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Investigation of mechanical properties of false banana/glass fiber reinforced hybrid composite materials

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ABSTRACT

The objective of the work presented in this article is to investigate the mechanical properties of false banana/glass fiber reinforced hybrid composite materials at different fiber volume fractions and orientation of hybrid (false banana and glass) fibers. False banana/glass fiber reinforced hybrid composites were designed considering effects of fiber orientation, volume fraction and then manufactured according to ASTM standards using hand-layup technique. The developed composites were then tested for their tensile, bending and compression properties. The standard test methods recommended by ASTM-D 3039 for tensile properties, ASTM-D790M for flexural properties, and ASTM-D3410M for compression properties were used to test the hybrid composites. Effect of volume fraction and fiber orientation on composite materials properties was analyzed. The results show that both volume fraction and fiber orientation significantly affect the mechanical properties of the hybrid composite of false banana/glass fiber.

1. Introduction

The global interest for lightweight and high performance materials is highly driven by the need for energy saving in various industries and engineering applications. As energy saving in many mechanical systems depends on the weight of the mechanical structure, synthetic fiber-reinforced polymers matrix composite materials are highly preferred in different applications due to their lightweight, high stiffness, and high ratio of specific strength to weight [1]. However, synthetic fiber composites have some known drawbacks including high production cost and some polluting effects on the environment during production and upon disposal.

The interest for natural fibre-reinforced polymer composites for diverse engineering applications in these days is driven by, among others, two factors (1) the growing needs to develop environment friendly material and (2) reduce or avoid use of synthetic fibres in fibre-reinforced composites. Natural fibre composites have many benefits of combining environmental friendliness (biodegradability and recyclability) with high specific strength and modulus [2]. On the other hand, these materials have some serious challenges including severe moisture absorption, weak fire resistance, durability, and demanding manufacturing/processing [3].

Many research results indicate that hybridization of different fibers, i.e. natural fibers with synthetic fibers, can reduce the limitations of the fibers and improve the mechanical properties of composites. For instance, Sathish et al. [4] conducted experimental study of the hybridized natural (sisal and jute) fibers with synthetic (glass) fiber and observed that the hybridization led to not only improvements of the composite in terms of the strength-weight ratio and mechanical properties, but also the cost of the products of the hybridized composites that is reduced. In the study reported by Hassan et al. [5], low-velocity impact and compression after impact tests were conducted on sandwich structures of banana/epoxy composites and found out, among others, that the maximum tensile stress and the tensile modulus of the composite, compared with epoxy resin, increased by about 90% and 22% respectively.

Furthermore, the mechanical properties (such as tensile, compressive and flexural strength) of fiber reinforced composites [6–8] are found to be affected by fiber orientation and fiber weight ratio. Jacob et el [9]. have also conducted an investigation on a natural rubber that is reinforced with untreated sisal and oil palm short fibers of different lengths in order to study the effects of concentration of the hybrid fiber reinforced rubber composites. Based on the study, they observed that the tensile strength and shear strength are reduced as a result of increased

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concentration, while modulus of elasticity of the composites increased. The experimental study reported in Ref. [10] investigated the effects of tensile strength of short glass fiber reinforced thermoplastics and indicated that the fiber orientations influenced the degree of anisotropy of the composite. As a result, the nonlinearity of the tensile strength and the modulus of elasticity dropped with the specimen angle.

This study is conducted to investigate mechanical properties i.e. tensile, compression and flexural strength of false banana and glass fiber reinforced epoxy hybrid polymer composite designed under different fiber orientations and fabricated by hand layup and compression mold. Effect of fiber orientation and fiber volume fraction are studied and reported.

2. Materials and methods

2.1. Materials used for experiment

In the present investigation, short randomly oriented E-glass fibers mat were used as reinforcing materials and epoxy resin ("SYSTEM # 2000 EPOXY") with a suitable hardener ("SYSTEM # 2060 HARDENER") used as matrix material. Epoxy resin and catalyst (hardener) as well as glass fiber were purchased from local suppliers of Ethiopia, Addis Ababa. The false banana fibers were extracted from the Enset plant manually by scraping the layers on plane wood as shown in Fig. 1((a) –(c)). The fibers have diameters in the range of 100–400 μm and has more than 1 m long, though the samples for this investigation were prepared by cutting according to sample design. The glass fibre diameter ranges of 3–20 μm [11].

In order to improve the adhesion fiber-composite, the raw false banana fibers surface was modified using a chemical treatment sodium hydroxide. NaOH with 8% concentration of alkali solution was used to treat the false banana fiber. The fibers were soaked at room temperature in NaOH solution for 8 h and then the fibers were washed with fresh water in order to reduce reactivity with environment. Finally, these fibers were dried in sunlight for four days.

2.2. Experimental design

The experiment was designed by considering false banana fiber orientation and fiber volume variation of both fibers. In several literatures [12,13], 30–50% volume fraction of natural fibers were used. Also as fiber volume increases more delamination is observed to take place between the fibers. Thus, considering those cases, a total 50% volume fraction (glass and false banana) fibers and 50% of the matrix were used in this study. Then, two factors that would influence the output to be measured (tensile strength, compressive strength and flexural strength) were considered. These two factors, which are referred to as control factors were set at three levels. The first factor, i.e. fiber orientation, was considered by fixing the fiber volume fraction of false banana to glass fiber ratio (F/G) at 25/25, while the second control factor, i.e. the fiber volume fraction was designed at the fixed orientation [G, 0_B, 0_B, G, 0_B, G] as indicated in Table 1 and illustrated in Fig. 2. In the designation of the sample ply, no orientation was given for the glass fiber because the fibers are randomly oriented (Fig. 3). In addition, when this composite was designed, the effect of water absorption of natural fiber (false banana) was also considered and hence glass fiber was used for the outer ply. To make an equal variation for each composite, the volume fraction or weight fraction of each constituent were calculated using the rule of mixture formulas for making the composite. Density of the false banana fibre, glass fibre mat and epoxy resin of 1.4 g/cm^3, 2.57 g/cm^3 and 1.2 g/cm^3 respectively [3,14] for each volume moulds of 300 mm × 300 mm x 3 mm was used.

Table 1
Control factors and levels.

Control factor	Level 1	Level 2	Level 3
Fiber orientation at constant volume fraction = 25/25)	[G, 0_B, G, 0_B, 0_B, G]	[G, 90_B, 0_B, G, 0_B, G]	[G, G,90_B, 90_B 90_B,G]
Fiber volume fraction at constant orientation = [G,0_B, 0_B, G, 0_B, G]	B/G = 10/40	B/G = 25/25	B/G = 40/10

2.3. Preparation of composite samples

The six designed composite materials used for this investigation were prepared using conventional hand lay-up method and compression molding technique is used to fabricate the composite. The composite was

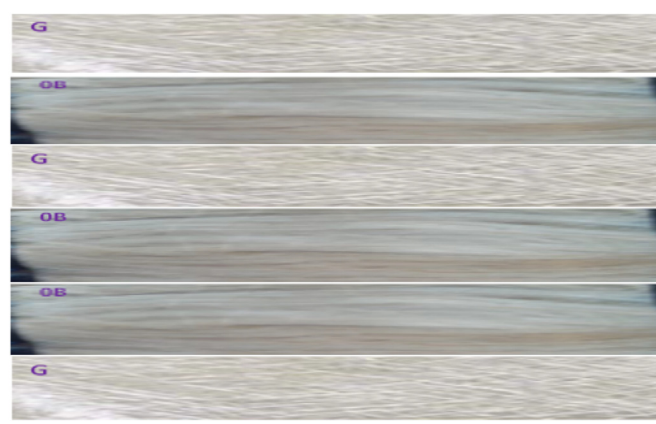

Fig. 2. Ply orientation in [G, 0B, G, 0B, 0B, G].

Fig. 1. Extraction of false banana from enset plant manually a). Enset plant b). Manual extraction on plane wood c). Extracted false banana fibre.

Fig. 3. Sample of randomly oriented glass fibre mat.

prepared with six plies of fibers depending on the parameters presented in Table 1. The 2:1 Epoxy resin to catalyst (hardener) chemicals were mixed well and painted on the plies layer by layer to bind the fibers. At first, the aluminum foam was placed over the steel plate to prepare the good and clean surface of the composite. Then Nelson wax is used as mold releasing agent between aluminum foil and the composite at the end of the curing time. After that, the epoxy resin spread on the painted wax. The fibers are over placed one by one and painted up to the last layer. Then, the prepared samples were compressed by wood compressor machine with a pressure of 5 MPa to remove any trapped air. Then it was left in the mold for 3 h under the same pressure and then the aluminum foil was removed from the composite samples.

2.4. Mechanical property characterizations

After composite material preparation, the tensile, compressive and three-point bending (flexural) tests were conducted for each specimen to evaluate the strength of each composite. The investigations were done on a universile test machine (UTM) at 0.5 mm/min cross-head speed of the machine for all test loads.

Tensile test: ASTM D3039 standard [15] was used for tensile testing of the samples. Tensile tests were performed on a universal testing machine using a sepcimen geometry of 3 mm × 20 mm x 220 mm and a gauge length of 120 mm. During the test, the specimens were placed in the grips of the UTM and axial tensile load was applied at both ends of the specimen.

Compressive test: ASTM-D3410 standard [16] was used for tensile testing of the samples. Compressive tests are performed on a universal testing machine using a specimen of 3.17 mm × 25 mm x 155 mm. During the test, the specimens were placed in the grips of UTM and axial compressive load is applied at both ends of the specimen.

Flexural test: The bending (flexural strength) is the ability of materials to resist fdeformation under an applied load. This test was performed as per ASTM D790 standard [17] using UTM. The prepared specimen has dimensions of 123 mm × 20 mm x 3.2 mm. Further, the support span to depth ratio is 32:1 and the support span length is 102.4 mm. The loading arrangement and failure mode is presented in Section 3.

3. Results and discussion

As stated in the previous section, the study reported in this paper focuses on three tests as a function of two control parameters, giving in total six test scenarios. For all six test scenarios (designed composites) a total of three specimens were used for repeatability in each test. The average values of the results are discussed in the following subsections.

3.1. Effect of false banana fiber orientation

Tensile and compressive strength test: Three types of false banana to E-glass fiber orientations ([G, 0_B, G, 0_B, 0_B G], [G, 90_B, 0_B, G, 0_B, G] and [G, G, 90_B, 90_B, 90_B, G]) in a constant short fiber randomly oriented glass fiber and for constant fiber volume fraction (B/G = 25/25) were used for tensile and compressive strength. For each of the orientations, three specimens were tested to obtain the average values. The testing process was continued until the specimen fractured, and the load at fracture point is used to calculate the strength of the material specimen. Stress–strain curves of each composite for tensile and compressive strength under different fiber orientations are depicted in Fig. 4(a) and (b) respectively. As can be obserbed from both figures, the material response and hence the maximum stress sustained before fracture depends on the fiber orientations. In other words, the plots in the figures show that the false banana fiber orientation affects the tensile and compressive strength of the false banana/glass fiber reinforced epoxy composite.

As depicted by the bar graphs in Fig. 5(a), the highest composite tensile strength obtained is 134.38 MPa, which occurred at fiber orientation of 0°, (i.e. [G, 0_B, G, 0_B, 0_B G]), while the lowest tensile strength value is 50.31 MPa for fiber orientations in the transverse (90°) direction. Similar to the case of tensile strength, false banana fiber orientation of 0°, among the three sets of fiber orientation, has the highest compressive strength, whose value is 47.357 MPa. The transverse (90^0) direction has the lowest compressive strength, which is 13.863 MPa. Comparing the maximum strength levels of false banana/glass fiber reinforced epoxy

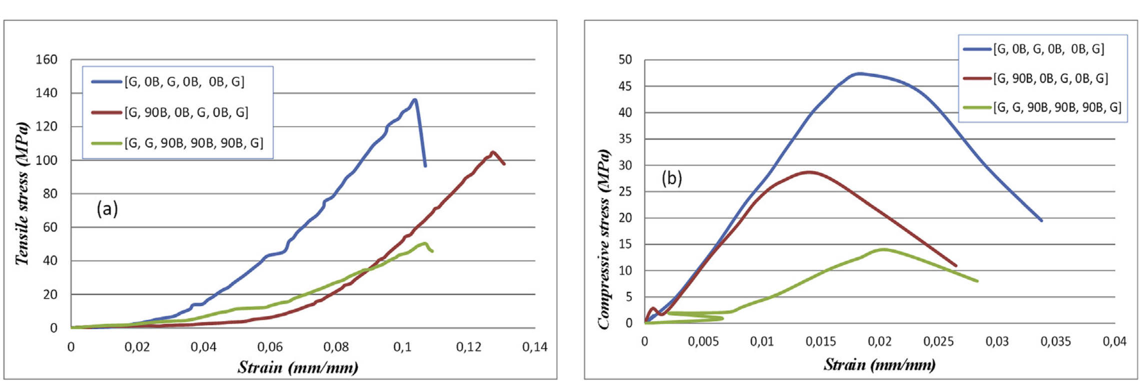

Fig. 4. Average stress –strain curves for various orientations (a) tensile and (b) compressive tests.

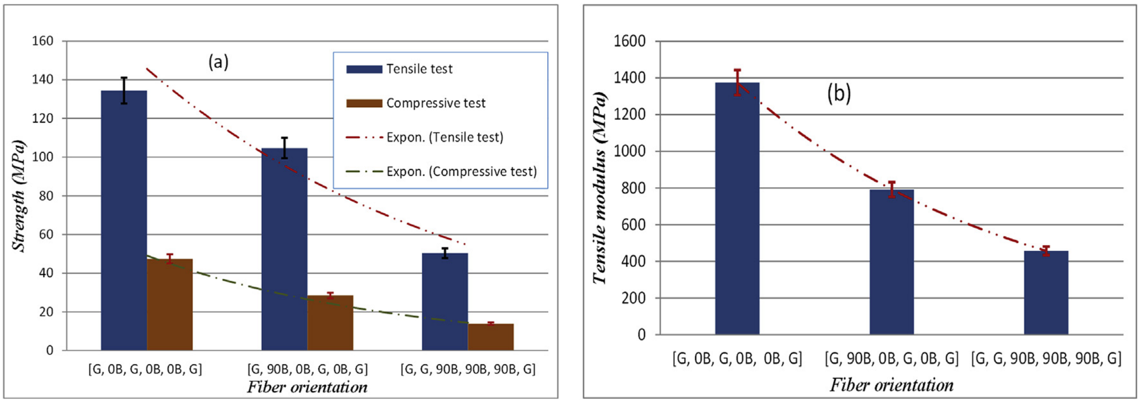

Fig. 5. Influence of fiber orientation of composites on (a) tensile and compressive strength and (b) tensile modulus of elasticity.

composites, the [G, 0_B, G, 0_B, 0_B, G] orientation, the highest compressive strength is about 35% of that of the tensile strength. The maximum compressive stress in the other two orientations is about 28% of that of the stresses in tensile test.

Fig. 5(b) shows bar graph representation of the calculated modulus of elasticity in tension for the three sets of test samples. The modulus of elasticity has similar trend as the variation trend of the tensile strength given in Fig. 5(a). The highest modulus of elasticity value of 1375.3 MPa was obtained by the fiber orientation of 0°, while the lowest tensile strength value, i.e. a lowest elastic modulus of 457.24 MPa, is for fiber s oriented in the transvers (90°) direction. When all the considered results are compared with pure glass, epoxy reinforced composite of fiber orientation [G, 0_B, G, 0_B, 0_B, G] has a high modulus of elasticity.

Many research results have confirmed that the highest strength of fiber-reinforced composites is observed when the composites are loaded in the fiber direction. The plots given in Fig. 5(a) are in full agreement with previous research results such as in Ref. [18], where the composites with the false banana fiber orientation at 0° exhibit the highest strength values while the strength significantly decreased with changes in orientation of the fiber from 0° orientation. The weakest strength is observed for fiber orientation in transeverse or perpendicular direction of the loading direction. The same results are also observed by previous studies such as Humberto et al. [19] who reported that composites with fibers along the loading direction have high strength and modulus of elasticity, while the transverse direction has poor mechanical properties.

Flexural strength test: - The 3-point bending test is widely used to determine the physical property of composite resin reinforced materials. Similar to the tensile and compressive tests discussed in the prvious subsection, three types of false banana to E-glass fiber orientations were used for the 3-point bending tests. The test was modeled as a simply supported beam with the load F_{max} applied at mid-span of a rectangular specimen of the span L between two rollers and the highest flexural strength was determined from Equation (1).

$$\sigma_{bf} = \frac{3F_{max}L}{2bh^2} \quad (1)$$

Where σ_{bf} = stress in the outer specimen at mid-span, F_{max} = the maximum load at mid-span of the test beam, L = support span, b = width of the sample and h = depth of the sample.

The flexural test results are tabulated and presented for both cases (under fiber volume fraction effect and fiber orientation effect) based on the maximum values of the three specimens. The average results obtained among the three specimens from each batch was used for the analysis.

Fig. 6 shows the average flexural strength comparison of each orientation used under this study. As can be observed from the figure, the flexural strength of the hybrid composites with orientation of [G, 0_B, G, 0_B, 0_B, G], [G, 90_B, 0_B, G, 0_B, G] and [G, G, 90B, 90_B, 90_B, G] of both

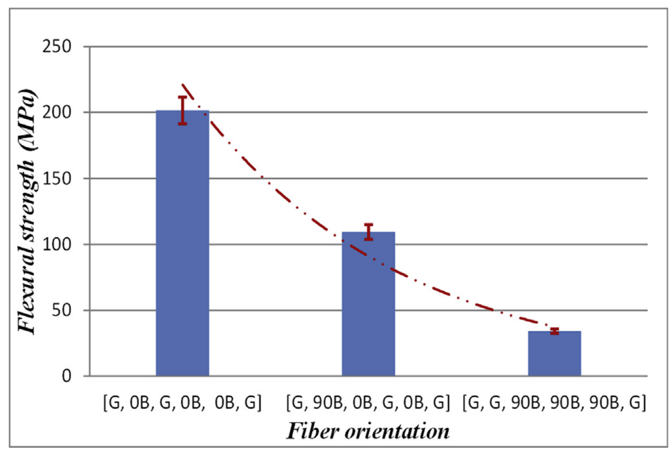

Fig. 6. Flexural strength vs fiber orientation of composites.

hybrid composites under the same vol/wt fractions (B/G = 25/25) are found to be 201.583 MPa, 109.33 MPa and 34.167 MPa respectively. In other words, the highest and the lowest flexural strengths were obtained for false banana fiber orientation of 0° and 90° respectively. This behavior can be correlated to hybridization effect as false banana fibers contributed higher flexural strength to the composite when oriented in 0^0 directions. As can be observed, the strength in flexural load (3-point bending) shows similar trend as in the cases of tensile and compressive loading. This result matches with a study conducted by Mosharraf et al. [20]. in which the effect of fiber orientation on flexural strength of fiber-reinforced composite was investigated and concluded that the orientation of the fibers influenced the flexural strength of the fiber-reinforced composites and the most effective position of the fibers is tension side (0° direction) reinforcement.

Comparison with pure glass fiber: For the sake of comparison, tests were conducted on samples of pure glass fiber (B/G = 0/50) and the obtained average results are given in Table 2. The maximum values for hybrid composite of false banana and glass fiber for loading in fiber direction is also given in the table. The results indicate that the mechanical

Table 2
Comparison of hybrid composite and results of pure glass fiber.

	Average ultimate tensile strength (MPa)	Average ultimate compressive strength (MPa)	Average flexural strength (MPa)
B/G = 0/50	96.89	43.73	165.5
Hybrid B/G = 25/25	134,38	47,357	201,357

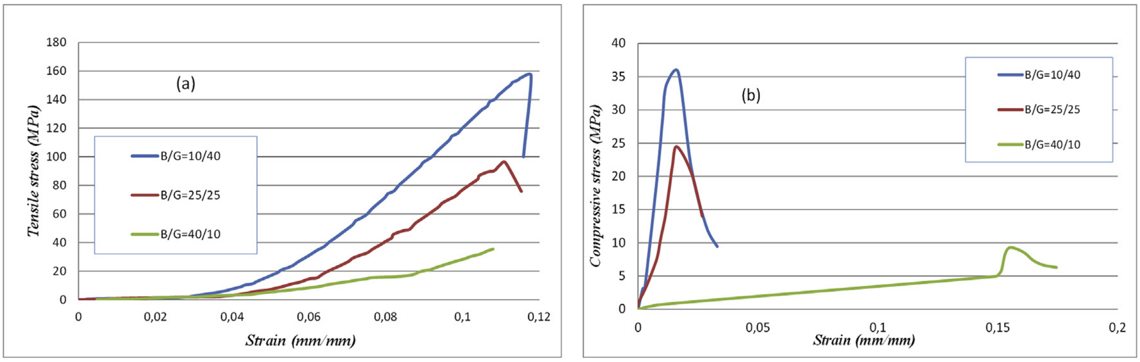

Fig. 7. Stresses –strain curves for various fibers volume fractions a) tensile and b) compressive tests.

properties, particulary theultimate tensile strength and the flexural strength are significantly higher for the hybridized composite.

3.2. Effect of fiber volume fraction

Tensile and compressive strength test: - Three types of false banana to E-glass fiber ratios (10:40, 25:25 and 40:10) in a 50% total fiber volume fraction were used for the tensile and compressive strength tests. For each of the ratios, three specimens were prepared for repeatability. The average stress-strain results of tensile and compressive strength tests are given in Fig. 7. In both tensile and compressive test cases, the effect of the false banana fiber volume fraction has similar trend in terms of the maximum stress level achieved. For each volume fraction, the maximum compressive stress level is about a fourth of the maximum tensile stress level. The false banana/glass fiber reinforced epoxy composite with a volume fraction of B/G = 40/10 behaves differently in terms of strain response, where it sustained the largest strain under load in the case of compressive loading. As can be observed from Fig. 7, in the case of sample B/G = 40/10, the material at higher compressive load reaches a point where sudden and appreciable increase in stress occurs without appreciable increase in strain because the material behaves almost rigid just before failure.

Comparative illustration of the tensile strength and the modulus of elasticity in tension is also illustrated in Fig. 8. The study indicates that the fiber weight fraction affects the tensile strength of the false banana/glass fiber reinforced epoxy composite (Fig. 8(a)), where increasing the false banana fiber volume fraction in the composites decreased the tensile strength. The highest composite tensile strength for the designed composites is 156.67 MPa which occurred for false banana fiber to glass fiber volume fraction of B/G = 10/40, while the lowest tensile strength value is 40.157 MPa and this was obtained at volume fraction of B/G = 40/10.

The strength of the false banana/glass fiber reinforced epoxy composite as a function of fiber type and its volume fraction under compressive load (Fig. 8(a)) shows similar trend as in the case of the tensile strength test. Increasing the false banana fiber volume in the hybrid composites contributes to lower compressive strength. The highest composite compressive strength obtained in this study is 35.687 MPa, which occurred for false banana fiber to glass fiber volume fraction of B/G = 10/40, while the lowest tensile strength value of 9.29 MPa was obtained at volume fraction of B/G = 40/10. The maximum average strength in compression is about a quarter of the strength in tensile test.

As can be observed from Fig. 8(b), the modulus of elasticity has similar effect to that of the tensile strength. The highest composite tensile modulus is 1355.6 MPa, which occurred for false banana fiber to glass fiber volume fraction of B/G = 10/40. The lowest tensile modulus value of 293.71 MPa was obtained for volume fraction of B/G = 40/10. In other words, the tensile strength and the modulus of elasticity increased with increasing the fiber volume fraction of the glass fiber. In a related study reported in Ref. [21], the effect of fibre volume fraction on tensile behaviour of banana, pineapple leaf fibre, glass reinforced epoxy resin composite materials indicated that as the mechanical properties vary with varying fibre types. Hybridisation between glass fibre and natural fibre has increased the tensile strength significantly.

Flexural strength*:* Similar to the case with tests of the influence of fiber orientation, fiber type volume fraction variation has great effect on the flexural strength results. Fig. 9 shows the comparative results of values of maximum flexural strength average of the test samples under different fiber volume fractions. The flexural strengths of the hybrid composites with volume fractions (B/G) of 10/40, 25/25 and 40/10 are found to be 222.083 MPa, 116.167 MPa and 54.667 MPa respectively. This result matches with the work reported in Ref. [7], where it is indicated that the variation of fiber type and their weight affect the flexural strength properties of fiber reinforced composites. In all the three

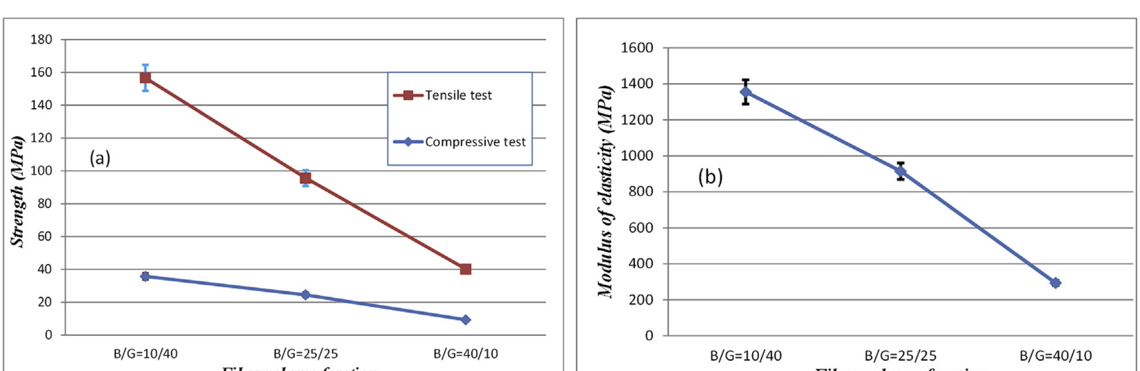

Fig. 8. Influence of fiber volume fraction on (a) tensile and compressive strength and (b) modulus of elasticity in tension.

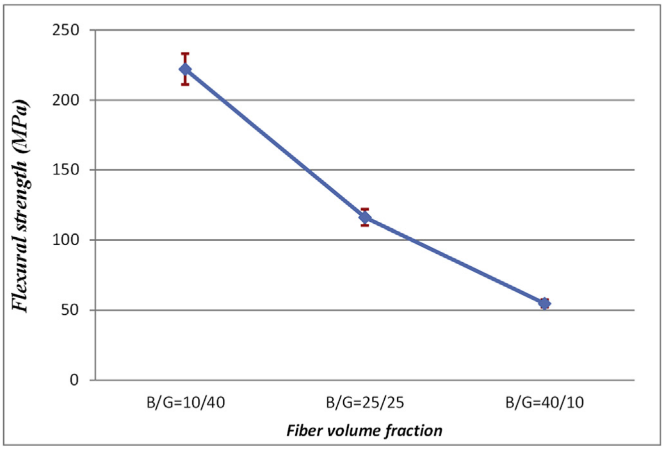

Fig. 9. Flexural strength vs. fiber volume fraction of composites.

mechanical properties studied in this research, it is observed that as the content of false banana fiber increases in the composite, its strength reduces.

4. Conclusion

In this study, the test samples for the false banana/glass fiber reinforced composites were fabricated using hand – layup techniques under different fiber orientation and fiber volume. The mechanical properties i.e. tensile, compressive and flexural strengthes of the hybrid reinforced composites were investigated according to recommendations of ASTM standard. The effect of false banana fiber volume fraction and fiber orientation were studied. The following conclusions are drawn with regard to the development, testing and analysis of false banana/glass with epoxy resin.

- For all experimental test results, the effect of false banana fiber orientations is found that 0° direction, i.e. fiber orientation along the load direction give better mechanical properties than the other designed composites (directions).
- In the test for fiber type volume fractions, the volume fraction sample $B/G = 10/40$, i.e. the lowest false banana volume fraction, has shown highest strength values compared with the other composite samples.

Generally, it is observed that fiber orientation and fiber type variation in terms of the volume fraction in the hybrid composites affect the mechanical properties of the composites.

Credit author statement

Temesgen Batu: Data collection, Testing and Investigation, Methodology, Result analysis, Original draft preparation. **Hirpa G. Lemu:** Conceptualization and Methodology, Supervision, Editing and Validation.

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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