Research Article

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The evaluation of the mechanical properties of glass, kenaf, and honeycomb fiber-reinforced composite

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Abstract: The development of hybrid composite materials using honeycomb structure, typically a lightweight material, is commonly used in aircraft structures. However, the use of honeycomb with natural or synthetic composite remains unexplored in the literature. Therefore, this study aims to partially replace synthetic fiber, woven glass with a natural fiber of woven kenaf and honeycomb core. An experimental analysis investigated the mechanical strength of three different compositions using glass, kenaf, and honeycomb materials for structural application purposes. The properties of the sample were evaluated through the tensile, flexural, and impact strength, and the morphological damage was observed using scanning electron microscopy. The results showed that the composition of GKGKG laminate composite is the highest in tensile strength (147.64 MPa) and modulus (3.9 GPa), while the GKHKG composite was good in flexural strength (219.03 MPa) and modulus (11.47 GPa). In terms of impact properties, there was a slight difference in energy level (20–30 J) by GKGKG and GKHKG, showing the optimal hybrid configuration of composite for the newly developed material. In conclusion, the application of the new hybrid of GKHKG composite is promising in semi-structural and structural light-weight applications.

Keywords: Kenaf fiber, glass fiber, Nomex honeycomb, hybrid natural/synthetic laminate composite, experimental analysis, mechanical properties

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1 Introduction

In the past few decades, composite-based natural fiber was developed in non-structural applications such as rope, bags, twine, and wood-based products [1]. These renewable resources have unlimited availability and can be grown within a short period of time [2]. Other than that, it will provide an alternative way to deal with agricultural residue [3]. Kenaf, which was used in this study, is eco-friendly in nature and has a low density and low lignin content. This fiber exhibits superior properties under flexural loading conditions compared to other natural fibers [4].

Recently, product-based natural fiber development mostly focuses on non-structural applications, due to the limitations in the mechanical behavior of natural composites compared to synthetic ones, which have superior strength and a lower weight, temperature, and electrical conductivity [5]. Hydrophilic behavior is the main limitation of natural fiber that makes the natural fiber low mechanical strength and poor compatibility with thermoplastic matrices [6]. Knowing that synthetic fiber will contribute to serious environmental problems due to the properties of non-biodegradable, non-renewable, and non-recyclable. Therefore, the hybridization of both natural and synthetic fiber may increase the strength, stiffness, modulus, moisture resistance, and thermal resistance of the composite [7]. Full replacement with natural fiber is not possible, primarily due to the synthetic properties that must be considered. However, partial replacement might achieve an improved strength-to-weight ratio, cost-effectiveness, and biodegradability. Synthetic fibers help to compensate for the weakness of natural fiber and improve the mechanical properties of the composite. Subash and Pillai [8] listed some of the applications for non-structural parts using a hybrid natural/synthetic composite in several industries such as pilot cabin doors and door shutters in the aerospace industry; interior door panels, door trims, and truck liners in the auto industry; and underbody coverings for automotive parts and heater housing in the construction industry.

The invention of new composite materials has been continuously improving performance to yield enhanced properties that are beneficial in commercial industries such as marine, aerospace, automotive, and construction [9]. For structural applications, natural composite hybridization is lacking in the literature. Majid et al. [10] studied the potential of hybrid glass/kenaf composite for the radome structure of aircraft under low-velocity impact performance and found a significant impact in energy (3 J for 3 mm composite thickness). Boegler et al. [11] investigated the weight reduction of natural fiber composites for ramie, flax, hemp, and sisal on load-bearing structures for the wing box Airbus A320-200. The findings show that using ramie fiber composites can decrease the weight ratio. Davoodi et al. [12] examined the mechanical properties of hybrid glass/kenaf fiber-reinforced composites for car bumper beam applications. The results show that the tensile strength and young's modulus of the composite were higher than commercial bumper beam materials. However, the use of honeycomb in hybrid natural fiber-reinforced composite is lacking in the existing literature. Zongwen and Jianxun [13] investigated the mechanical properties of the sandwich composite structure of basalt and Nomex honeycomb to promote the application and development of green and lightweight materials.

After an in-depth review of the literature, it can be concluded that a study on hybrid natural fiber-reinforced composite for structural application is a relatively new topic for researchers. In addition, the use of honeycomb in hybrid natural–synthetic laminate composite has not been widely explored. The primary objective of this research is to evaluate the mechanical properties of tensile, flexural, and impact behavior of hybrid glass–kenaf–honeycomb (GKHKG)-reinforced epoxy composites for unmanned aerial vehicle wing skin applications. The combination of natural–synthetic-reinforced composite is a novel material for aircraft structure application. The significance of these research is to produce a superior property, eco-friendly in nature with minimal cost. An addition of honeycomb as a core in GKHKG-reinforced epoxy composite is to investigate the capability of the composite to absorb energy. The comparison of the GKHKG-reinforced composite with the other two variations of the composite through experimental analysis had been made between hybrid glass–kenaf–glass composite (GKGKG) and hybrid kenaf–glass–kenaf composite (KGKGK)-reinforced composites to investigate and compare their mechanical performance. These variations were chosen to observe the mechanical performance between the composite by changing the stacking sequence of fiber and adding honeycomb as a core in the same number of layers.

2 Methodology

2.1 Preparation of hybrid composite

Glass fiber was used from E-glass type with a mass of 200 $g\cdot m^{-2}$ and 0.3 mm thickness while kenaf fiber (*Hibiscus cannabinus* L.) has a density of $\pm 1.2\ g\cdot cm^{-3}$ and a thickness of 2 ± 0.2 mm. Nomex honeycomb structure is from hexagonal cell type. The thickness of the honeycomb structure is 2 mm with the size of the unit cell 3.2 mm. These materials were used to produce a 300 mm × 300 mm composite laminate sample with several variations. Epoxy resin (EpoxAmite 100) and hardener (103 Slow) were used as the matrix of the material. A hand layup technique with a mixture of epoxy resin and hardener was employed to manufacture the composites, which is commonly used in commercial processes and is relatively less expensive compared to other processes.

The weight ratio of the matrix and fiber was 70:30, while the mixed proportion of the epoxy and hardener was 3:1, as recommended by the manufacturer. Each composite laminate of GKHKG, GKGKG, and KGKGK was taken 30% of the fiber weight fraction from the total weight of the composite. It can be defined by manual calculation. The total fiber weight of GKHKG, GKGKG, and KGKGK is 158, 205, and 178 g, respectively. It was reported by Yahaya et al. that the mechanical performance of kenaf/kevlar composite with fiber volume fraction of 31.4% has excellent tensile and flexural strength compared to other composite compositions [14]. The hybrid banana/jute composite study also shows a superior performance at 30% of fiber loading compared to other composites [15]. In other literature, the Charpy and Izod impact tests of hybrid Malva and jute fibers with epoxy resins were carried out, and among the 10, 20, and 30% volumes of hybrid fiber specimens tested, the 30% volume fraction of fibers achieved the best results [16].

A lamina sequence and orientation of composite laminate play an important role to achieve the desired strength and stiffness of composite, as well as in dynamic response [17]. Three types of composites with different sequences of fiber arrangement were chosen based on an empirical evaluation. Three types of fibers which are aramid honeycomb (H), glass fiber (G), and woven kenaf (K) was used to fabricate a five layers laminate composite. Three variations of the layering sequence was created, which is GKHKG, GKGKG, and KGKGK, where each of the layers were laid in 0/90° orientation. Synthetic fiber was preferred to use as a skin layer due to its capability to improve mechanical strength [18]. Honeycomb has the advantage to absorb energy during impact loading, and is suitable as the core of the composite [19]. The natural fiber in the composite laminate can stop the propagation of matric cracking [20]. So that it needs to be put between glass fiber and honeycomb core. As for epoxy, it is tough and malleable but has an extremely low tensile strength. Therefore, by combining all the fibers with epoxy, each characteristic of the structure could compensate for the weakness of each material, to ensure that all fibers are able to bond and create a tougher composite.

The factor that might increase the strength of the composite is the thickness of the composite laminate. Based on the study of three layers of glass/kenaf fiber, suggesting the thickness of composite laminate to be increased to provide better impact resistance [10]. Several aspects were investigated: layer skin performance, presence of honeycomb in composite, and fiber loading comparison for synthetic and natural fiber in composites laminate. The final fabrication was left to cure under a loaded condition for 24 h. The final thickness of the GKGKG, KGKGK, and GKHKG laminate composite was 4.5, 4, and 6 mm, respectively, while the density of each composite was 0.506, 0.494, and 0.293 $g \cdot cm^{-3}$.

2.2 Mechanical testing (tensile, flexural, and low-velocity impact tests)

The purpose of mechanical testing is to determine the mechanical parameters such as strength and deformation of the composite that will be used for composite structure design. ASTM standard was used as a guideline for the fabrication and also testing to evaluate the properties of the materials. Figure 1 shows the ASTM standard sizing of testing specimens for the tensile, flexural, and low-velocity impact tests.

A tensile test was performed on all fabricated composites using a Universal Testing Machine at 11 kN applied load and 5 $mm \cdot min^{-1}$ speed range. Five pieces of 250 mm × 25 mm specimens (Figure 1a) were attached to the machine with an axial gauge length of 100 mm, based on ASTM D638 standard [21], and testing was conducted at room temperature. The tensile properties such as tensile strength, tensile strain, modulus of elasticity, elongation, proportional limit, yield point, yield strength, and reduction in the area of the composite were obtained from the testing [22]. Tensile properties from the laminate composites are influenced by the number of layers, type of fiber, fiber orientation, stacking arrangement, adhesion between fiber and matrix, fiber strength, and modulus [9,13,23]. Tensile testing was performed by applying the same force to the material when they were opposing each other along the same axis. The specimens were placed on the holder in the longitudinal direction and were elongated to a gauge length, due to the force that was applied before it was fractured. The physical condition of all the composite laminates after tensile testing is shown in Figure 2.

Similar to the tensile test, a total of five specimens for three types of composite samples with a dimension of 125 mm × 12.7 mm (Figure 1b) were prepared as per the ASTM D790 standard for flexural testing [24]. The test was conducted in three-point loading using the Universal Testing Machine. The specimens were placed horizontally on two supports with a span length of 72 mm for GKGKG, 64 mm for KGKGK, and 96 mm for GKHKG, respectively. The span length was calculated based on the support span-to-depth ratio of 16:1, where the depth of the specimens represents the average composite thickness [24]. A force was applied at the center of the specimens with a speed of 2 $mm \cdot min^{-1}$, until they were fractured. The flexural strength and modulus of the composite were investigated based on the test results. The three-point loading was used to investigate the capability of the composite to withstand bending force before reaching the ultimate

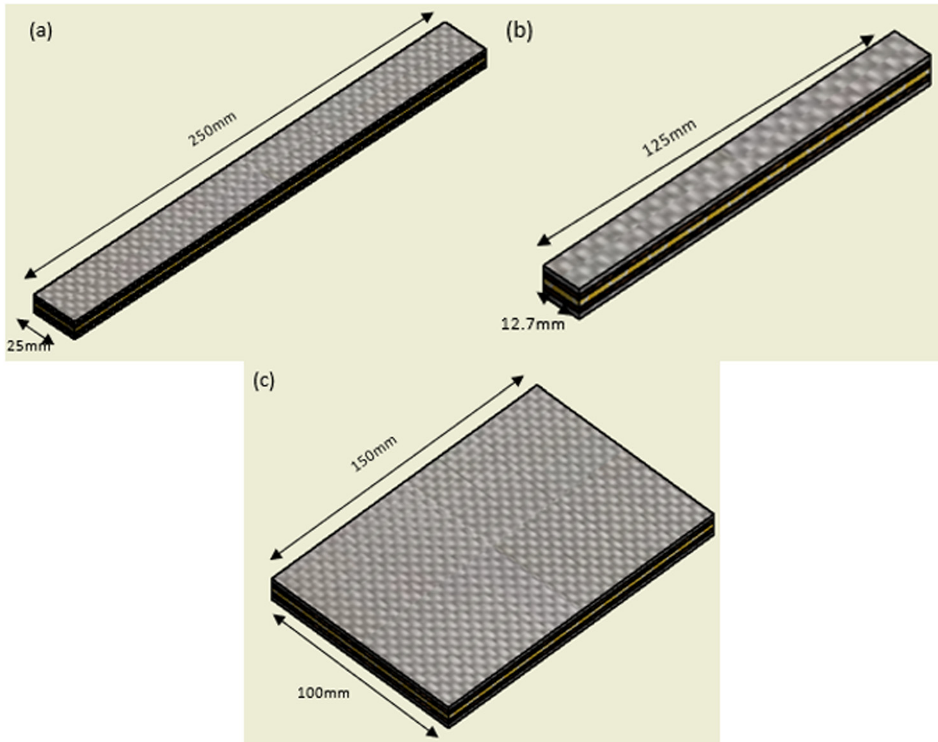


Figure 1: Composite sample sizing according to ASTM standard: (a) tensile ASTM D638, (b) flexural ASTM D790, and (c) low-velocity impact ASTM D7136M.

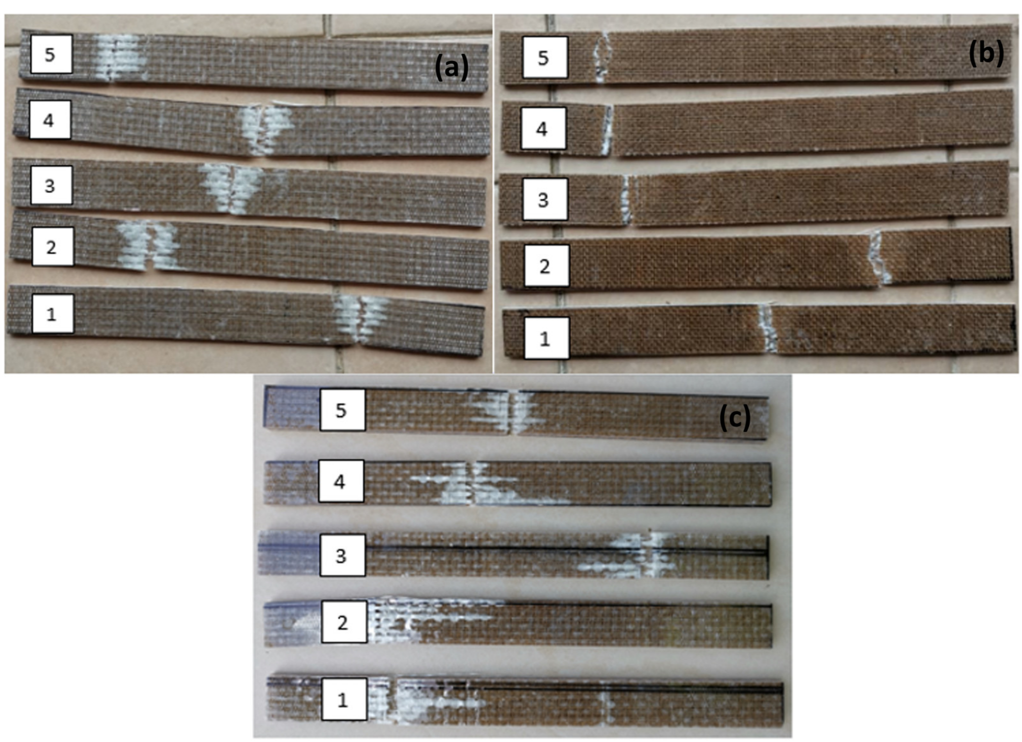


Figure 2: Composite sample after tensile testing: (a) GKGKG, (b) KGKGK, and (c) GKHKG.

stress. Flexural testing can be performed by combining two stresses: compressive and tensile [23]. The top surface layer is subjected to the former, while the bottom surface layer is subjected to the latter. The result of the physical condition of composite GKGKG, KGKGK, and GKHKG after testing is shown in Figure 3.

The low-velocity impact test specimens were prepared with a size of 150 mm × 100 mm (Figure 1c) according to the ASTM D7136M standard [25]. The testing was performed using the Drop Weight Impact Tester model Imatek IM10, with various impact energy values. A pilot test was initially performed to measure the highest impact energy that the material can withstand [20]. The highest impact energy without full penetration for all composites was 30 J. Therefore, to observe the damage progression, an increment of 20, 25, and 30 J was chosen. The specimens were clamped at the fixture base before allowing the impactor to drop on it. The force-time, energy-displacement, and velocity were investigated. The amount of peak force, peak deformation, absorb energy, and impact strength were obtained from the testing. The damage characteristic of the composite after impact will be discussed.

3 Result and discussion

3.1 Tensile properties

The average of each composite laminate results is obtained and summarized in graph as shown in Figure 4. The graph plotted for the determination of tensile strength and modulus of various laminate composites. The ultimate tensile strength of the GKGKG, KGKGK, and GKHKG composite was 147.64, 121.45, and 73.41 MPa, respectively. The GKGKG composite exhibited the maximum tensile strength (147.64 MPa) compared to other laminate composites, attributable to the high volume of glass fiber included. The higher volume of glass fiber used in hybridization with kenaf fiber yields a higher tensile strength and also the stiffness of the composite [26,27]. The tensile properties of the composite depend on fiber strength, modulus, fiber geometry, and adhesion of the matrix [18]. The graph shows that a tensile modulus of the GKGKG composite exhibited the highest value (3.9 GPa). It happens because the increasing tensile strength also increased the tensile modulus [26].

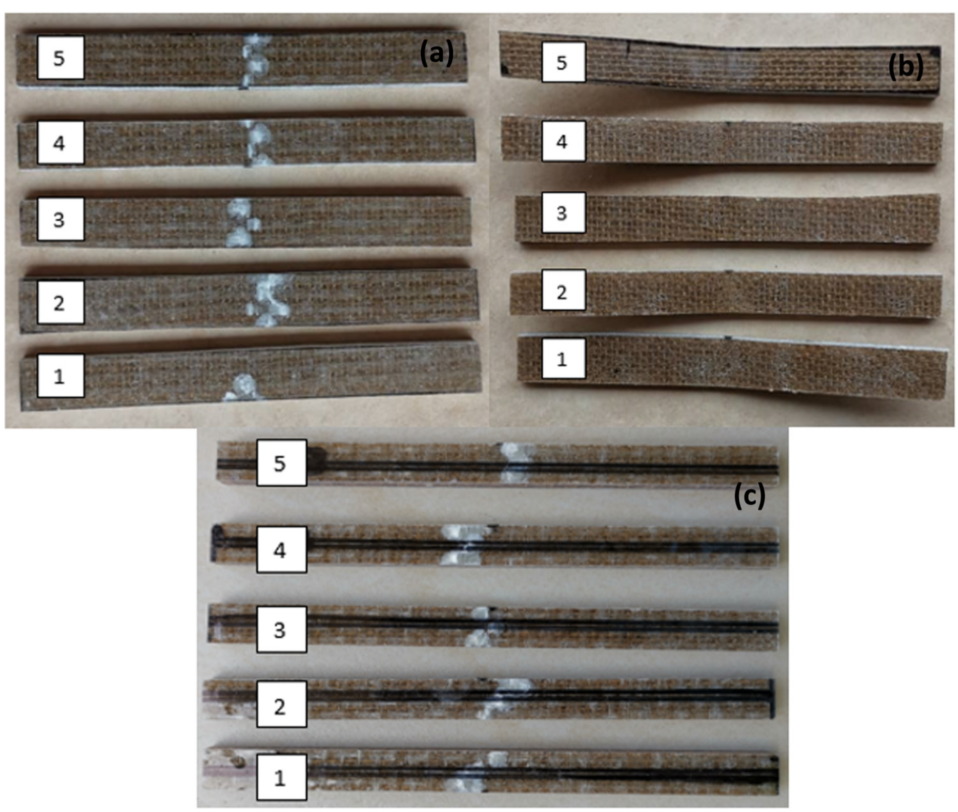


Figure 3: Composite sample after flexural testing: (a) GKGKG, (b) KGKGK, and (c) GKHKG.

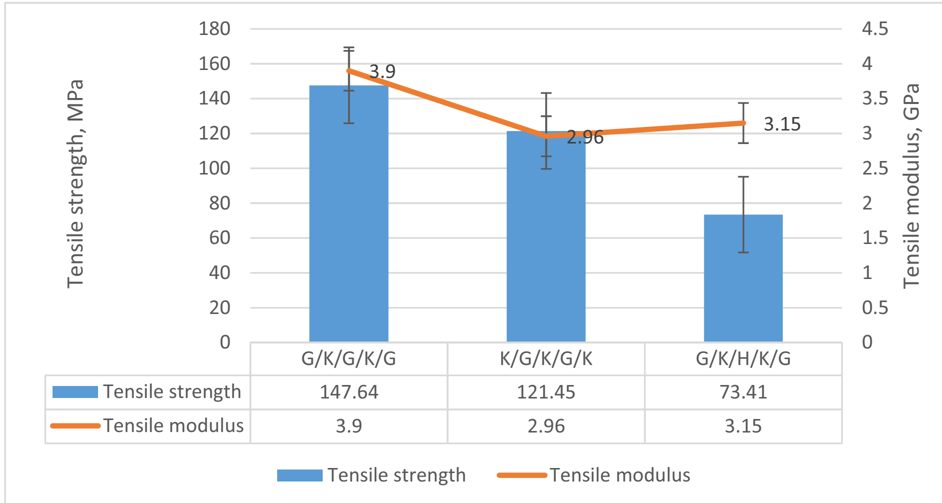


Figure 4: Tensile strength and modulus of the laminate composites.

In terms of the GKHKG composite, the addition of honeycomb as a core resulted in poorer tensile strength (73.41 MPa) compared to other laminate composites, but this resulted higher in tensile modulus than in the KGKGK composite (3.15 GPa). A tensile modulus is an indicator showing that the composite has a high level of stiffness [27]. However, the effect of composite thickness on the composite strength and stiffness was not apparent [28]. The stiffness of the composite is affected by the honeycomb core with the high core density and the cell shape of honeycomb itself [28]. A higher strength of fiber in the outer layer of the composite also improves its mechanical properties [29]. Hence, the addition of glass fiber in the GKHKG composite reduced the risk of tensile failure. Also, can be proved from the study of hybrid carbon–kenaf where the carbon fiber as a skin had the highest tensile strength (210.49 MPa) than kenaf–carbon (134.65 MPa) since it had natural fiber as a composite skin [1].

3.2 Scanning electron microscopy (SEM) analysis

The damage morphology from tensile-fractured specimens was investigated under SEM analysis. SEM is important in observing the interfacial adhesion between the fiber and the matrix, the interfacial properties, internal structure, and internal cracks of the failure surface structure for the tested composite specimens, as it plays a vital role in the mechanical behavior of the composites [24].

During the SEM observation, a cutting from the GKHKG tensile fracture was taken. Figure 5a shows matrix cracking between glass and kenaf fiber, as well as debonded glass fiber from the inner layers after a tensile test. It demonstrated the highest tensile strength. Generally, matrix cracking occurred while applying a load in the transverse direction, until the composite fractured completely. (Figure 5b) shows a good fiber-matrix adhesion of kenaf, glass and honeycomb with the epoxy. A debonding of glass fiber from the inner layer resulted due to poor bonding with the composite, and fiber breakage in the composite materials (Figure 5c). According to Figure 5d, a group of glass fibers pulled out after the tensile testing and showed good fiber–matrix adhesion.

3.3 Flexural properties

Then, the results of flexural testing for three variations of composite are summarized in Figure 6. Interestingly, the results show that GKHKG laminate composites exhibit a higher flexural strength (219.03 MPa) and flexural modulus (11.47 GPa) compared to GKGKG and KGKGK composites. In the context of flexural strength, the stiffness of the material can be seen based on its modulus [27]. Moreover, the thickness of the honeycomb core may increase the stiffness and flexural strength of the composite [30]. The greater the thickness, the greater the flexural strength and stiffness of the structure [13]. As previously mentioned, the thickness of the GKHKG composite is higher

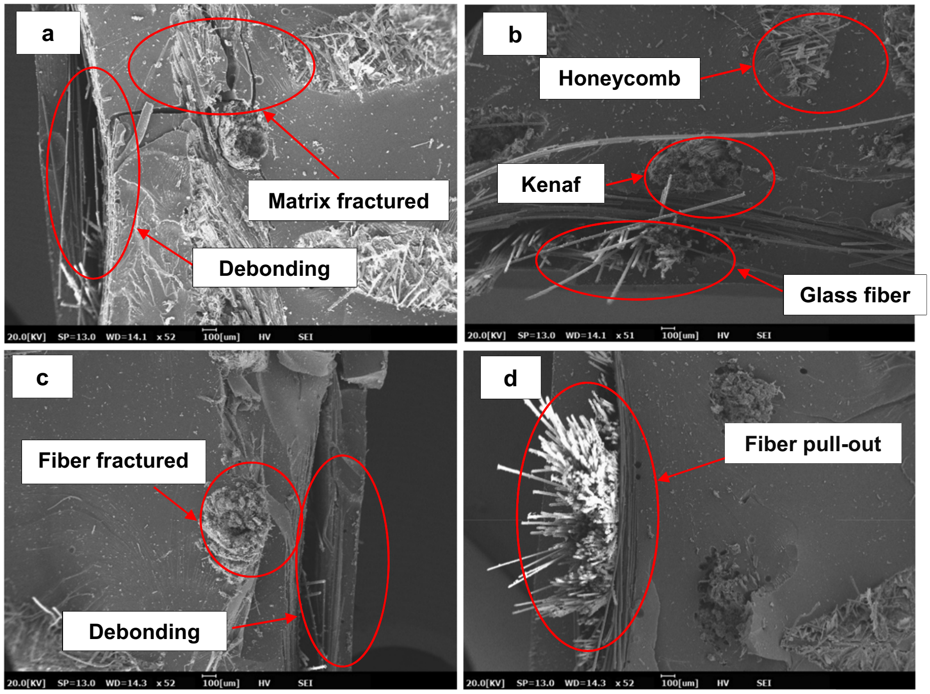
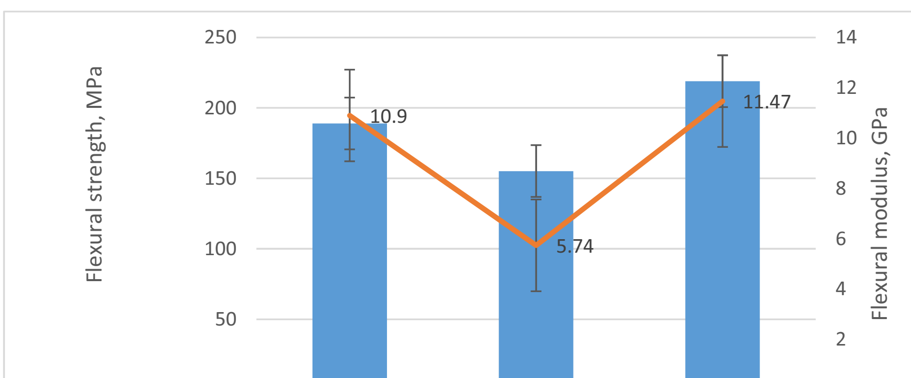


Figure 5: SEM micrographs of glass-kenaf-honeycomb composite at different magnifications showing (a) matrix cracking between glass and kenaf fiber (b) good adhesion between fibers and matrix (c) debonding of the glass fiber (d) fiber pull-out of the glass fiber.



	G/K/G/K/G	K/G/K/G/K	G/K/H/K/G
Flexural strength	188.99	155.22	219.03
Flexural modulus	10.9	5.74	11.47

Figure 6: Flexural strength and modulus of the laminate composites.

than that of the GKGKG and KGKGK composites (6 mm), primarily due to the presence of honeycomb as a core.

In contrast to tensile, the flexure strength of the hybrid GKGKG composite is lower (188.985 MPa) compared to the GKHKG composite. This is likely due to the use of the Nomex honeycomb as a core. This material has excellent compression and shear properties, according to the flexural test [18]. Based on the graph, the hybrid KGKGK composite clearly shows poorer of flexural strength (155.221 MPa) and flexural modulus (5.74 GPa) compared to the other composites. This is due to the higher volume of natural fiber, kenaf in this composite. A higher volume ratio of natural fiber than synthetic fiber reduces the flexural strength and modulus of the composite [31]. The flexural strength of a composite depends on the outer layer of the composite [32]. The skin layer of glass fiber, GKGKG, and GKHKG composites exhibited high flexural strength than the KGKGK composite. On the other hand, the composite fracture occurred when compressive and tensile were the top and bottom surface failure simultaneously.

3.4 Comparison of tensile and flexural behavior of GKHKG composite with other natural–synthetic fiber-reinforced polymer composites

A property behavior of GKHKG composite was compared with other studies in a similar field of natural–synthetic composite intended to measure the performance level of tensile and flexural strength among these composites. A study had been looking at hybrid carbon/kenaf and hybrid glass/kenaf. A detail of the studies is represented in Table 1. Most of the composites have a similar fiber orientation, the resin used, the lamination technique, and applying kenaf as a natural fiber reinforcement. The first study was about the effect of four variations in hybridization carbon/kenaf composite with a different stacking sequence, which resulted a CKCKC composite having superior properties than others [1]. The second study was validating an experimental result of glass/kenaf composite (GKGKG) using finite element analysis for structural application [4].

Figure 7 shows a tensile and flexural stress result by three composites including a present study, GKHKG. The graph indicates that involving a carbon fiber in composite laminate was giving the highest strength among the composites for both tensile and flexural stress of 210.49 and 221.7 MPa, respectively, due to strength characteristics owned by the carbon fiber and high stiffness compared to glass fiber [9]. In addition, carbon fiber can withstand higher temperatures and is lighter than glass fiber [26].

Table 1: Natural–synthetic composite detail and methodology

Material	Variation	Resin	Fiber loading (%)	Method	Orientation	Testing	Reference
Carbon, kenaf	C/K/C/K/C K/C/K/C/K C/C//K/C/C K/K/K/K/K	Epoxy + hardener	40	Vacuum infusion	0°/90°	Tensile, flexural	Ikhw et al. [1]
Glass, kenaf	G/K/G/K/G	Epoxy + hardener		Hand lay-up	0° & 90°	Tensile, flexural, charpy impact	Ramesh and Nijanthan [4]
Glass, kenaf, honeycomb	G/K/H/K/G	Epoxy + hardener	20	Hand lay-up	0°/90°	Tensile, flexural, low-velocity impact	Present study

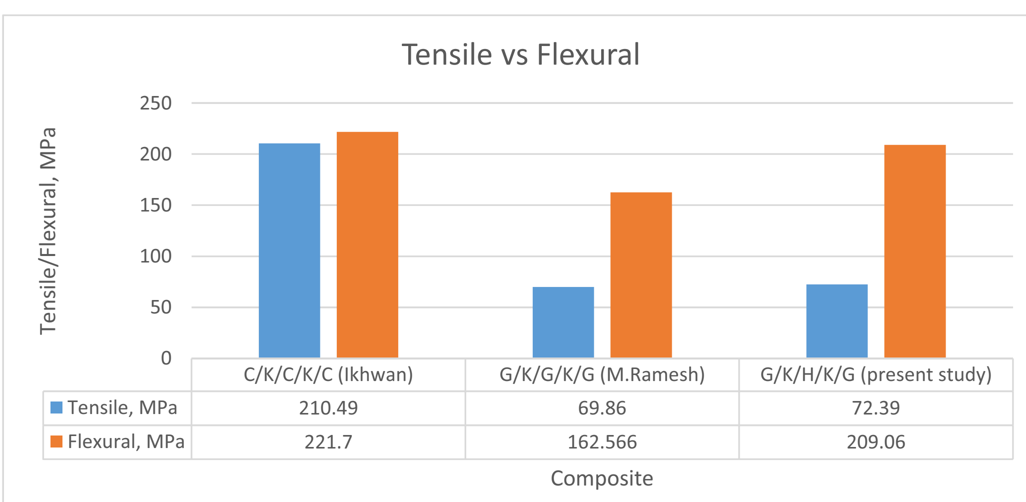


Figure 7: Tensile and flexural strength with different hybrid composites.

Although the strength characteristic of glass fiber used in the present study is less than carbon, glass fiber is a typically less-expensive material and less brittle [4]. The glass fiber is preferable in various research due to its ease of processing, and high material availability. The combination of this two advantages results in making the material more cost-effective compared to other synthetic fiber materials. In addition, its high strength and stiffness properties will contribute to the hybridization of advanced composites with superior strength [33]. Comparing a GKHKG composite with a hybrid GKGKG, it was shown an equal trend but slight differences for both tensile and flexural stress. A present study used aramid honeycomb as a core due to the lightweight and excellent compression and shear properties of the material [19]. In fact, the tensile strength and modulus of an aramid honeycomb core are higher than compression and it was proved [34]. Hybrid GKHKG has a tensile strength of 72.39 MPa while GKGKG composite is 69.86 MPa. Flexural strength data also showed that GKHKG composite (209.06 MPa) was higher than GKGKG composite (162.566 MPa). Moreover, a study of GKGKG composite strength was suggested for some structural applications, while GKHKG properties are higher than GKGKG composites.

3.5 Low-velocity impact properties

A preliminary low-velocity impact test was done first to determine the highest energy level that the composite can withstand without full penetration of the material [20], which was 30 J. Impact energy values of 20, 25, and 30 J were with different velocities of impact, based on adjustment of the falling height of the impactor. Three specimens were tested for each impact energy. The calculation of the actual impact energy can be derived as Equation (1).

$$E = mv^2/2, \quad (1)$$

where E = impact energy, J; m = mass of impactor, kg; and v = impact velocity, m·s^{-1}.

Results from the testing are tabulated in Table 2. The output data were analyzed with regard to peak force, peak deformation, absorbed energy, and impact energy. All composite laminates were generated in a close-loop curve for different impact energy values, as presented in Figure 8. This means that the impact force reached its peak force, and the impactor rebound after hitting the top surface of the specimen without penetrating the material [12,15]. The sample can have a small fracture on both surfaces. The energy was fully transferred to the specimen at the point that the striker hit and maximum displacement occurred during this point. The area under the closed loop curve represents the absorbed energy during the impact event [16].

The GKGKG curve in Figure 8 shows the highest peak force of 20 and 30 J, with an impact energy of 5–6 kN, which was less in deflection than the GKHKG and KGKGK samples for all impact energy values. The rebound of the striker can be seen from the composite curve as an indication that the sample was not fully penetrated. The GKHKG reached a higher peak force of the 25 J impact energy curve (6.77 kN) compared to the other composites. The displacement of this composite was slightly higher than the GKGKG composites, and it ascended in parallel with the increasing impact of energy. For the KGKGK composite, all curves showed the lowest peak force and the highest deflection at all energy levels. The impact strength of both GKGKG and GKHKG was in close range, with no obvious differentiation in peak force or displacement. When the impact event occurred, the inner layer of the kenaf fiber for the GKGKG and GKHKG composite absorbed a greater amount of energy than the glass fiber. Therefore, the kenaf fiber inner layers failed before the glass fiber in the outer layers, experiencing delamination, debonding, and fiber pullout [21]. In contrast to the

Table 2: A data from low-velocity impact testing

Energy (J)	Composite specimen	Impact energy (J)	Velocity (m·s^{-1})	Peak force (kN)	Peak deformation (mm)	Absorbed energy (J)
20	GKGKG	18.11	2.66	5.17	5.86	22.76
	GKHKG	20.18	2.81	4.57	7.97	12.54
	KGKGK	19.94	2.8	4.2	9.09	18.24
25	GKGKG	24.91	3.13	5.8	7.73	26.58
	GKHKG	25.11	3.14	6.77	8.41	18.38
	KGKGK	25.52	3.16	4.5	10.74	25.82
30	GKGKG	29.17	3.38	5.85	8.71	32.41
	GKHKG	30.26	3.44	5.38	10.37	26.07
	KGKGK	29.62	3.41	3.78	14.04	31.74

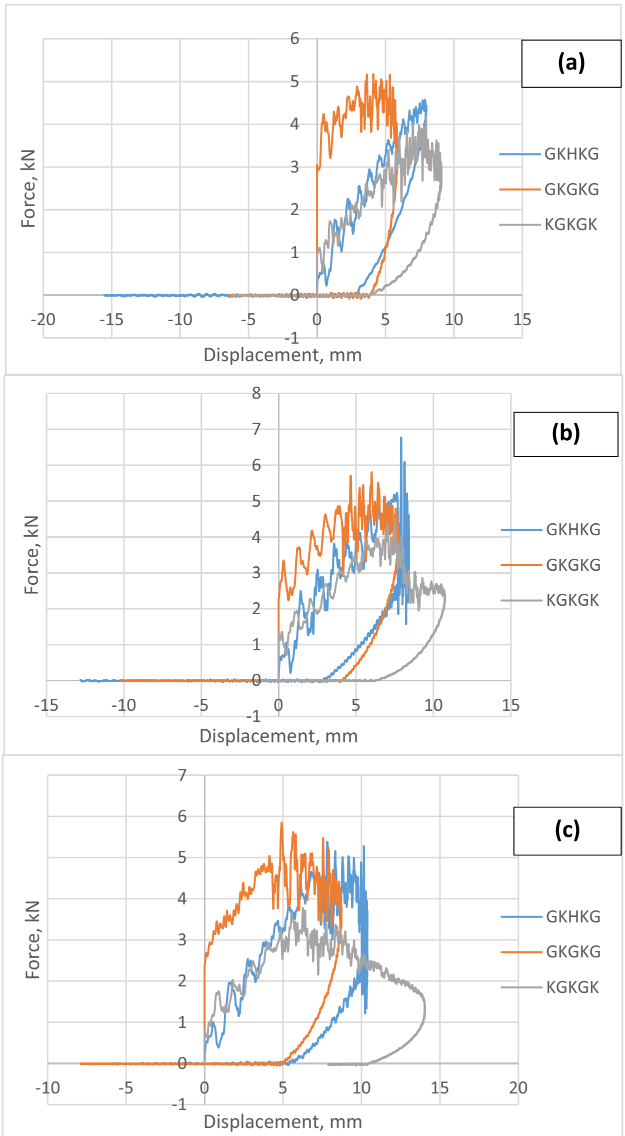


Figure 8: Force vs displacement of all types for different impact energy levels. (a) 20 J, (b) 25 J, and (c) 30 J.

KGKGK composite, the outer layers of kenaf fiber initially failed before each layer took up the slack. From the overall observation, all curves were generated by the sawtooth curve, which means that the fiber slowly started to become damaged [12].

3.6 Damage characterization

Damage characterization of different types of composite samples was analyzed visually based on the impacted point on the top and on the damaged area at the bottom of the specimens. The damage point area was measured and recorded. Generally, the damaged area occurred in the matrix crack on the specimen surface, which shows a slight change color and the location of the delamination.

According to Table 3, all the impacted points taken are the highest impact energy values of the 30 J specimens of both sides, which were created in a different damage pattern. From the observation of damage characterization, the GKHKG laminate composite showed a combination of circular and directional cracking on the top surface and created circular damage at the bottom surface when it reached the peak force. Directional damaged cracking was formed at the GKGKG laminate composite on the top surface, but there was a similar circular damage pattern with the GKHKG composite at the bottom. The damage showed delamination of fiber before it started to break. In different KGKGK laminate composites, a perfectly circular hole damage formed at the top of the specimen, and a damaged crack was uniformly spread out from the impact point at the bottom surface. A measurement of the circular damaged area shows a difference in the GKHKG sample, which was 47.91% larger than the KGKGK sample, and 37.5% more than the GKGKG sample. There was a 16.67% difference in the damaged area between the GKGKG and KGKGK composites. From the data given, it can be concluded that a factor influenced the mode of the damage radius, due to the kenaf fibers, which acted as a stopping mechanism for the propagation of matrix cracking and limited the radial crack propagation [20]. The fiber type and arrangement also play a role in forming the damage propagation. It can be proved from the study of low-velocity impact glass and kenaf with three variations showed different damage characteristics, where the glass fiber formed a circular cracking and kenaf showed directional cracking [20]. In contrast to this study, a kenaf fiber of the composite formed circular cracking in the same way as the glass fiber. The main reason for this fact is that different damage propagation occurs by different types of fiber laminations and arrangements.

3.6.1 Comparison of impact behavior GKHKG composite with other natural-synthetic fiber- reinforced polymer composites

For the impact behavior, it shows a significant difference in a carbon–flax composite about 42% higher than other hybrid composites (Figure 9). Carbon–flax composite, which is fabricated in seven layers of fiber, has a maximum absorbed energy of 44.6 J [35] compared to glass–kenaf–honeycomb composite (26.07 J) and glass–kenaf

Table 3: Damage analysis of three types of composites

Impact energy	Top	Bottom	Damaged radius (mm)	Damaged area (mm^2)
GKGKG			30	1,050
KGKGK			50	2,500
GKHKG			48	2,304

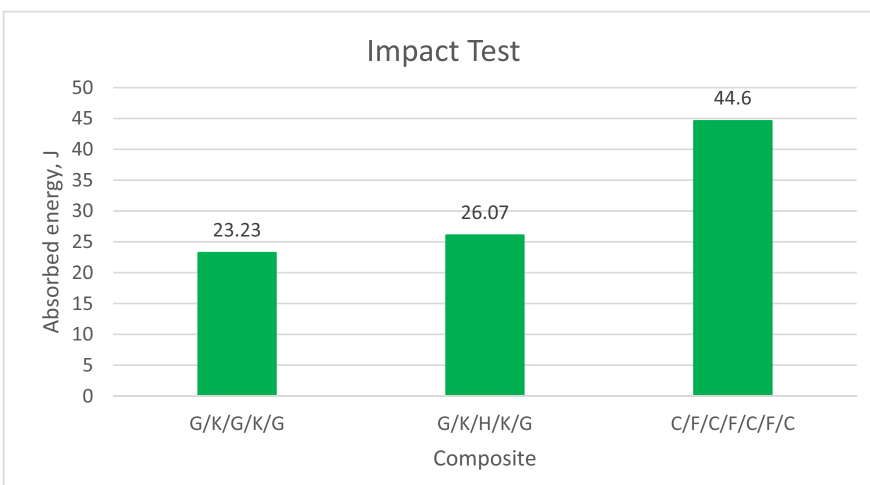


Figure 9: Comparison of absorbed energy by three different composites.

composite (23.23 J). Some of the factors that contribute to an obvious difference between carbon–flax composite with others is the total number of fiber laminate and the type of fiber in this composite. The effect number of layers is much more sensitive than adhesive composition in dynamic response as it can enhance significantly impact energy [36]. Moreover, in a group of natural fibers, flax fiber has a higher strength compared to kenaf fiber [37]. Focusing on the composite that used glass fiber as a reinforcement, GKHKG and GKGKG composite, there are slight differences in absorbed energy between the composite where a GKHKG composite is 10% higher than GKGKG. It can be seen that an aramid honeycomb was assisted to get better energy absorption performance than using glass as a core [13,38]. In addition, honeycomb cores with continuous fiber will reach higher peak force and energy absorption simultaneously for the large deflection and high strain application [19,39]. Therefore, for the glass–kenaf–honeycomb composite that was studied, a composite core performance was used in this composite giving more advantage to the property's behavior compared to other materials; in fact, the honeycomb proved its performance capability through the experimental, which can withstand excellent strength and good in energy absorption [13,40].

4 Conclusion

In the field of composite engineering, a hybridization of synthetic and natural fiber may potentially reduce the cost of production and will develop high-performance composite materials. In addition, a partial synthetic replacement may increase the high strength-to-weight ratio and increase the biodegradability of existing synthetic composites. The incorporation of a honeycomb core structure added the advantage of reducing a composite weight and had the capability to absorb energy during crushing. The experimental results can be summarized that:

- GKGKG composite achieved a higher value of 147.64 MPa in tensile strength compared to GKHKG and KGKGK composite laminates, which achieved 73.41 and 121.45 MPa, respectively.
- A hybrid laminate composite of GKHKG has a superior flexural strength than GKGKG and KGKGK where the flexural strength of the GKHKG composite reached 219.03 MPa.
- In terms of impact performance, the hybrid composites can withstand impact energy up to 30 J. GKGKG composites displayed the best impact properties than other composites with the highest impact load of 5.85 kN and absorbed energy increased to 32.41 J.
- In a comparison of natural–synthetic composites on tensile and flexural properties to other studies, a hybrid composite glass/kenaf/honeycomb has overcome the strength of hybrid glass/kenaf, which has a similar number of plies, orientation, and method of fabrication in terms of tensile and flexural. However, this composite shows significantly less strength than hybrid composite carbon/kenaf.
- In impact performances as well, glass/kenaf/honeycomb still has a higher value of absorbing energy than glass/kenaf composite but obviously lower than carbon/flax composite, which has seven layers of fiber.
- Addition of honeycomb in this study achieved a slightly higher mechanical strength and stiffness due to the higher volume of synthetic fiber in the composite like the GKGKG laminate composite. In advantage, GKHKG composite was more lightweight than GKGKG and KGKGK composite.
- From the current empirical investigation of the mechanical performance, the hybrid GKHKG composites can be potentially applied in semi-structural and structural lightweight applications.

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Conflict of interest: David Hui, who is the co-author of this article, is a current Editorial Board member of *Reviews on Advanced Materials Science*. This fact did not affect the peer-review process. The authors declare no other conflict of interest.

Data availability statement: The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

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