while simultaneously minimizing thermal conductivity. Optimizing the porosity of the composite material can be achieved by implementing various techniques, such as controlling the volume fraction and arrangement of coir fiber reinforcement within the natural rubber matrix during the manufacturing process. Post-processing methods such as heat treatment or surface modifications could also be investigated to fine-tune the composite porosity. Optimizing the porosity of the coir fiber-reinforced natural rubber composite is integral in ensuring that the material meets the thermal insulation requirements for roofing applications while maintaining its structural integrity. By addressing the porosity factor, the composite can effectively achieve the desired balance between mechanical strength, thermal performance, and energy efficiency, thus enhancing its suitability for sustainable and environmentally friendly roofing insulation solutions.

2.3 Manufacturing of coir fiber polymer composites

Optimizing the composite's manufacturing process is necessary to ensure that coir fiber is properly distributed and aligned. The focus has been on implementing Vacuum-Assisted Resin Transfer Molding (VARTM) to enhance control over the resin infusion process and achieve a uniform distribution of natural rubber matrix within the coir fiber reinforcement. Manufacturing coir fiber-reinforced natural rubber latex composites addresses the difficulties faced in current manufacturing methods for coir fiber-reinforced materials, including insufficient resin distribution and limited fiber-matrix interaction. The mechanical and thermal properties of these composites depend on volume fraction and arrangement of coir fiber reinforcement within a natural rubber matrix. The primary intention of this study is to analyze the mechanical and thermal properties of the developed composite material as a roofing insulator for residential buildings. Several methods can be employed to optimize the porosity of the coir fiber-reinforced natural rubber latex composite manufactured by VARTM. These may include adjusting the vacuum level during the resin infusion process, exploring different molding pressures, and introducing innovative surface treatments to regulate the porosity at a micro level. These methods help ensure the composite maintains its structural integrity while achieving the desired thermal insulation properties essential for roofing applications.

2.4 Potential applications of coir fiber composites

One potential application of coir fiber composites is in noise-reducing materials. The natural acoustic damping properties of coir fiber can be used to build soundproofing and acoustic insulation products, such as partitions, wall panels, and ceiling tiles, contributing to the improvement of indoor environmental quality and the reduction of noise pollution. Another potential application lies in the development of ebonite rubber, a type of hard rubber used for various industrial and commercial applications. The incorporation of coir fiber into rubber compounds can improve the mechanical properties, such as tensile strength and impact resistance, making the resulting material suitable for applications such as automotive components, sports equipment, and industrial machinery parts. Additionally, the use of coir fiber as a filler in natural rubber compounds has demonstrated potential for property development, enhancing characteristics like tensile strength, tear resistance, and hardness (Rachmawati & Widiarini, 2021).

2.5 Knowledge gap

The next research phase involves conducting experiments to validate the effectiveness of the identified methods for porosity optimization. This experimental validation will provide crucial data on the composite's mechanical strength, thermal conductivity, and insulation performance, further contributing to developing a sustainable and energy-efficient roofing material. Implementing these methodologies for porosity optimization will significantly enhance the composite's suitability for roofing insulation applications, addressing the industry's needs for environmentally friendly and high-performance materials. The research aims to improve the production process of coir fiber-reinforced natural rubber composites using VARTM and evaluate the thermal properties of the composite for roofing insulation applications. A study must examine the influence of coir fiber length on the effectiveness of reducing thermal conductivity in coir fiber-reinforced natural rubber composites, particularly for roofing insulation for buildings. The expected results include an enhanced production method for creating a natural bio-composite material. The importance of this research lies in its potential to generate a sustainable, environmentally friendly, and bio-degradable composite.

3. CONCLUSION

In conclusion, the coir fiber-reinforced natural rubber composite manufacturing process using VARTM offers a sustainable and eco-friendly alternative to traditional composite materials. The remaining work includes research on novel VARTM techniques, exploration of coir fiber reinforced natural rubber composites' mechanical and thermal properties for roofing insulation applications in buildings, and publishing in recognized conferences.

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