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An experimental comparative study of the mechanical properties of synthetic carbon/glass fiber composites and natural palm fibers for automotive hood applications

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Abstract

There is an increased interest in natural fiber composite materials as alternatives for metals in the manufacture of automotive hoods in the automotive industry. This study aims to experimentally investigate the mechanical properties of hybrid composites of synthetic fibers carbon/glass and natural palm fibers in a polyester matrix. Composites were manufactured by the vacuum-assisted layering process, including carbon/glass hybrid laminates 45 wt. % fibers, palm fiber laminates 30 wt. % fibers with unsaturated polyester resin under ambient conditions in 24 hours. Test results revealed that carbon/glass hybrid composites had excellent mechanical properties in terms of tensile strength 274 MPa and impact energy absorption capability 1.25-2.1 J, contrary to poor mechanical strength and energy absorption capabilities of palm fiber composite tensile strength 47 MPa; 0.25-0.44 J. Flexural test confirmed the better mechanical resistance in bending of the hybrid synthetic composite, resisting up to 9 kN load before failure, while the palm fiber composite failed at a load of 1.58 kN due to brittleness of its structure and weak interaction with the polyester matrix. Despite having great benefits for the environment, due to mechanical weaknesses, further fiber treatment may be required to improve natural fiber material performance.

I. Introduction

In recent years the technology to manufacture composites have significantly improved and in turn composite material is becoming popular in applications such as the automotive and aerospace industries. In particular, Initially, traditional materials, whether metal or synthetic fiber, that were being used in the automotive industry were found to be very poor in terms of recyclability and biodegradability, and hence were causing several types of pollution and severe disposal complications that needed to be eliminated as soon as possible [1], [2]. Composite materials, defined by the heterogeneous integration of two or more constituent phases with divergent physical and chemical properties, have revolutionized modern engineering by enabling tailored solutions for high-performance applications [3], [4].

The mechanical performance of fiber-reinforced composites depends critically on the type of fiber, its size ratio, interfacial bonding, and manufacturing method. Reviewed lightweight kanaf composites for automotive applications, confirming that natural fibers can achieve acceptable tensile and flexural properties when properly optimized [5]. Demonstrated that increasing the glass fiber content from 20–60% in vinyl ester composites proportionally improves tensile strength and impact resistance until the base material is saturated [6]. Similarly, [7] showed that adding 5% cut carbon fibers to polymer concrete significantly improves Young's modulus and flexural strength. However, natural fibers such as date palm fibers often suffer from misalignment and poor bonding to the base material as noted [8], resulting in reduced impact resistance. To overcome these limitations, computational methods such as the finite element micromechanical model validated by study [9] enable the prediction of hybrid composite properties prior to fabrication. Furthermore, a study [10] emphasized that fiber/matrix modification such as alkaline treatment or bonding agents and hybridization with synthetic fibers are key strategies to bridge the performance gap between natural and synthetic fiber composites in automotive structural parts, such as engine covers. Throughout the world the automobile sectors have been working on durable and robust material where the weight of the material does not play an essential role however, gradually it has become apparent that lightening the structure of the vehicle has remarkable positive impacts on the performance of the vehicle as stated by [11] meanwhile a better functioning of the vehicle can also be attained by making weight an important consideration along with strength and stiffness according to the findings of [12]. Natural fiber-reinforced composite materials have been a subject of intensive interest to academics and industry practitioners in the context of lightweight structural design, especially in the automotive field. Natural fiber composites have attracted scholarly attention from the end of the 19th century owing to several benefits such as low density, economic considerations, and environment-friendly nature. Research in this area has primarily been aimed at making use of the materials in aerospace and automobile vibration control and sensing because of the requirement of alternative materials with similar attributes to metal but reduced weight and increased strength. Such studies have led to the evolution of AVC and composite materials [13], [14], [15], [16]. In this regard some pioneering work in glass fiber-reinforced vinyl ester composites and studied the effect of fiber weights (20%, 40%, 60%) [17]. Tests performed including tensile strength, compressive strength, flexural strength, impact strength, and hardness of the materials; it was found that fiber addition improves these characteristics, provided matrix-fiber saturation limits are observed. Likewise, experimental studied [18] with carbon fiber-reinforced polymer concrete and added 5% of chopped carbon fibers (length = 6.5 mm; diameter = 0.12 mm) in unsaturated polyester resin along with silica, sand, and stone fillers. The outcomes include an increase in tensile strength, Young’s modulus, and flexural strength. Advancements in computational modeling have further refined composite design. One study used [19] employed finite element analysis and the Mechanics of Structure Genome homogenization method to predict the effective mechanical properties of flax/jute-epoxy hybrid composites. By validating numerical results against analytical models (rule of mixture, Halpin-Tsai, Tsai-Hahn equations), this work established a framework for optimizing natural fiber composites through micromechanical analysis. while suggested that expanded the discourse by reviewing the historical and contemporary applications of natural fibers such as kenaf, sisal, and hemp in automotive and aerospace industries, emphasizing their mechanical, thermal, and ecological benefits [20].

Recent studies highlight a shift toward regionally sourced and sustainable fibers characterized date palm fiber reinforced epoxy laminates fabricated via contact molding noting acceptable tensile properties despite variability in fiber alignment [21]. Concurrently, investigated fiberglass reinforced polymer FRP composites analyzing the effects of fiber morphology (milled, textile, mat) and calcium carbonate/silica additives on flexural performance. Their results showed the mechanical properties peaked when the fiber size ratios were critical before decreasing due to insufficient base material, which is consistent with previous saturation principle [22]

The objective is clarified at the end of the introduction: This study aims to conduct a comparative evaluation of the tensile, flexural, and impact properties of synthetic carbon/glass hybrid composites versus natural palm fiber composites for automotive engine cover applications under identical manufacturing conditions and polyester matrix. The stress-rate sensitivity of randomly oriented glass fiber-reinforced composites used in automotive engine covers at room temperature is investigated to contribute to the design of lightweight and cost-effective solutions that meet mechanical performance and sustainability requirements in low-speed collision scenarios.

2. Materials and methods

2.1 Natural fibers

Natural fiber composites are increasingly replacing metals in automotive non-structural components due to their sustainability and cost benefits. Industry leaders have invested in NFC R&D, with validation studies confirming their efficacy in low-stress applications, as depicted in Fig.1 and Fig. 2.

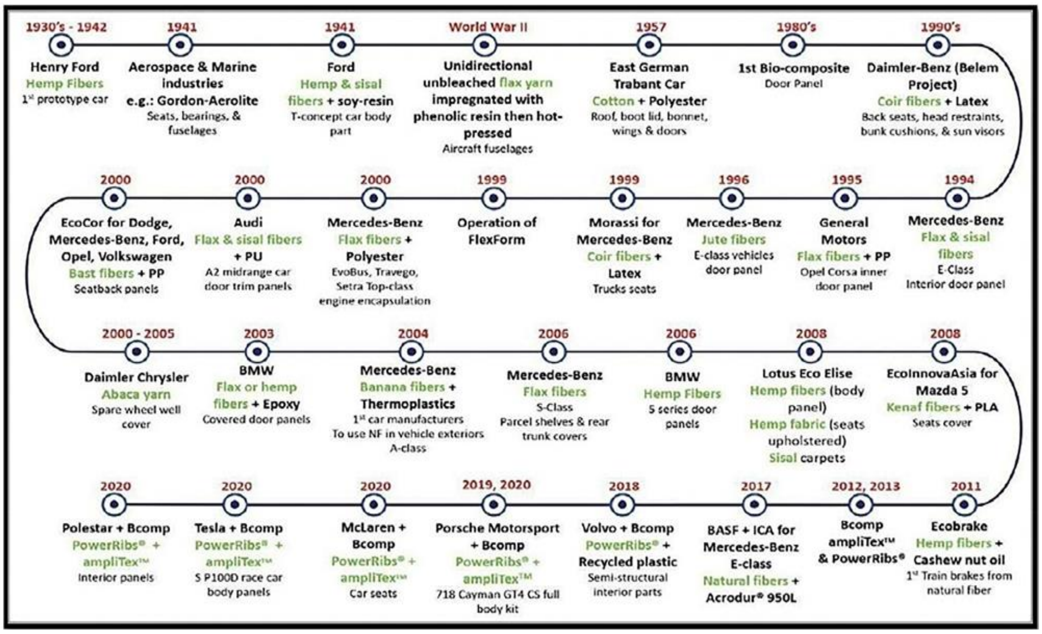


Fig. 1. History of Natural Fibers-based automotive products (with permission) [11].

Fig. 2. Parts that can be manufactured from automotive polymers [23].

2.2 Material used

This study evaluates glass fiber, carbon fiber, and palm fiber composites with polyester resin for automotive hoods. Glass fiber polyester systems offer cost effectiveness durability and moderate weight reduction 1.8–2.1 g/cm^3 but lag behind carbon fiber's superior strength to weight ratio 500–700 MPa, 1.5–1.6 g/cm^3, which enhances rigidity for premium vehicles despite higher costs. As shown in Fig. 3 and Fig. 4 Polyester resin ensures robust adhesion and environmental resistance optimizing manufacturing processes. Palm fiber composites show sustainability potential but face challenges like thermal instability >200°C. Material selection balances performance, cost and eco-goals guiding lightweight efficient automotive design. [23]. In this experiment, there was no use of any chemicals for treating the date palm fiber before adding it to the epoxy matrix. The date palm fibers were merely physically cleaned and dried before being introduced into the epoxy matrix. No use of any chemicals such as NaOH or any coupling agent was made for fiber surface modification. The purpose of this method was:

1. To investigate the properties of untreated fibers in composite materials.
2. To avoid doing anything which can affect the structure of fibers.
3. To ensure a simple process and environmental-friendly process of preparation.

(a) *(b)* *(c)*

Fig. 3. **(**a) carbon fiber (b) glass fiber (c) polyester.

Fig. 4. Natural palm fiber.

2.3 Sample preparation

Two glass molds (40 × 40 cm) were coated with a mold-release wax to facilitate demolding and prevent surface damage Fig. 5. A measured volume of polyester resin was uniformly applied to the mold surface using a brush, followed by sequential layering of fiber reinforcements. Each fiber layer was impregnated with additional resin to ensure interfacial adhesion and eliminate voids. The layup was subjected to vacuum-assisted debulking for 15 minutes to evacuate entrapped air, after which the assembly was vacuum-bagged and cured at ambient conditions for 24 hours. Post curing, the composite panels was carefully demolded yielding defect-free samples of specified thickness. Fiber volume fraction was calculated using the Mold volume and matrix volume. Considering that the Mold volume is 40×40 cm with a height of 4 mm, the composite volume becomes 640 cm^3. As the epoxy and hardener volume are 400 mL and 8 mL, respectively, the matrix volume is 408 mL. In such a case, the approximate fiber volume fraction would become 36.25 vol%, whereas the matrix volume fraction is 63.75 vol%. But the actual weight fraction cannot be found without knowing the mass and density of fibers.

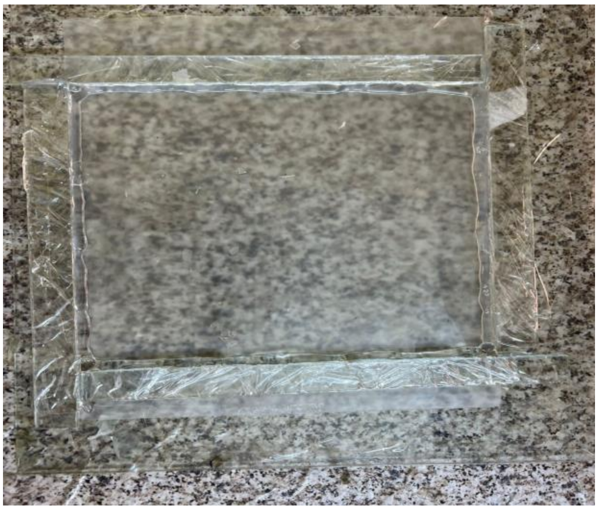


Fig. 5. Prepare mold for samples.

2.4 Experimental setup

Two distinct formulations were prepared using glass molds (40 × 40 cm):

1. Carbon/Glass Fiber-Polyester Composite:
   - A stoichiometric mixture of 400 mL polyester resin and 8 mL hardener (2% v/v) was combined with alternating layers of carbon and glass fibers.
   - Four fiber layers were sequentially impregnated, achieving a final thickness of 4 mm.
2. Palm Fiber-Polyester Composite:
   - A blend of 800 mL polyester resin and 16 mL hardener (2% v/v) was infused with palm fiber mats.
   - Two fiber layers were laminated to attain a 4 mm thickness.

Both composites underwent vacuum degassing (15 minutes) to eliminate air voids, followed by ambient curing (24 hours) prior to demolding. Shown in Fig. 6.

Fig. 6. Carbon fiber and palm fiber after pouring into the mold.

2.5 Device used

The experimental testing was carried out using two principal apparatuses: a universal testing device for tensile and flexural tests, and an impact testing device for impact resistance measurements.

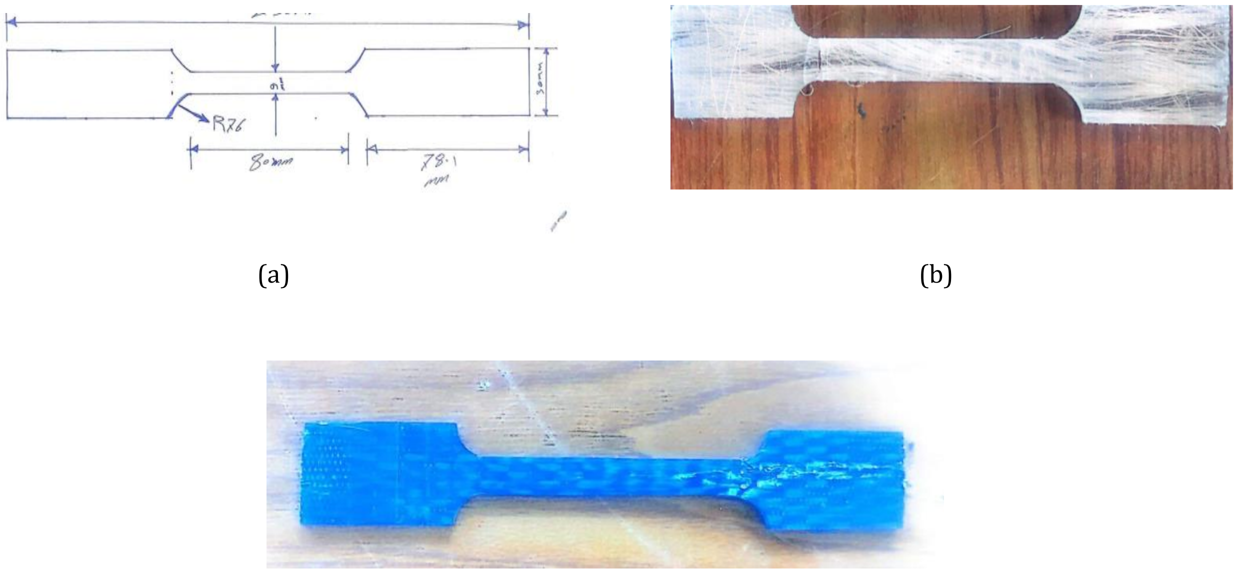
2.5.1 Tensile test device

It is an electro-mechanical device used to measure tensile, bending, and compression tests with a calculator. The calculator and device begin to operate electrically, then the device program opens and the test is selected according to what is required. Here we will change the parts of the device according to the required test, the sample is fixed tightly and work begins through the device program.

properties, including elastic modulus, Toughness, maximum tensile strength, and elongation were measured by a device Universal Tensile test in the Strength of Materials Laboratory in the Department of Materials Engineering, University of Technology. See Fig. 7

Fig. 7 Tensile test device.

The specimen was Prepared by cutting a uniform sample from a carbon plate and a palm plate by CNC from the material of interest. The testing procedures for the carbon and palm fiber reinforced composites were carried out based on the guidelines set by ASTM standards. The tensile strength of the composite material was determined using the ASTM D638 standard, with the specimens being in dog-bone form. The flexural strength of the materials was tested following the ASTM D790 standard, with the test specimens having rectangular shapes of 127 mm x 12.7 mm x 3.2 mm. Also, the impact strength was determined using the ASTM D7136 standard. The impact test specimens were in square form, with geometrical dimensions of 100 mm x 100 mm x 5 mm. See Fig. 8.



(a) (b)

(c)

Fig. 8. (a) tensile test specimen dimension (b) fiber palm tensile test specimen (c) fiber carbon tensile test specimen**.**

The test defines the grip separation rate (strain rate) while recording the applied force and specimen elongation until the specimen fractures, capturing data throughout the process. Monitor the test for any unusual behavior or deviations from expected results, as shown in Fig. 9.

Fig. 9. Tensile test specimen after applied force and fracture.

2.5.2 Impact test device

The appropriate impact test type (Charpy or Izod) was selected based on the material and parameters as shown in Fig. 10. Release the pendulum to strike the specimen at a specific location. Record the absorbed energy or the appearance of the fracture in the specimen after impact. The test was repeated on several samples to ensure consistency.

Fig. 10. Impact test device.

3. Results and discussion

3.1 Tensile test and bending test results

The tensile and bending test results showed some remarkable distinctions in the mechanical behavior of carbon/glass fiber composites compared to the palm fiber composite. The tensile test showed that carbon/glass fiber had a higher maximum tensile strength of 274

MPa, while the palm fiber composite had a noticeably lower strength value of 47 MPa Fig. 11 and Fig. 12. Such a difference illustrates better ability for load transfer and stress resistance in carbon/glass hybrids due to the combined reinforcing properties of the synthetic fibers in polyester. Palm fiber is known for being light and environmentally friendly material but is rather brittle and breaks easily, thus having poor stress resistance. Regarding the bending test, the carbon/glass composite demonstrated higher mechanical performance when it resisted 9 kN force before failing, while the palm fiber composite had a much lower resistance of 1.58 kN Fig.13 and Fig.14. The fragility and inability to create strong bonds with resin likely caused early failure of the palm fiber composite. Such results confirm previous experiments on synthetic composites with their higher fiber content and stronger interaction with matrices [6], [18]. The significant variations in the mechanical properties of the carbon/glass hybrid composite and the palm fiber composite may further be explained in terms of the failure mechanisms involved and the nature of bonding between the components. It is seen that the tensile strength of the carbon/glass composite is substantially higher 274 MPa than that of the palm fiber composite 47 MPa. This is largely due to the high efficiency of stress transfer from the fibers to the polymer matrix in the former case. The reason behind this is the efficient bonding between the carbon/glass fibers and the polymer matrix. In the latter case, however, the fiber/polymer composites failed early due to inefficient interfacial bonding. It should be noted that natural fibers have hydrophilic surfaces whereas polyester resin has hydrophobic surface. Hence, there is poor compatibility and hence weak fiber/polymer bonding. The failure mechanism in such a case includes fiber pull-out, interfacial debonding, and void formation, thereby reducing stress transfer efficiency.

Fracture mechanics analysis reveals that the carbon/glass hybrid composite possesses enhanced toughness due to mechanisms of fiber breakage, matrix cracking, and crack bridging. The interaction between the carbon and glass fibers is responsible for increased toughness of this composite in terms of energy dissipation based on the higher value of absorbed impact energy 2.1 J. Palm fiber composites, however, display low energy absorption levels of 0.25–0.44 J, indicating the dominance of fast crack growth processes and absence of plastic deformations. Moreover, comparison of these results with theoretical models, such as the rule of mixtures, reveals that the experimentally obtained trends correspond to those typical of synthetic composites, where the mechanical properties are increased proportionally with fiber content and interfacial strength. At the same time, there is divergence in the properties of palm fiber composites due to such aspects as poor bonding, misalignment of fibers, and heterogeneity. These properties diminish the efficiency of reinforcing. This implies that the improvement in interfacial bonding through chemical treatment such as alkaline or silane treatment is necessary to optimize the mechanical characteristics of palm fiber composites.

For instance, [6] demonstrated that higher fiber weight percentages 20–60% improved tensile and flexural strength in glass fiber-reinforced vinyl ester composites though saturation thresholds limited further gains. Similarly, Kassid [18] observed that carbon fiber reinforcement in polymer concrete significantly elevated tensile and flexural resistance. The current results extend these principles to automotive hood applications emphasizing the tradeoffs between performance and sustainability.

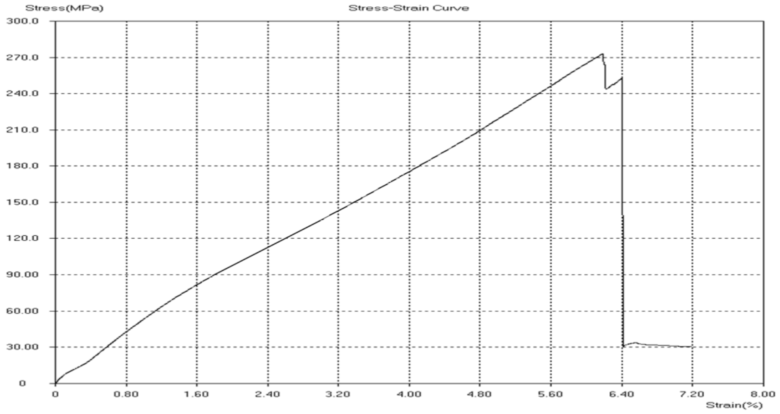


Fig. 11. Uniaxial tensile stress strain curves for specimen of natural carbon fiber with Glass fiber.

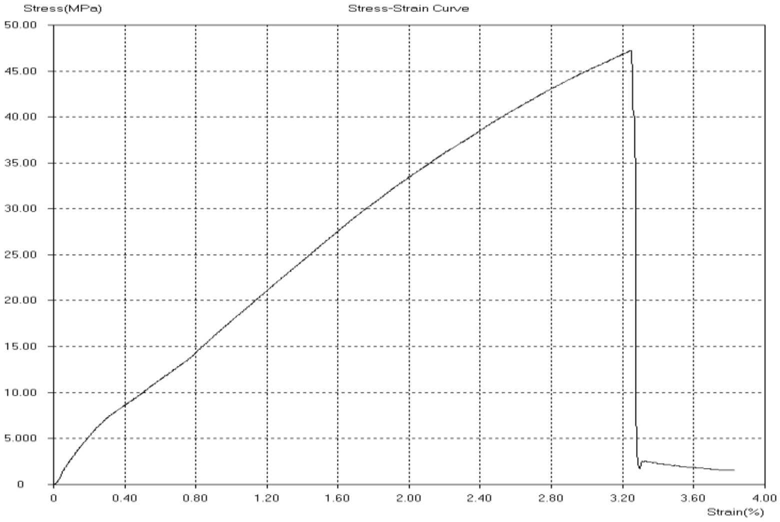


Fig. 12. Uniaxial tensile stress strain curves for specimen of natural palm fiber .

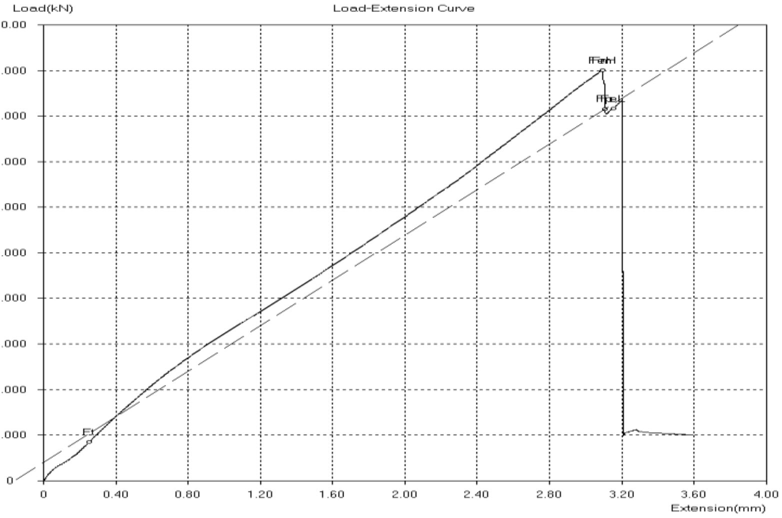


Fig.13. Bending test for specimen of natural carbon fiber with Glass fiber.

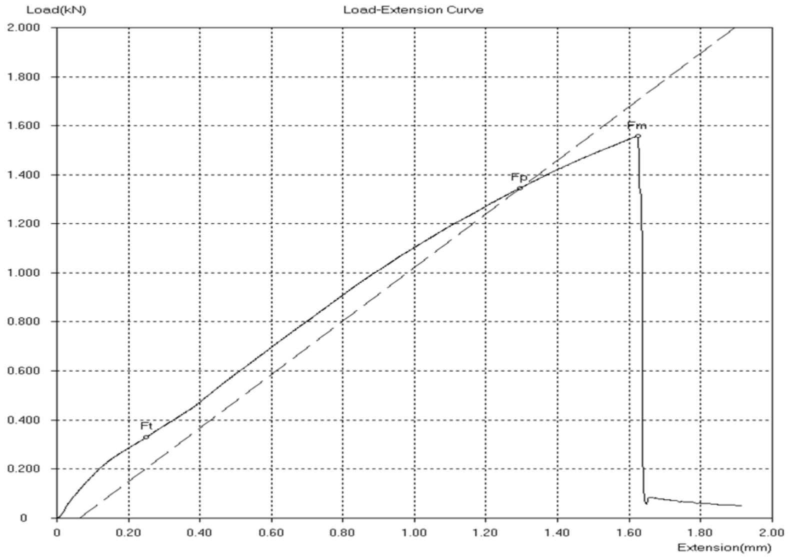


Fig. 14. Bending test for specimen of natural palm fiber.

As can be seen from the stress-strain graph presented in Fig. 15 below there are marked variations between the mechanical response systems. Furthermore, a comparison analysis has been done of the results obtained in the study for tensile strength properties compared to published studies on composites using both natural and synthetic fibers. The carbon/glass hybrid system presents performance comparable to the synthetic fiber systems while the palm fiber system presents a lesser performance than untreated natural fiber systems.

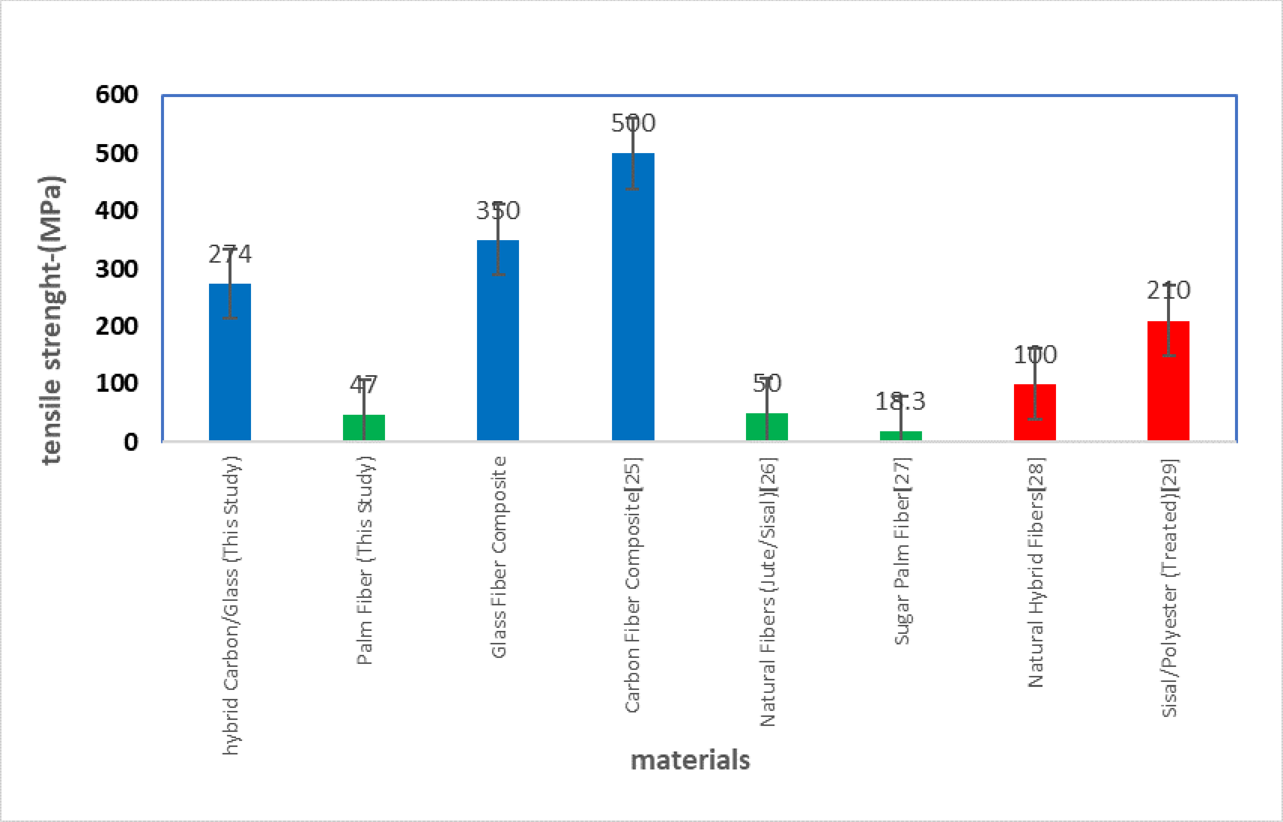


Fig. 15. Comparison of tensile strength test between the present study and literature values for synthetic and natural fibre composites.

3.2 Impact test results

Four carbon fiber and palm fiber samples were subjected to a specific amount of energy using an impact measuring device as shown in Table 1. After the hammer strikes the sample, the center of the sample fractures or is damaged. The device calculates the amount of energy absorbed by the sample during fracture. This energy is usually measured in joules . The higher the absorbed energy, the stronger the material is. Brittle materials, such as palm fiber, absorb less energy and break easily. Impact testing further highlighted the performance gap between the composites. Carbon/glass fiber samples absorbed energy values of 2.1 J and 1.25 J, while palm fiber composites absorbed only 0.44 J and 0.25 J Table 1. The high energy dissipation of the carbon/glass composites can be attributed to the ductile failure of the material and proper stress transfer, while the brittle failure mode of the palm fiber caused the cracks to propagate rapidly and dissipate little energy. Differences in the impact strengths obtained 2.1 J for one and 1.25 J for another may be associated with possible variations in the alignment of the fibers and resin transfer during fabrication. All these findings are consistent with research on natural fiber composites where poor impact strength is due to poor fiber/matrix bonding and temperature instability [24], [25]. Indicated that although date palm fiber reinforced laminates possess adequate tensile strength, their impact strength is low due to poor alignment of fibers. This finding reiterates the fact that although natural fibers like palm fibers are eco-friendly materials, mechanical limitations must be addressed to enhance their applicability in automobiles.

Table 1. Results of impact test.

NO.	Material	The amount of energy absorbed
1	Carbon fiber with glass	2.1 J
2	Carbon fiber with glass	1.25 J
3	Palm fiber	0.44 J
4	Palm fiber	0.25

4. Conclusions

It is evident from the analysis presented above that the composites of carbon/glass fiber composites possess higher mechanical properties than the palm fiber composite for hood application in the automotive industry. Material hybridization and processing techniques play an important role in formulating high-performance and eco-friendly composite materials.

- Tensile Properties: The carbon/glass fiber composite attained a maximum tensile strength of 274 MPa, about 5.8 times higher than that of the palm fiber composite at 47 MPa. The huge disparity is explained by the high tensile strength of the synthetic fibers coupled with their good bonding with the polyester resin matrix.
- Bending Properties: Under three point bending test, the carbon/glass fiber composite sustained a maximum load of 9 kN before fracturing compared to 1.58 kN for the palm fiber composite. Poor adhesion of the natural fibers with the resin resulted in early development and growth of cracks.
- Impact Energy: The impact energy absorption was recorded as ranging from 1.25 to 2.1 joules for the carbon/glass hybrid composites and 0.25 to 0.44 J for the palm fiber composites. The former exhibited energy dissipation on failure while the latter showed brittle behavior after cracking.
- Sustainability vs. Mechanical Performance Trade-off: Though the palm fiber composite is sustainable and eco-friendly since it is a biodegradable and renewable material with lower carbon footprint, its strength and impact resistance are currently inadequate for automotive engine hood manufacturing applications where it is needed.

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