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Morphological study on composite materials developed through reinforcing natural and synthetic woven fabrics from glass and hemp

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Abstract. The composites made of natural and synthetic fiber reinforced materials are getting attentions continuously for different engineering applications. Previously, only synthetic fibers were considered for the reinforcement materials due to their superior mechanical properties. However, with the span of time natural fibers are also gaining popularity for their sustainable features. However, the pretreatment of fiber materials could enhance the thermomechanical performances through improving the fiber to matrix interfaces. In this regard, a comparative study is conducted between the synthetic glass and natural hemp woven fabrics to investigate their morphological (before and after the tensile loads) properties. Furthermore, the mechanical tensile properties (tensile and flexural) also shown improved mechanical performances of the products. Glass fiber reinforced epoxy composite shown 79 (1.8) MPa tensile strength, whereas the hemp fibers reinforced composites only provided 39 (1.5) MPa. In case of flexural characteristics, glass fibers also showing better strength by 196 (32.8) MPa than that of hemp 48 (3.5). Thermal stability of the products was also tested using TGA (Thermogravimetric analysis)/DTG (Derivative thermogravimetry) analysis and found that glass fiber reinforced composites have better stability than that of hemp. The results obtained from the developed composite materials clearly reflects the significant differences between the two types of woven fabrics.

1. Introduction

In current times, there is a significant interest growing on natural fiber reinforced sustainable biocomposites. However, there is also some efforts going on to compare the properties of natural and synthetic fiber reinforced composite materials. As the hemp is also a natural fiber [1], hence it is becoming a potential candidate for composite materials development. On the other hand, glass is a most popularly used materials for composite too [2, 3]. However, some efforts are also going on to improve their thermomechanical characteristics. The compatibility of the woven reinforcements could play an important role for enhancing the fiber to matrix interactions which could facilitate the improved thermo-mechanical properties from the developed materials [4-6]. It is tried in this study to develop the fiber to matrix interaction in composite system through applying the pretreatment to the fiber materials.

The interfaces are generated when the fibers with higher strength and stiffness are reinforced with a polymer matrix in composite system. There are several treatment process available to improve the fiber to matrix interfaces [7, 8]. Alkaline treatment which is also termed as mercerization treatment as well is a popularly used natural fiber treatment process [9]. The woven flax fabric was treated with alkaline solutions for improving the fiber to matrix performance characteristics. A proposed reaction mechanism is shown in equation **(1)**. The alkaline treatment reduces the diameter of fiber through increasing the fiber aspect ratio thus develops a rougher surface topography which enables improved mechanical performances of natural fiber reinforced biocomposites. The possibility of reaction is also

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increased through the fiber treatment which consequences better fiber to matrix bonding too [10]. The mercerization process also further influences the molecular orientation and degree of polymerization of cellulose crystallinity in hemp for the removal of cementing polymers like hemicellulose and lignin [10].

$$Hemp\ woven\ fabric - OH + Na - OH \rightarrow Hemp\ woven\ fabric - O - Na + H_2O \quad (1)$$

Conversely, glass fiber treatment by vinyltrimithoxysilane to improve the glassy surface through generating a functional film to transfer stress from polymer to fiber through increasing fiber wettability and compatibility [11]. In this regard, the woven glass fabric was treated by silanes to improve the fiber adhesion property in composite matrix system.

2. Materials and methods

The glass woven fabrics (plain weave, grid size: 4.4 mm × 4.5 mm) having 230 g/m^2 density were bought from Tolnatext company in Hungary. The hemp woven fabric was purchased from Rambutan Vietnam. The epoxy resin (CAS 25068-38-6) and hardener (epoxy katalizator, Cas-Szam 112-24-3) were collected from Novia Kft. (Romania). The mixing ratio of epoxy resin:hardener was 100:35.

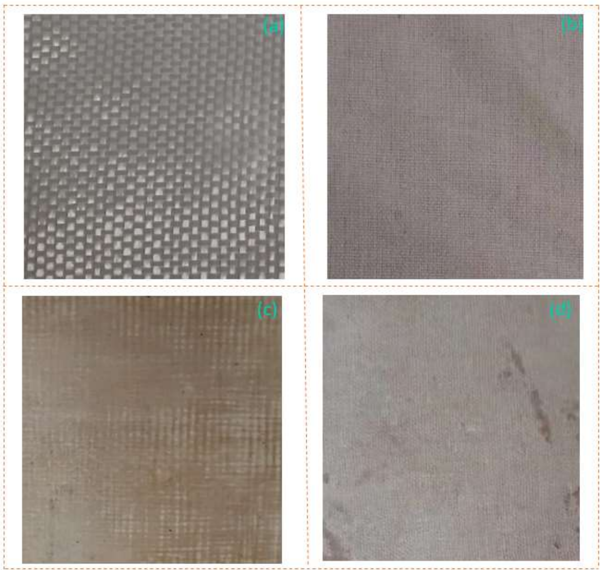

Figure 1. Photographs of developed control fibers and their composites at: (a) glass fabric, (b) hemp fabric, (b and (c) glass fabric reinforced epoxy composite, and (d) hemp fabric epoxy reinforced composite.

The glass and hemp woven fabrics were pretreated with vinyltrimithoxysilane and alkaline NaOH solution (5%), respectively. The glass pretreatment was performed at room temperature, whereas the hemp was pretreated at 100 °C for 45 min. The fabric samples were then dried at 80 °C for 7 min. Later, four layers of hemp and four layers of glass woven fabrics were prepared by 400 × 400 mm^2 dimensions. Initially, the glass woven fabrics were stacked one over another through coating with epoxy resin and hardener mixture uniformly. The hemp woven fabrics were also laminated similarly. The laminated composites were then dried at room temperature for 24 h to ensure better curations (). The SEM (Scanning electron microscopy, Hitachi S 3400 N, Japan) characterization of the developed composites were performed. Mechanical properties were performed using Instron machine (United States). TGA analysis was conducted using Themys thermal analyzer (Setaram instrumentation, France) within 25 to 750 °C under nitrogen atmosphere at 10 °C/min.

3. Results and discussion

The SEM images of the developed composites are shown in Figure 2 which represents the morphological structure of the fractured and unfractured surfaces. The photographs before applying the tensile loads do not show the appearance of respective fibers like glass/hemp as only surfaces could be seen here, which is maybe for the strong coating of the epoxy resin on the surfaces.

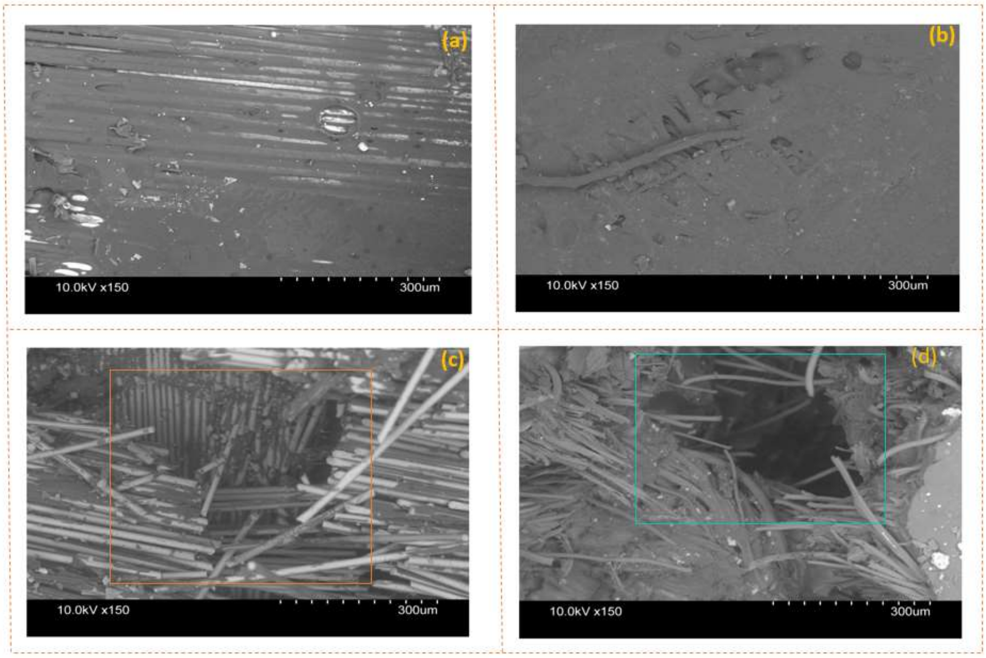

Figure 2. SEM morphologies of developed composites at different magnifications before and after fracture: (a and c) glass/epoxy and (b and d) hemp/epoxy.

However, the fractured SEM images shown the existence of fibers in the composite matrix system. The glass woven fabrics are biaxial, hence less adhesive contact is observed within the stacked layers which is prone to more delamination upon the tensile loads. Conversely, amount of resin for glass fabrics also found lower compared to flax woven fabrics as seen in Figure 2 (a and b). The phenomenon also agreed with previous study by other researcher [9, 12]. It is further found that bonding between hemp and epoxy is higher than the glass/epoxy composites. In this regard, it could be summarized that hemp/glass with epoxy composite could enhance the better adhesion property between the reinforcements and polymer to form hybrid composites with better performances.

Moreover, mechanical properties were also investigated in terms of tensile and flexural performances (Table 1). It is seen that glass fibers reinforced composites shown higher tensile and flexural properties than the hemp fibers. The tensile strength shown by the glass fiber composite is 79 (1.8) MPa, whereas hemp fiber reinforced composites shown 39 (1.5) MPa only. Similarly flexural properties shown by glass and hemp fiber reinforced composites are 196 (32.8) and 48.9 (3.5) MPa, respectively. Youngs modulus also shown the similar effects. The results found here also goes in line with some other researches for flax/glass fiber reinforced polymeric composites [2, 13]. It maybe that, the mercerization of the fibers provided an improved mechanical property due to the strong reinforcement effect between the fibers and polymers as seen in SEM images (Figure 2).

Table 1. Mechanical properties of developed composites.

	Tensile strength (MPa)	Youngs modulus (GPa)	Flexural strength (MPa)	Youngs modulus (GPa)
100% glass/epoxy laminates	79 (1.8)	7 (0.05)	196 (32.8)	53 (3.2)
100% hemp/epoxy laminates	39 (1.5)	3 (0.06)	48 (3.5)	5 (0.25)

TGA and DTG analysis were also conducted to investigate the thermal stability of the composites (Figure 3) further. It is seen that, 100% glass woven fabric reinforced epoxy composite display better thermal stability compared to 100% hemp woven fabric reinforced epoxy composites. It maybe that the glass fibers are more thermally stable compared to natural hemp fibers [14]. DTG analysis demonstrates that about the presence of glassy materials (Figure 3), cellulose, hemicellulose, and lignin in the products. The composite products initially losses some weight (3 to 5%) until 100 °C maybe due to the presence of moisture [15, 16]. However, glass fibers did not show this trend like as the hemp fibers reinforced composites. Therefore, hemp fibers losses more weight especially after 300 °C.

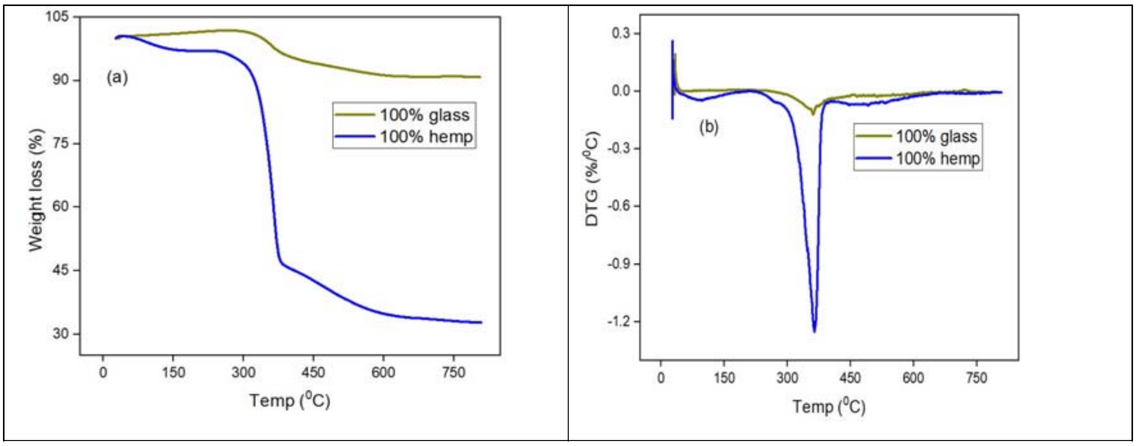

Figure 3. Thermal properties analysis: (a) TGA and (b) DTG.

4. Conclusion

The glass and hemp woven fabric reinforced composites showed significant differences between the morphological properties. The pretreatment has significantly improved the fiber to matrix adhesion properties. Although the unfractured composites did not show the presences of glass and hemp fibers on the laminated composites but the fractured surfaces showed the explicit presence of them. Tensile and flexural properties also found impressive, whereas glass fiber reinforced composites shown higher performances than that of flax. Additionally, glass fiber reinforced composites also displayed higher thermal stability than that of hemp. However, further researches are needed to conduct for developing some hybrid composites through reinforcing both the hemp and glass woven fabrics together with the

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polymeric matrix for investigating their thermomechanical performances. Besides, the developed materials could be used safely against crack propagation through minimizing the environmental pollutions. The inferred results also further clarified the class of materials in terms of mechanical and fracture characteristics.

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