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A New Textile Waste-Based Sample for Thermal Insulation in Building

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Abstract:- The development of lightweight, high-performance materials for thermal insulation in buildings has been a key focus of research in recent years. Textile waste can be considered as an everlasting fuel for fulfilling the need for these lightweight insulation materials. Accordingly, composites made from textile waste can be considered the most potential candidate to make competing products as they can have a wide spectrum of properties.

In this study, we investigate the thermal, mechanical, physical, and microstructural properties of samples made from polyester waste (PW) and Carboxymethyl Cellulose (CMC) for use as thermal insulation in building applications. The samples were made by combining varied weight ratios of PW and CMC solution. The mixture is then molded into a 20*20 cm compression mold. Finally, the composite was dried to form a stiff, solid panel. The thermal conductivity of the samples was assessed using a hot plate device, and their mechanical properties were assessed through compressive and flexural tests. The results showed that the thermal conductivity of the samples was in the spectrum of standard insulating materials such as fiberglass and foam. Furthermore, the panels demonstrated excellent mechanical properties, including a high degree of stiffness and strength, making them suitable for use in construction applications. Further analysis using Scanning Electron Microscopy (SEM) revealed that the PW-CMC samples had a well-defined morphology, and that the CMC acted as an adhesion agent between the PES fibers, leading to a uniform and stable composite material with improved mechanical and thermal properties.

Overall, our findings suggest that the fabricated PW-CMC samples have great potential as a lightweight, high-performance thermal insulation material for use in building applications. The unique combination of low thermal conductivity and excellent mechanical properties make these panels an attractive alternative to conventional insulation materials, offering significant energy savings and reduced environmental impact.

***Keywords**: Thermal insulation, textile waste, composites, bio-binder.*

1. Introduction

As the global population continues to urbanize, the construction industry faces increasing scrutiny due to its substantial environmental impact. Buildings, from their initial concept to daily operation, account for a significant share of energy consumption and carbon emissions, highlighting the urgent need for innovative solutions that harmonize the built environment with environmental sustainability [1].

Recognizing that the built environment is a major player in energy consumption and environmental degradation, there is a growing realization that the role of energy efficiency in building design and operation is paramount.

Boosting energy efficiency in buildings stands out as one of the most effective means to reduce their environmental footprint [2].

Integrating energy efficiency into building design and construction is a complex undertaking. Architects, engineers, and policymakers are all contending with the challenge of minimizing energy use in buildings without sacrificing comfort and functionality. This challenge has prompted a comprehensive reevaluation of building systems, encompassing intelligent climate control, lighting, and, notably, the adoption of cutting-edge insulation solutions [3].

Among the strategies to enhance energy efficiency, thermal insulation takes center stage. Effective thermal insulation not only minimizes heat loss during colder months but also curbs excessive heat gain during sweltering summers. This results in significant reductions in energy consumption for heating and cooling, leading to substantial cost savings and a notable decrease in greenhouse gas emissions [4].

The market offers a variety of thermal insulation materials, each with unique characteristics, necessitating the careful selection of materials tailored to specific building and environmental conditions. Insulation materials can be categorized as inorganic (such as glass and rock wool) or organic (including cellulose and polyurethane). Although polymeric insulation materials are effective, concerns about their environmental impact have spurred research into eco-friendly alternatives [5]–[7].

Researchers, recognizing the urgent need for eco-conscious solutions, have been fervently working to pioneer a new generation of bio-based insulating materials. These innovative materials represent a shift toward sustainability, incorporating elements like natural fibers, cardboard, and biodegradable biomaterial binders [7], [8]. By integrating such environmentally friendly components into these composites, they manage to enhance insulation properties while significantly reducing the carbon footprint associated with insulation materials [9].

One particularly exciting development in this realm is the repurposing of textile waste, which encompasses a spectrum of discarded fabrics and clothing scraps. This seemingly unwanted material reservoir has evolved into a valuable resource, presenting a unique opportunity to craft sustainable, high-performance composite materials. By breathing new life into textile waste, these composites not only reduce the burden on landfills but also contribute to the sustainable, circular economy we aim to foster. This creative approach represents a win-win scenario, where waste becomes a resource, and sustainable solutions pave the way for a more environmentally responsible future in the construction industry.

Another facet of innovation in this exploration lies in the incorporation of biopolymers as binders in the preparation of these composite insulation panels. Biopolymers, derived from renewable sources, offer an eco-friendly alternative to conventional synthetic binders. The use of biopolymers not only aligns with sustainability goals but also contributes to reducing the environmental impact of sample fabrication.

Building on these points, in this work we aim to create a new composite combination using carboxymethylcellulose (CMC) as the binder and Polyester waste (PW) as the composite reinforcement. The study delves into the thermal, mechanical, and physical properties of the prepared samples. Additionally, scanning electron microscopy (SEM) is employed to investigate the micro morphology of the composites.

2. Materials and Methods

A. Reagents

Carboxymethyl cellulose (CMC) was purchased from *Alfa Aesar*. Polyester waste (PW) was obtained from a local textile company.

B. Composite preparation

Several composite thermal insulation panels were developed in this work using various mass ratio of polyester waste (PW) and carboxymethylcellulose (CMC). Table 1 lists the components of the prepared insulation panels. Several steps were involved in the production of samples, comprising raw material preparation, homogenization, molding, compression, drying, and demolding. Figure 1 depicts the step-by-step production of samples. The samples were all 20×20 cm in size and almost similar in thickness of 2 cm ±0.2 cm.

Table 1: Samples compositions

Sample	PW weight (g)	CMC weight (g)
S1	120	6
S2	120	8.4
S3	120	10.8
S4	120	13.2
S5	120	18

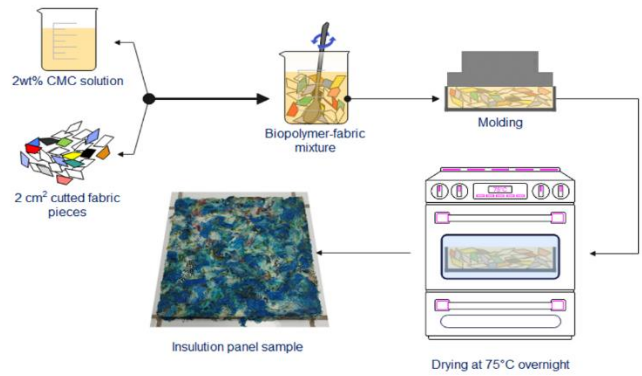

Figure 1: Preparation procedure

3. Characterization

A. Physical characterization

The apparent density (ρ) of samples is calculated in accordance with ASTM C303-10 [10] A precision balance g is used to weigh the samples. In addition, the samples' length, width, and thickness are measured with a digital caliper. The sample volume is then calculated using **Eq.1.**

$$\rho = \frac{l \times L \times e}{V} \times 100 \quad \textbf{(1)}$$

Where l, L, e, and V are the length, width, thickness, and volume of the sample.

B. Mechanical characterization

The ASTM C165 [11] was used to evaluate the compressive strength of the samples. Samples with dimensions of 20×20 cm were examined using an INSTRON 5967 universal testing equipment. The deformation rate was set at one centimeter per minute. **Eq.4** was then used to calculate the compressive strength (σ_c).

$$\sigma_c = \frac{P}{A} \quad \textbf{(4)}$$

To evaluate the bending characteristics of the insulation panels, a 3-point bending test to 20×4 cm test samples was performed on the INSTRON 5967 universal testing equipment according to the ASTM C203 [12]. The test sample was loaded at a rate of 0.5 cm/min. Afterward, the flexural strength (σ_b) and modulus of elasticity (E) was calculated for each composite using **Eq.5** and **Eq.6**.

$$\sigma_b = \frac{3PL}{2bd^2} \quad \textbf{(5)}$$

$$E = \frac{PL^3}{48ID} \quad \textbf{(6)}$$

C. Thermal characterization

The thermal conductivity of the samples was determined using the guarded hot plate method using the λ-Meter EP500e thermal conductivity analyzer, in accordance with ASTM C177 [13].

D. Morphological characterization

Scanning Electron Microscopy (SEM) using the Hirox SH4000 M instrument was used to examine the morphological features of the samples.

4. Results and discussions

A. Apparent density

The apparent density measurements of the prepared samples are depicted in Figure 2. The data collected show that the apparent density of the prepared samples ranges from 180 to 230 Kg/m^3. The samples with the largest amounts of CMC have the highest apparent density. This association can be due to higher bending between the PW and CMC, which results in a compact arrangement, hence increasing the overall density of the samples.

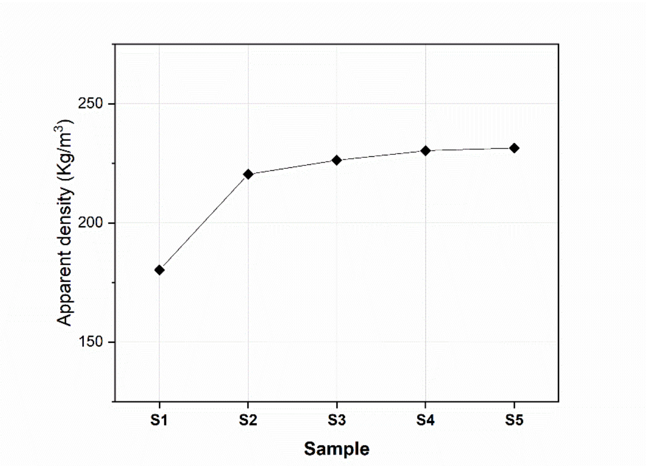

Figure 2: The apparent density of the composite samples

B. Thermal conductivity

Table 2 outlines the thermal conductivities of the composite developed in this study, with measured values ranging from 49.9 to 51.4 mW/m.K. These results demonstrate that the thermal performance of the developed composite aligns well with established insulating materials. Notably, the reported values fall within the range commonly observed for effective insulation materials, affirming the composite's potential as a viable insulation option.

Comparing the thermal conductivities of the developed composite with existing insulation materials, such as fiberglass, foam boards, and mineral wool, reveals a competitive performance. Fiberglass typically exhibits thermal conductivity in the range of 30 to 40 mW/m.K, while foam boards and mineral wool fall within a similar range. Therefore, the developed composite's thermal conductivities, ranging from 49.9 to 51.4 mW/m.K, position it as a promising candidate with performance comparable to or even exceeding some conventional insulation materials.

It is noteworthy that as the binder content within the composite increases, there is a modest reduction in thermal conductivity. This phenomenon can be attributed to the role of Carboxymethyl Cellulose (CMC) in enhancing the compactness and structural integrity of the composite. The increased binder content contributes to the creation of a panel with a more tightly packed and well-structured matrix, characterized by smaller and evenly spaced pores.

These microstructural modifications induced by CMC result in an improved insulation performance, leading to a decrease in thermal conductivity. This finding underscores the effectiveness of the composite in minimizing heat transfer through its structure. By leveraging the unique properties of the binder, the composite achieves enhanced insulating capabilities, making it a compelling choice for applications where thermal insulation is crucial.

In conclusion, the developed composite exhibits thermal conductivities comparable to well-known insulation materials. The influence of binder content on thermal conductivity, with a noticeable decrease as binder content increases, highlights the success of microstructural modifications in enhancing the material's insulation properties. This suggests that the composite has the potential to offer a competitive alternative in various insulation applications.

Table 2: Thermal conductivity of the prepared composite samples

Sample	Thermal conductivity (mW/m.K)
S1	51.4
S2	50.8
S3	50.4
S4	49.9
S5	50.2

C. Compressive and flexural strength

Figure 3 gives an in-depth description of the mechanical features displayed by all the samples under investigation. The research reveals remarkable trends in compressive and flexural strength that significantly increase as the composite material's binder content increases. In particular, S4 and S5 samples had much greater compressive strength values than the other samples, reaching 217 and 351 KPa, respectively. The lower porosity of those panels can be credited for the observed increase in compressive strength. Higher binder concentration levels within the composite appear to be significant in reducing empty spaces and, as a result, eliminating the presence of vacuum areas. In summary, Figure 3 underscores the influence of binder content on the mechanical properties of the samples, with a substantial increase in compressive and, presumably, flexural strength. The enhanced strength, particularly in the S4 and S5 samples, positions the composite as a promising material for applications where both thermal insulation and mechanical robustness are essential considerations.

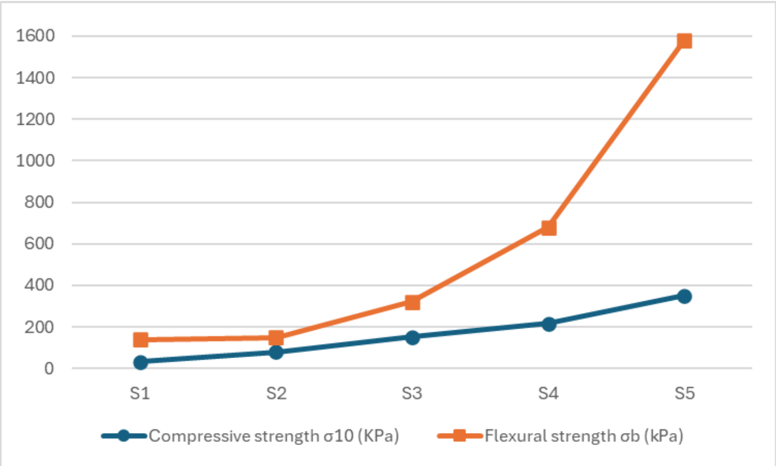

Figure 3: SEM images of the composite samples

D. Microstructural analysis

Figure 4 depicts the SEM images of the composite samples. The presence of CMC is readily visible in the SEM images of samples 1 and 2 as aggregate-like formations. These granular deposits can be seen on the surface of the PW fibers. As more CMC is injected, a significant transition occurs, resulting in the creation of a thick gel-like deposit film of CMC that effectively covers the holes between the fibers. This film contributes to a more stable and robust link between the cardboard aggregates, improving the composite's overall cohesiveness. As a result of the improved interfacial adhesion, the samples are more resistant to deformation and can handle higher loads.

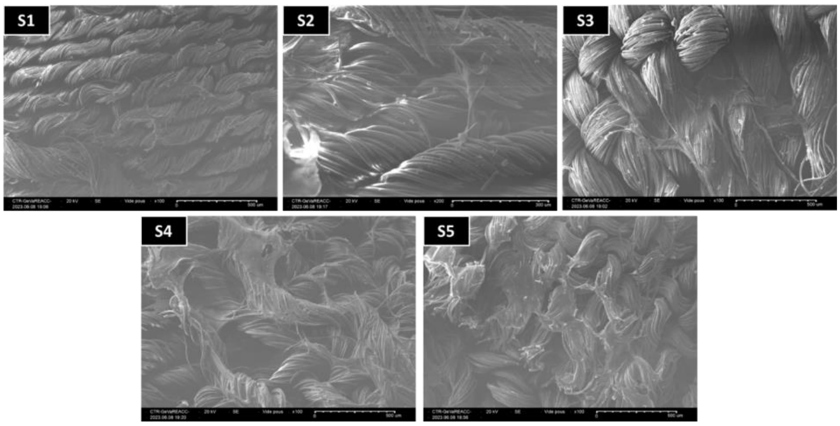

Figure 4: SEM images of the composite samples

5. Conclusion

In this work we have investigated a new composite combination for thermal insulation in buildings. Polyester waste was used as the reinforcement of the composite and carboxymethyl cellulose was used as an ecofriendly bio-binder. The prepared composites showed good thermal insulation characteristics with a thermal conductivity range from 49.9 to 51.4 mW/m.K. Also, the prepared composite exhibited good mechanical proprieties with compressive and flexural strengths reaching 351.02 kPa and 1.58 Mpa, respectively.

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