PROPERTIES OF WOOL FIBERS REINFORCED COMPOSITES

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ABSTRACT

Natural fiber-reinforced composites (NFRCs) have gained significant attention for their array of advantages, including biodegradability, low density, and cost-effectiveness compared to synthetic fiber-reinforced composites. The surge in interest is driven by a global shift towards sustainability and eco-conscious practices across various industries. Consequently, there has been a significant increase in exploration and innovation within the realm of natural fiber composites, reflecting a collective effort towards more environmentally friendly material solutions. Industries such as automotive, construction, aviation, and aerospace are increasingly exploring the use of natural fiber composites. However, the flammability of natural fiber-reinforced composites is a major challenge that needs to be addressed. Wool fiber, known for its natural flame-retardant and self-extinguishing properties, has been widely used in the textile industry to produce apparel, but its use in composite production has been limited. This study explores the feasibility of using wool fibers for composite reinforcement, primarily for applications where fire resistance is required. In this work, wool woven fabric and unidirectional (UD) wool roving were used as preforms, and a bio-based resin was applied through resin infusion techniques to produce the composites. The prepared composite samples were subjected to tensile, three-point bending, thermal insulation, and fire-resistance experimental investigations. The results obtained from the experimental investigations indicate that wool fiber has promising potential as a reinforcement material in composite applications mostly where fire resistance is critical.

KEYWORDS

Wool fiber; Composite; Fire resistance; Mechanical properties; Sustainability; Natural fibers.

INTRODUCTION

Nowadays, most fiber-reinforced composites available on the market for various applications are made from glass or carbon fibers. However, due to the urgent environmental issues related to climate change and pollution, there is a growing need to focus on sustainable solutions and valuable alternatives. In light of these environmental challenges, there has been considerable interest in utilizing sustainable materials and processes [1] [2]. Natural fibers have become particularly prominent among the various options explored, especially as reinforcement materials or fillers in composite manufacturing. In the last decade, Industries such as automotive, construction, aviation, and aerospace are increasingly exploring the use of natural fiber-reinforced composites. Various research has been carried out in recent years on flax and other natural fiber-based composites [3–5].

Despite multiple benefits, such as environmental sustainability, ease of disposal at end-of-life, recyclability, and low cost, the commercial use of natural fiber-reinforced composites (NFRCs) remains limited in engineering applications. Their adoption in commercial domains is hindered by challenges like high moisture absorption, low thermal stability, and poor fire resistance. Fortunately, the issue of moisture absorption has been successfully addressed through alkali treatment or acetylation. Recently, the challenges of low thermal stability and poor fire resistance have also received attention. However, the main approaches used to address these challenges is the use of flame-retardant chemicals, but this have raised concerns about preserving the eco-friendly characteristics of NFRCs [6–8].

Therefore, in this work, the potential of using fibers with an inherent fire resistance property as a reinforcement material was explored. Wool fiber, primarily made of keratin, stands out as a noteworthy choice because of its renewable nature, biodegradability, flame resistance, and thermal insulation properties. Because of these qualities, wool fiber-reinforced composites are attractive options for use in a variety of industries where material performance and sustainability are crucial.

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EXPERIMENTAL

Materials

The study utilized a wool fiber-based woven fabric with a plain structure and a unidirectional (UD) wool roving as the reinforcing phase, along with a bio-based resin as the matrix phase. The wool fiber was chosen primarily for its inherent thermal insulation, flame resistance, and biodegradability, making it advantageous for applications that require environmental sustainability and safety in temperature-sensitive environments. The wool fiber preforms utilized are shown in Figure 1. The matrix phase comprises a bio-based, low-viscosity green epoxy resin selected specifically for its compatibility with natural fibers and low environmental impact. Derived from renewable resources, this resin exhibits favorable mechanical strength, adhesion to natural fibers, and a reduced carbon footprint compared to petroleum-based alternatives. Additionally, it provides a stable polymer network upon curing, ensuring effective load transfer between the wool fiber reinforcement and the matrix.

Methods

The composite samples were prepared using a resin infusion technique, shown in Figure 2a. Two variants of composites, wool-woven fabric and UD wool roving reinforced composites, were prepared using the resin infusion technique. For the woven fabric-based composites, four layers of the fabric were used, while for the unidirectional (UD) composite, the equivalent density of yarn was overlaid based on the density of the yarns per centimeter of the four layers of woven fabric. The resin infusion process began by arranging the preform layers in the desired orientation on a glass plate treated to prevent adhesion. A peel ply and flow mesh were placed over the preform stack to aid resin flow, and the setup was sealed with a vacuum bag. After leak testing, a vacuum pump created a pressure differential to draw the resin, pre-mixed with hardener and degassed, through an inlet port and into the fiber layers. Once infused, the composite was cured under vacuum at room temperature and then post-cured at 50 °C for 24 hours in an autoclave to enhance mechanical properties. The final composite was inspected for uniformity and structural integrity before being subjected to experimental investigations.

<u>Experimental investigations of the composite samples</u>

The prepared composite samples were subjected to mechanical and thermal property investigations in order to evaluate the potential of using wool fiber-based preforms as a composite reinforcement. On the Instron testing machine, the tensile and three-point bending tests were conducted according to IS0 527-4: 1997(E) and ISO 14125:1998(E). The flammability experimental investigations were conducted according to ISO 4589-2. In addition to these experiments, the thermal property of the composite samples was also investigated. The number of specimens used for each test was based on the specimen size and amount described in each standard mentioned above for those specific experimental investigations.

RESULTS AND DISCUSSION

The results obtained from each experimental investigation carried out for both variants of composites produced are presented and discussed in this section.

The result of tensile and flexural bending investigation of both types of composite samples, as presented in Figures 3 & 4, indicates that the UD_wool fiber reinforced composite sample exhibited a 105.97% and 26.89% higher flexural bending and tensile strength, respectively, compared to the woven fabric-reinforced composite sample. However, in the perpendicular direction, the woven fabric-reinforced composite sample demonstrated relatively higher bending and tensile strength. This difference evolves around the orientation of fiber reinforcement; the UD alignment of fibers provides enhanced flexural resistance and tensile strength along the fiber direction, while woven composites contribute to higher resistance in orientations where unidirectional fibers are less effective.

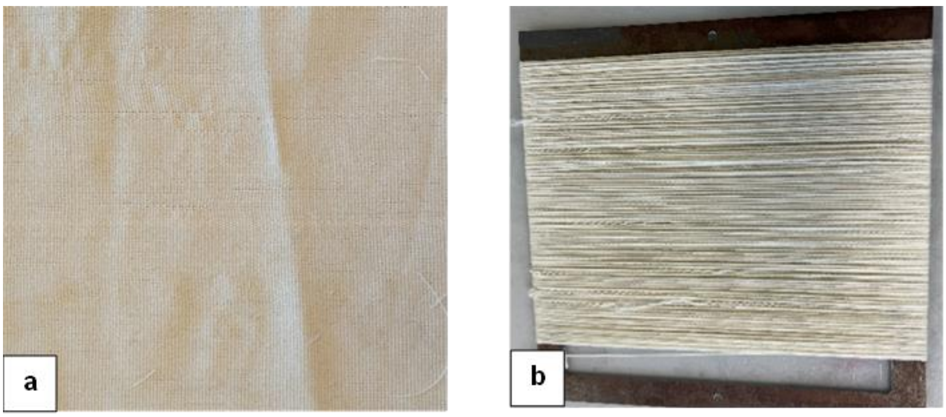

Figure 1. Wool fiber-based composite preforms. (a) Woven fabric, (b) Unidirectional wool roving.

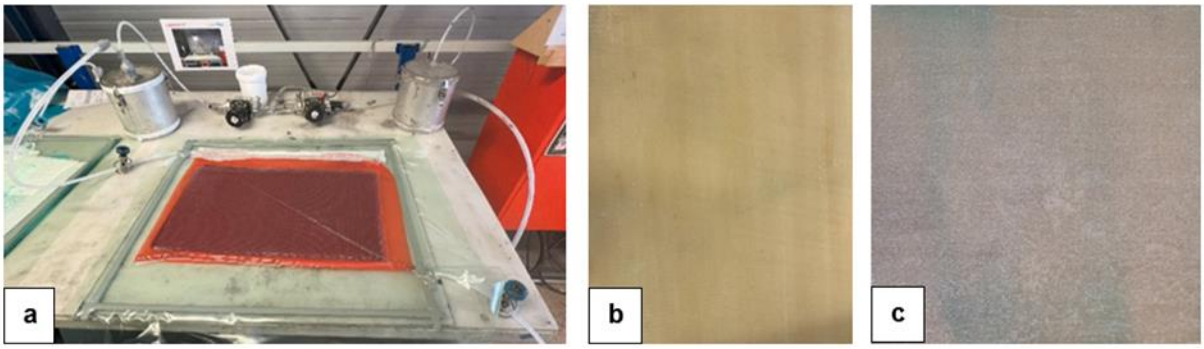

Figure 2. (a) Resin infusion technique, (b) UD wool roving reinforced composite, (c) Woven fabric reinforced composite.

Figure 3. Flexural bending strength of the wool fiber reinforced composites.

Figure 4. Tensile strength of the wool fiber reinforced composites.

The Limiting Oxygen Index (LOI) is defined as the minimum amount of oxygen required to sustain the flaming combustion of a material. The degree of flammability is ranked based on the LOI percentage of each material, where a material with an LOI of less than 20.95% is considered flammable, 20.95% < LOI < 28% is classified as slow-burning, 28% < LOI < 100% is considered self-extinguishing, and an LOI greater than 100% indicates a nonflammable material. To assess the flammability of the materials, an average LOI percentage of 24.55% and thermal resistance of 19.57K/W was obtained for both composite variants, with almost similar values for each variant. The LOI value obtained signifies that the use of wool fiber as a composite reinforcement can enhance the flammability of the composite.

CONCLUSIONS

This work investigated the possibility of using wool fiber-based preforms as a reinforcement material. The experimental investigation of UD and wool woven fabric reinforced composites has yielded several significant findings regarding their mechanical and flammability properties.

- It was observed that the mechanical properties of the wool woven fabric reinforced composites are notably lower compared to those of unidirectional (UD) wool roving reinforced composites in the fiber direction. This indicates that the reinforcement architecture significantly influences the composite's overall performance.
- The limited oxygen index (LOI) values obtained for the composite samples produced in this study demonstrate that wool fiber can effectively mitigate the flammability concerns associated with natural fiber-based composites. This finding highlights the potential of wool as a viable reinforcement material to enhance fire resistance.
- When examining the tensile and flexural bending strength properties obtained with the literature, the UD variant of the wool fiber-based composites exhibited commendable performance relative to other natural fiber-reinforced composites, such as flax and hemp. This suggests that wool fiber possesses reasonable mechanical characteristics within this sector.

In summary, the results of this research indicate that wool fiber has considerable potential as a reinforcement material when compared to more established natural fibers like flax and hemp. Although the mechanical properties of the wool-based composites developed in this study are promising, they remain lower than some alternative natural fibers available in the sector. Future research will focus on the incorporation of wool fibers with other reinforcement materials to further enhance the mechanical properties and to continue addressing the flammability issues inherent in natural fiber composites.

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