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Mechanical property characterization of water hyacinth and glass fiber reinforced hybrid composite

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ABSTRACT

While composites of natural fibers have got more attraction because of their advantages, there are some limitations. Therefore, hybridization is a way to minimize some of the limitations of natural fibers composite. This article reports on the study conducted to investigate the mechanical properties of a hybrid glass/water hyacinth reinforced polymer composite using five different forms of volume fractions. The hybrid composite was prepared by hand lay-up method according to ASTM D3410 and ASTM D3039 standards for compression and tensile tests, respectively. The material properties of the composite were analyzed to explore the influence of fiber volume fraction. The results indicate that the mechanical properties change as a function of the volume fraction. Thus, the addition of glass fibers influenced the results of both tensile and compressive properties.

1. Introduction

Among the natural fibers that are extracted from plants, hemp, sisal, false banana, kenaf, jute, and water hyacinth are the most common fibers [1–3]. Recent studies indicate that several automotive components are made from natural composites because they are relatively biodegradable, environmentally friendly, and inexpensive [4,5]. The disadvantage of natural fibers, on the other hand, is poor compatibility, lower durability, and moisture content [6]. In order to improve issues related with compatibility, many studies have performed fiber modification by chemical methods such as alkaline treatment [7,8] and silane treatment [9,10]. Furthermore, hybridization of the natural with glass fibers are investigated to improve the mechanical properties of the composites [11,12] because glass fibers have better mechanical properties than natural fibers [13].

Water hyacinth (Eichhornia crassipes) (WH) is one of the types of natural fibers, which is a free-floating plant that grows mainly in tropical and subtropical climates [14]. It grows rapidly and reaches a height of 5–8 cm and can stand up to 28 years in rivers and canals [15]. Since this plant reduces oxygen levels, affects fisheries, and interferes with irrigation and transportation [16–18], it is considered as one of the undesirable weeds. On the other hand, studies indicate that the WH plant is suitable plat for use as a fiber it has poor mechanical properties [19].

One way to improve the poor mechanical properties of natural fibers is developing hybrid composites by combining natural and glass fibers [20]. Jarukumjorn and Suppakarn [21] conducted an experiment on hybridization of glass fibers with sisal fiber reinforced polypropylene composites. They reported that hybridization of sisal with glass/polypropylene composites improved the mechanical properties by up to 50%. The improvement in interfacial adhesion between the matrix and fibers improved the overall flexural, impact and tensile properties of the sisal-polypropylene composite. At the same time, thermal stability was also improved. The thermal decomposition of the fabricated composites improved with increasing glass fiber content, though the water absorption properties were decreased. Moreover, Ramesh et al. [22] studied the same properties with different volume fractions of fibers and described that the tensile properties of the sisal fiber composites were improved.

Braga and Magalhaes [23] investigated both the thermal and mechanical properties of a hybrid composite material made of jute/glass fibers as reinforcement and epoxy as matrix. The results show that the mechanical properties increased with a higher per-

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centage of glass fibers, since jute fibers absorb more water than glass fibers. Tensile strength increased by more than 50%, but significant improvement in flexural strength was not yet evident. The above research shows that the production of hybrid composite is a good way to improve the mechanical properties of the material. It is also observed that the property of plant fibers varies with the climate condition where the plant was grown, and hence more localized studies are required.

There exists an abundant amount of WH in many areas in Ethiopia, and it is considered as unwanted wed because it is threatening the life of other plants. This study is part of an effort to convert the unwanted wed to a useful resource through creating better understanding of the material characteristics of the WH fiber. Recognizing the poor mechanical properties of the plant, this study investigates the hybrid WH /glass fiber with polyester composite and the effects of their mechanical properties at different fiber volume fractions.

2. Materials and methods

2.1. Materials

Phthalic anhydride-based TOPAZ −1110 TP unsaturated polyester resins with Luperox® *K*10 catalyst and glass fibers purchased from World Fiberglass & waterproofing engineering plc in Addis Ababa, Ethiopia, were used in this study. The water hyacinth fibers were collected from Lake Koka in the Oromia region, Ethiopia. The density of the materials used in the study are shown in Table 1 [24,19].

2.2. Methods

2.2.1. Fiber preparation

Water hyacinth fibers (Fig. 1c) chopped fiber were cut to a length of 10 mm. To increase the binding of the fiber, the WH fiber was modified by alkaline treatment with sodium hydroxide (Fig. 1b). The fiber was modified with 5% NaOH concentration for 4 h at room temperature, based on the study of Ray and Sarkar [7], who reported that when jute fibers were treated with 5% NaOH, changes occurred within 2–4 h after treatment. After 8 h of treatment with 5% NaOH, the percent brake elongation decreased by 23%, which analytically means that the fiber becomes brittle and harder. After treatments, the fibers were washed with distilled water and then dried. The glass fibers used were short and randomly oriented fibers (Fig. 1d). To remove the sizing agents in the glass fibers, were heated at 200 °C for 4 h.

2.2.2. Composite fabrication

The hand lay-up technique was used to prepare the five different composite materials. In most studies, a volume fraction of 25–50% [25] of natural fibers is used. In the present work, a volume fraction of 50%, 30%, 25%, and 20% glass fibers/ WH with unsaturated polyester resin was considered. The constituent of the composites and their percentages are shown in Table 2.

Table 1
Density of materials.

Designation	Density (g/cm^3)
Water hyacinth fiber	1.2
Glass fiber	2.54
Unsaturated polyester resin	1.2

2.2.3. Characterization

After the composite material was manufactured, the strength of all specimens was evaluated in tensile and compression tests. The tensile and compression tests were performed according to the ASTM D3039 [26] and ASTM-D3410 [27] standard, respectively, on a universal testing machine (UTM) (Fig. 2b) with a crosshead speed of 0.5 mm/min. The rectangular mold made of mild steel with dimensions of 300 mm × 200 mm × 2.5 mm and 150 mm × 100 mm × 5 mm were used for the tensile and compression tests, respectively. A chrome-plated mold was used to protect against rust and to provide a surface smoothness. The mold was cleaned, and a cut fiber was fed into the mold. The fiberglass was used as a mat and the resin was applied to the mold. The second mat was placed on top of the first mat and the process was repeated up to 5 layers. Finally, the mold was closed and inserted into a hydraulic press machine to cure for 24 h (Fig. 2a).

3. Result and discussion

3.1. Tensile properties

The tensile strength results of the three different volume fractions of the composites are shown in Fig. 3. The prepared composites have the highest tensile strength of 223.83 MPa, which occurred at fiber volume ratio of 20WH/30GF, while the lowest is 106.5 MPa at 30WH/20GF. This means that the interfacial adhesion between the matrix and the fibers contributes to the increase in tensile strength. Obviously, the tensile strength of WH /GF hybrid composite is affected by the fiber volume fraction. The plots of the results shown in Fig. 3 indicate that increasing the volume fraction of WH fiber decreases the tensile strength of the composite, while increasing the glass fiber volume fraction increases the tensile strength. The results reported from this study agree with other works on hybrid of glass fibers and different natural fiber reinforced composites. For instance, it has been reported in [28] that the hybrid composites exhibited the highest strength. Elkazazet et al [29] have also reported that the tensile strength properties varied with the volume fraction of the randomly oriented glass fiber reinforced polyurethane composites. Their conclusion indicates that the tensile strength properties of the fabricated composite increased as the glass fiber content increased.

3.2. Compression properties

The results of the compressive strength of the three composite types are shown in Fig. 4. As depicted, the composite 20WH/30GF has the highest compressive strength, which is of 63.52 MPa, while the composite 30WH/20GF has the lowest compressive strength (44.88 MPa). Furthermore, the results clearly show that the compressive strength of WH /GF composite varies with the change in fiber volume fraction, where the highest WH volume ratio (30WH) has the lowest compressive strength.

As can be seen in Fig. 5, the results of compressive strength increase with the change in the volume fraction of WH /glass fibers. The plots in the figure also show that the compressive strength increases progressively with the volume fraction of glass fibers. This agrees with the study reported by Kumar and Vasanthanathan [30] on the mechanical characterization of the composite reinforced with glass/sisal fibers in which they concluded that the hybrid of glass/sisal fibers has higher compressive strength than the non-hybrid.

Fig. 1. a) Untreated water hyacinth fiber b) NaOH treated of water hyacinth fiber c) Chopped water hyacinth fiber d) E-glass Fiber.

Table 2
Designation and proportion (in %) of constituent materials.

Designation	Polyester resin	WH fiber	Glass fiber
WH/Polyester	50	50	–
30WH/20GF/Polyester	50	30	20
25WH/25GF/Polyester	50	25	25
20WH/30GF/Polyester	50	25	30
GF/Polyester	50	–	50

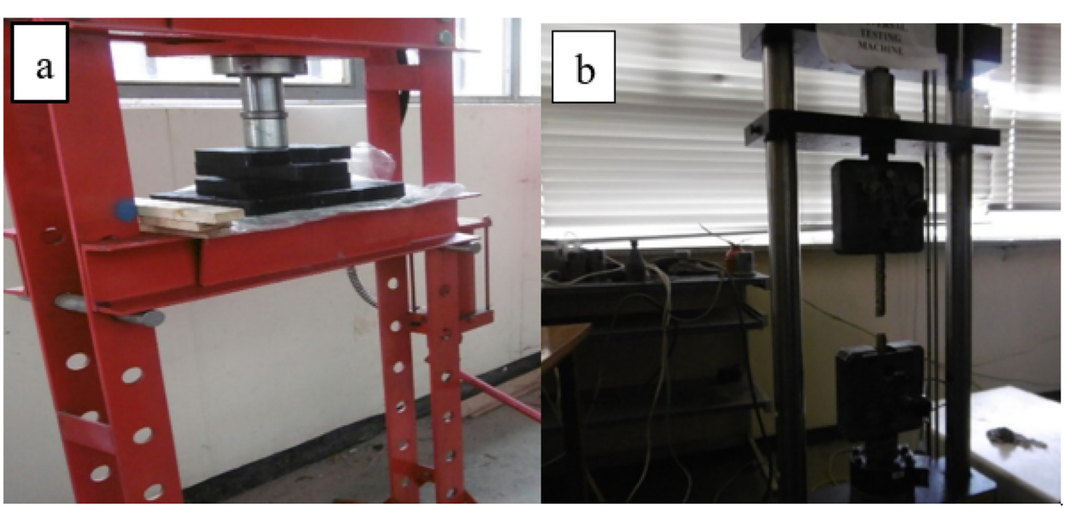

Fig. 2. a) Hydraulic pressing machine b) Universal testing machine (UTM).

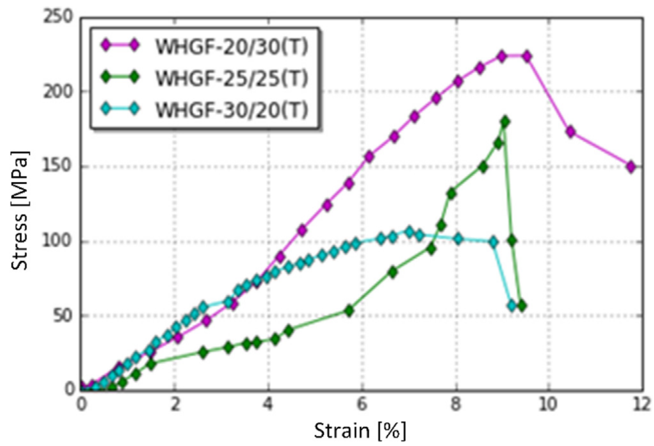

Fig. 3. Stress –strain curves under tensile test for various fibers volume fractions.

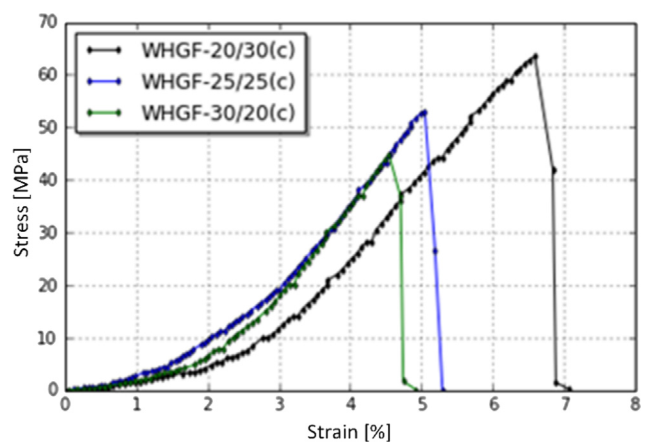

Fig. 4. Stresses –strain curves under compressive test for various fibers volume fractions.

3.3. Comparison of hybrid composite with glass and water hyacinth fiber

From Fig. 6, it can be observed that the maximum value of the hybrid composite in both tensile and compressive strength was obtained for WHGF-20/30, while the minimum value was obtained for WHGF-30/20. This implies that the strength decreases with decreasing glass fiber content. As can be observed from the plots in the figure, the composite reinforced with pure water hyacinth obtained the lowest tensile and compressive strength compared to the other hybrid and pure glass fiber composites. The results obtained in this study agree with other studies such as the work of Arthanarieswaran et al. [31] who studied the effect of hybridization of glass fibers in a composite reinforced with sisal and banana fibers of epoxy and reported that when the glass fiber content increases, the tensile strength also increases simultaneously.

4. Conclusion

The mechanical properties of the hybrid of WH /GF reinforced composite were investigated. The effect of volume ratio of WH / GF composite as well as the hybrid composite affecting the mechanical properties were analyzed. From the present experimental results, the following conclusions are drawn.

- Hybridization significantly improves the mechanical properties of the composites reinforced with water hyacinth fibers.
- Depending on the results, the volume fraction of the fibers affects the strength. When the content of glass fibers increases, the values of tensile and compressive strength increase. On the other hand, when the volume of glass fibers decreases, the tensile and compressive strengths decrease.
- The mechanical properties of the composite reinforced with water hyacinth fibers are lower compared to those of the hybrid reinforced polymer composite.
- In conclusion, the fabrication of a hybrid glass fiber reinforced composite (WH) with a suitable and proposed fiber volume ratio improved the mechanical properties.

CRediT authorship contribution statement

Samrawit A Tewelde: Conceptualization, Investigation, Methodology, Software, Writing – original draft. **Hirpa G Lemu:**

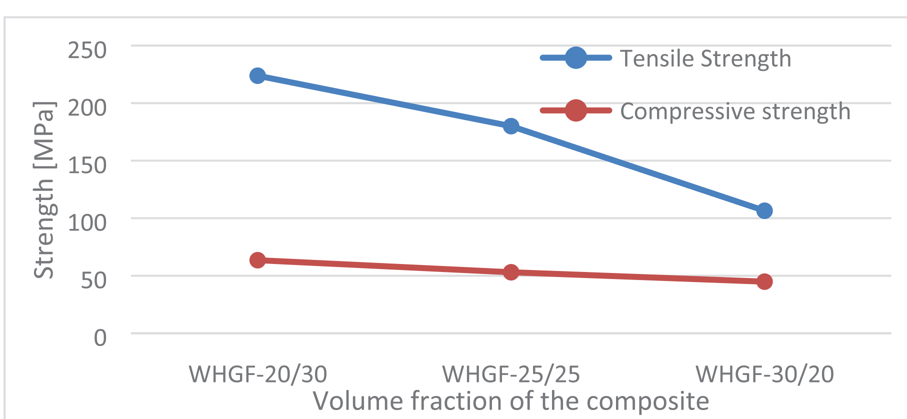

Fig. 5. Influence of fiber volume fraction on tensile and compressive strength.

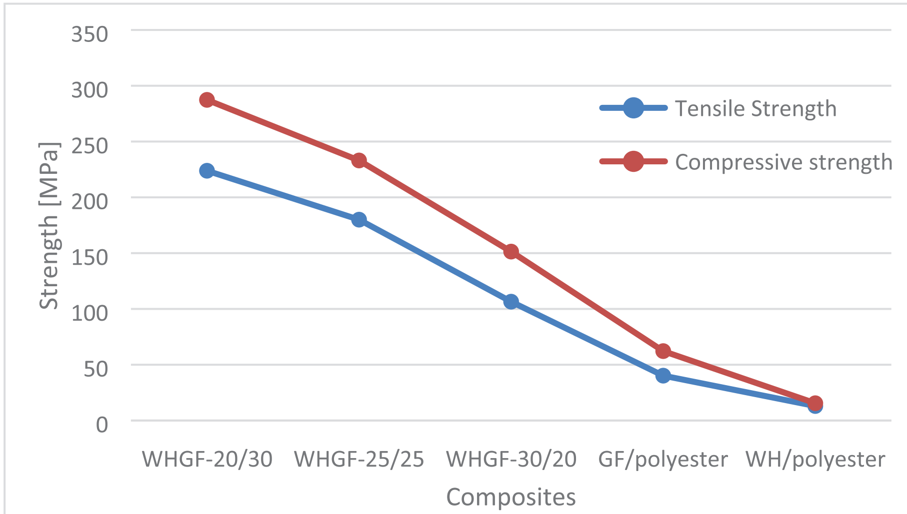

Fig. 6. Comparison of hybrid composite with pure glass fiber and pure water hyacinth.

Supervision. **Jonathan B Dawit:** Data curation, Validation, Visualization.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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