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High velocity impact, flexural and dynamic mechanical properties of flax/carbon/Kevlar reinforced bio-phenolic/epoxy composites

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ABSTRACT

This work investigated the effect of hybridization of flax fabric (FF) with carbon/Kevlar fabric (CK) on the flexural, dynamic mechanical analysis and high velocity impact. Hand lay-up technique was used to fabricated different ratio of flax to carbon/Kevlar hybrid composites, which were hot-pressed and then cured. It was revealed that increase in ratio of CK has improved the flexural properties, storage modulus, loss modulus, energy absorption and ballistic limit of the composites. Interestingly, hybrid composite with ratio 25:75(FF:CK) has highest flexural properties, storage modulus and loss modulus among the other composites. The cole-cole plot and damping factor reveals that hybrid composite with ratio 25:75(FF:CK) has the strongest fibre/matrix adhesion. The hybrid composite with ratio 25:75 (FF:CK) displayed the highest Tg. Based on high velocity impact test, it was shown that there is not much different in energy absorption and ballistic of the hybrid composites compared to plain CK composite. FF/CK hybrid composites have the potential to be used in high performance application such as ballistic helmet.

1. Introduction

Currently, environmental footprint issues are becoming prevalent topic due to exponential increase in human population on earth [1]. The petroleum resource depletion and present-day regulation about protection of environment also requires research heading towards scientific community's attention to the development of eco-green products in automotive, constructions, packaging industries and various applications in order to focus on sustainability, renewability, and economic growth related to materials [2,3]. Previous studies found that natural fiber material from flax, hemp, bagasse, bamboo, kenaf, jute, pineapple leaves and oil palm have increased the mechanical strength, stiffness, density, thermal performance and cost effectiveness of product [4–6]. The exponential transformation of natural fiber reinforced polymer composite (NFPC) has been exemplary efforts to replace conventional materials while maintaining their strength performance with minimal environmental impact.

The demand for stronger and lighter materials is growing rapidly, and hybrid composites are one of the developments that can be used to improve the composite properties [7]. Moreover, composites, which combine synthetic and natural fiber, have drawn lot of interest and utilized in wider applications [8,9]. Natural fibers have many advantages, but they also have some significant disadvantages. For example, they exhibit substantial moisture absorption, limited wear resistance, and low impact strength. These limitations can overcome with aid of hybridization methods between synthetic and natural fibers [10–12]. Various studies investigated methods of hybridization [13–16]. They obtained optimum development by merging additional fibers with single fiber in polymer matrix such as varying fiber angle, layer by layer stacking and ideal orientation of fiber [17]. Moreover, hybrid fiber acts as more effective load transfer medium between layers than single fiber reinforcements. To further enhance the properties of NFPC, synthetic fiber was incorporated into composite by substituting natural fiber with synthetic fiber to produce hybrid composite. According to review reports, composites made from Kevlar and carbon fiber, Kevlar and glass fiber, as well as carbon and glass fiber have shown improved mechanical properties [18–20].

In addition, flax is one of the natural fibers presently utilized in thermoplastic matrix composite panels for internal automotive constructions [4]. Sathish et al. [21] studied on hybrid composite consist of flax fabric (FF) and bamboo (B). The hybrid composites with a ratio 30:10 (FF: B) showed better mechanical performance compared to other

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hybrid composites. According to Fiore et al. [22], the hybridization of FF/carbon reinforced plastic composites enhanced the flexural performance compared to FF composite alone. The analysis showed that FF/carbon hybrid composites accomplished excellent flexural modulus and strength values with 221% and 100% higher than plain FF composite, respectively. Priyanka et al. [23] have studied hybrid composites consisting of Kevlar and carbon fibers. The dynamic mechanical analysis (DMA) was performed under temperature (30 °C–180 °C) and frequency ranging from 1 to 50 Hz. The DMA results showed that it was affected by inter-yarn hybridization of carbon and Kevlar yarns.

Furthermore, Shen et al. [24] used DMA machine and scanning methods for temperature, frequency, and amplitude to study unidirectional FF-reinforced composite laminates with various delamination areas and cross position. It was determined that the delamination of the composite in various sizes of FF and places had considerable impact on dynamic mechanical properties. Another study conducted by Selvaraj et al. [25] on basalt/flax hybrid composite, finding reveals an increase in damping factors up to 122% of hybrid composite with FF as core layer and basalt as outer layer.

Ballistic materials have been the subject of extensive research, especially for military applications. Impact resistance and weight are critical factors for ballistic/impact resistant performance. Kevlar fiber composites are used to make personal body armour due to their high strength-to-weight ratio and excellent impact resistance [26,27]. Sarkar et al. [28] investigated the ballistic performance of a hybrid composite composed of carbon and glass fiber. A varied series of carbon/glass hybrid composites was manufactured with a projectile velocity ranging from 400 to 500 m/s was employed during the testing. The study concluded that glass/carbon hybrid composite with stacking sequence G-C-G-C-G gave best performance. Delcourt et al. [29] conducted ballistics tests of dry stacked flax fibers. The result obtained lower mechanical properties of natural fibers like flax which are unable to compete with high performance fibers. However, combining stronger synthetic fibers with natural fibers may improve performance and make it more affordable.

A number of significant studies have concentrated on enhancing natural fiber polymeric composites by employing high-performing resins. Generally, a polycondensate called phenolic resin is produced by phenols (such as phenol, cresol, and xylenol) and aldehydes such as formaldehyde under catalysis of acids or alkalis at specific temperature [30]. Phenolic resins are widely used in variety of applications from common materials and building material products to advance aerospace products. This favourable review results from the fact that phenolic thermoset resins possess numerous appealing properties including great mechanical strength, heat and flame resistance, and better in dimensional stability, as well as good resistance to various solvents [31–33]. Jin et al. [34] reported that due to their rigidity, brittleness, easy to crack, and strongly cross-linked epoxy resins are not suitable for few applications, including structural materials. Thus, to deal with current problem, initiatives have been undertaken to enhance the properties of matrix by applying blending formulation of bio-phenolic and epoxy resin for widespread application [35].

The combinations of various types of fibers and polymer matrix will considerably alter the properties of the composites. According to the assessment of the literature, no work has been published on hybrid composites that use flax fabric (FF) and carbon/Kevlar (CK) as reinforcement and blends of bio-phenolic/epoxy polymer. The present study investigates the effects of different fibers ratio of FF and CK for flexural, dynamic mechanical, and high velocity impact of hybrid composites. The aim of this study is to develop ballistic helmet using hybrid composites of FF/CK.

Table 1
Details of FF and CK fabric.

Reinforcement	Flax fabric	carbon/Kevlar fabric
Type of weave	Plain weave	Twill weave
Weight	160 gsm	210 gsm
Yarn count	14 × 14	14 × 14
Thickness	0.3 mm	0.3 mm
Carbon fibre	–	Pyrofil TR30S 3K
Kevlar fibre	–	Kevlar® 49
Moisture content before oven dry	11.27%	4.87%
Moisture content after oven dry	7.20%	2.33%

2. Materials and method

2.1. Materials

In this study, FF and CK fabric were used as reinforcement materials. Dongguan Zhouma Textile Co. Ltd. supplied FF. While Tazdiq Engineering Sdn. Bhd. provide epoxy (D.E.R* 331), epoxy hardener (Jointmine 905-3S) and CK fabric. Bio-phenolic resin obtained from Chemovate Girinagar and Evergreen Sdn. Bhd supplied Teflon sheet. Table 1 summarizes the details of FF and CK fabric.

2.2. Fabrication of composites

The composites were fabricated using hand lay-up process and cured using a hot press. The composites were fabricated with dimensions of 150 × 150 mm with two distinct thickness of 3 and 6 mm. Composites with 3 mm thickness were fabricated for flexural and dynamic mechanical analysis while, composites with 6 mm thickness were fabricated for high velocity impact testing. Hybrid composite of FF/CK was fabricated with different ratios which are 25:75 (25FF75CK), 50:50 (50FF50CK) and 75:25(75FF25CK). As control, FF composite and CK composite were fabricated. The reinforcements were trimmed to size 150 × 150 mm and placed in an oven at 60 °C for 24 h. The polymer blend containing 20 wt% bio-phenolic with epoxy was prepared and stirred for 10 min. When bio-phenolic was uniformly distributed in epoxy, pour the hardener into the mixture with a ratio of 2:1 (Epoxy: Hardener) and continued to stir for another 2–4 min. A Teflon sheet was used to prevent the sample from sticking to steel plate. The layering sequence of resin and reinforcement are shown in Fig. 1. The fiber loading was maintained at 50 wt%. After the materials were prepared the mould was placed into hot press and allowed to cure at 150 °C with pressure of 30 tonnes. Furthermore, similar layering sequences for the composites with a thickness of 6 mm was prepared. The formulation of the fabricated composites and number of layers for both 3 and 6 mm composites are shown in Table 2.

3. Characterization

3.1. Flexural properties

The flexural test (ASTM D790 [36]) was handled on a universal testing machine (UTM) manufactured by Instron, model 5567, with Bluehill Universal software (Shakopee, USA). The sample dimensions were 127 × 12.7 × 3 mm, they were cut using a JETMAC JMWBS-14 saw for 5 replicates. The support span and crosshead speed were calculated using Eqs. (1) and (2). The samples were conditioned in a chamber at 23 ± 3 °C and 50 ± 10% relative humidity for 24 h before testing.

$$L = 16d \tag{1}$$

$$R = 0.01L^2/6d \tag{2}$$

where:
R: crosshead motion (mm/min)
L: Support span (mm)

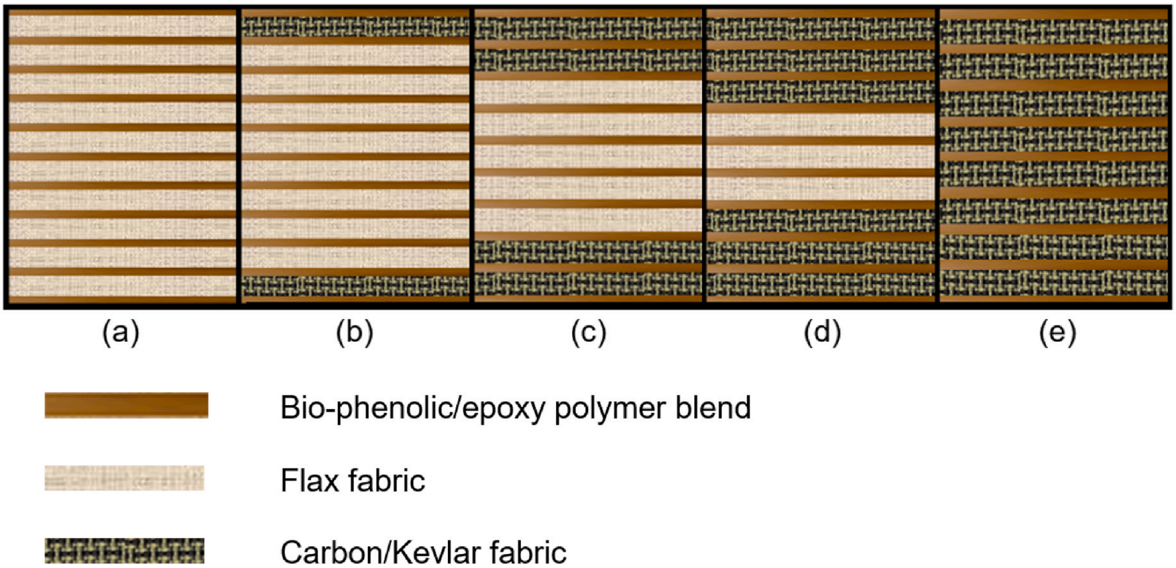

Fig. 1. Layering sequence of fabricated composites, a) FF, b) 75FF25CK c) 50FF50CK, d) 25FF75CK and e) CK.

Table 2
Information of fabricated composites.

Composites	Weight ratio of Flax fabric/ carbon/Kevlar	The weight ratio of bio-phenolic/ epoxy	Number of layers (FF/ CK) (3 mm)	Number of layers (FF/ CK) (6 mm)
FF	100/0	20/80	10 (10/0)	20 (20/0)
75FF25CK	75/25	20/80	10 (8/2)	20 (16/4)
50FF50CK	50/50	20/80	9 (5/4)	18 (10/8)
25FF75CK	25/75	20/80	9 (3/6)	18 (6/12)
CK	0/100	20/80	8 (0/8)	16 (0/16)

d: depth of beam (mm)

3.2. Dynamic mechanical analysis (DMA)

DMA was performed on 60 × 12 × 3 mm samples using DMA 800 instrument following the ASTM D4065 [37] standard. The samples were heated from 30 to 150 °C at a rate of 10 °C/min in three-point bending mode at a frequency of 1 Hz. One sample was tested for each type of composites.

3.3. High velocity impact (HVI) test

HVI testing was performed using single-stage gun experimental setup. Samples of size 100 x 100 × 6 mm thickness were used. Three replicates were tested in each group and mean values were reported. Fig. 2 shows the experimental setup. The gas tunnel chamber is around 4 m long. Helium gas acts as a propellant for the hemispherical stainless-steel projectile, which acts as the bullet in this test. The compressed air pressure was kept constant at 6 bar, while the helium gas pressure was maintained at 100 bar. The weight, diameter, and length of the hemispherical stainless-steel are 5 g, 8 mm, and 13 mm respectively. When the trigger is pulled, the air pressure causes helium gas valve to open. The projectile, which is contained inside the gas tunnel barrel, begins moving immediately and hits the sample at a velocity of around 300–340 m/s.

A high-speed camera called "NAC's Hot Shot 512sc" with the capability to capture images at frame rates of more than 200,000 frames per second was used. The impact velocity and residual velocity of the projectile was measured using Hot Shot software system. The impact energy, residual energy, energy absorption (Eabs), and ballistic limit (V_{50}) can be calculated using the following equations:

$$\textit{Impact energy} = 1/2(mv_i^2) \quad (3)$$

$$\textit{Residual energy} = 1/2(mv_r^2) \quad (4)$$

$$E_{abs} = (mv_i^2 - mv_r^2)/2 \quad (5)$$

$$\text{Ballistic limit} = \sqrt{v_i^2 - v_r^2} \quad (6)$$

Where,
v_i: impact velocity
v_r: is the residual velocity.
m: the mass of the projectile.

4. Results and discussion

4.1. Flexural properties

The study was designed to evaluate the influence of different ratios of FF and CK on the flexural properties of composite and the results are depicted in Fig. 3. Fig. 3(a) depicted flexural strength of the FF, CK and hyrbrid composite. The result showed that flexural strength of CK composite (433.91 MPa) is superior as compared to FF composite (128.96 MPa). Simply substituting 25% of the FF with CK results in substantial enhancement of the composite's flexural strength, achieving 2.2 times higher compared to flexural strength exhibited by FF composite. The flexural strength of hybrid composites increases as the ratio of CK increases. Increasing in flexural strength of hybrid composite with incorporation of CK was due to the fact that carbon and Kevlar fiber has higher strength compared to flax fiber. The flexural strength of the composite can be enhance by hybridization of lower strength of fiber with higher strength of fiber. Noorunnisa et al. [38] found that combination of sisal fiber and carbon fiber improves the flexural strength of the hybrid composite. The improvement of flexural strength of hybrid composite was due to superior properties of carbon fiber compared to sisal fiber. Hybrid composites, 25FF75CK has the highest flexural strength which is 356.76 MPa showing reduction in flexural strength about 17.78% compared to CK composite.

The effect of substituting FF with CK on flexural modulus of FF composite is depicted in Fig. 3(b). Research findings shows that FF composite have significantly lower flexural modulus than CK composite. Substituting 25% of FF with CK significantly improved the flexural

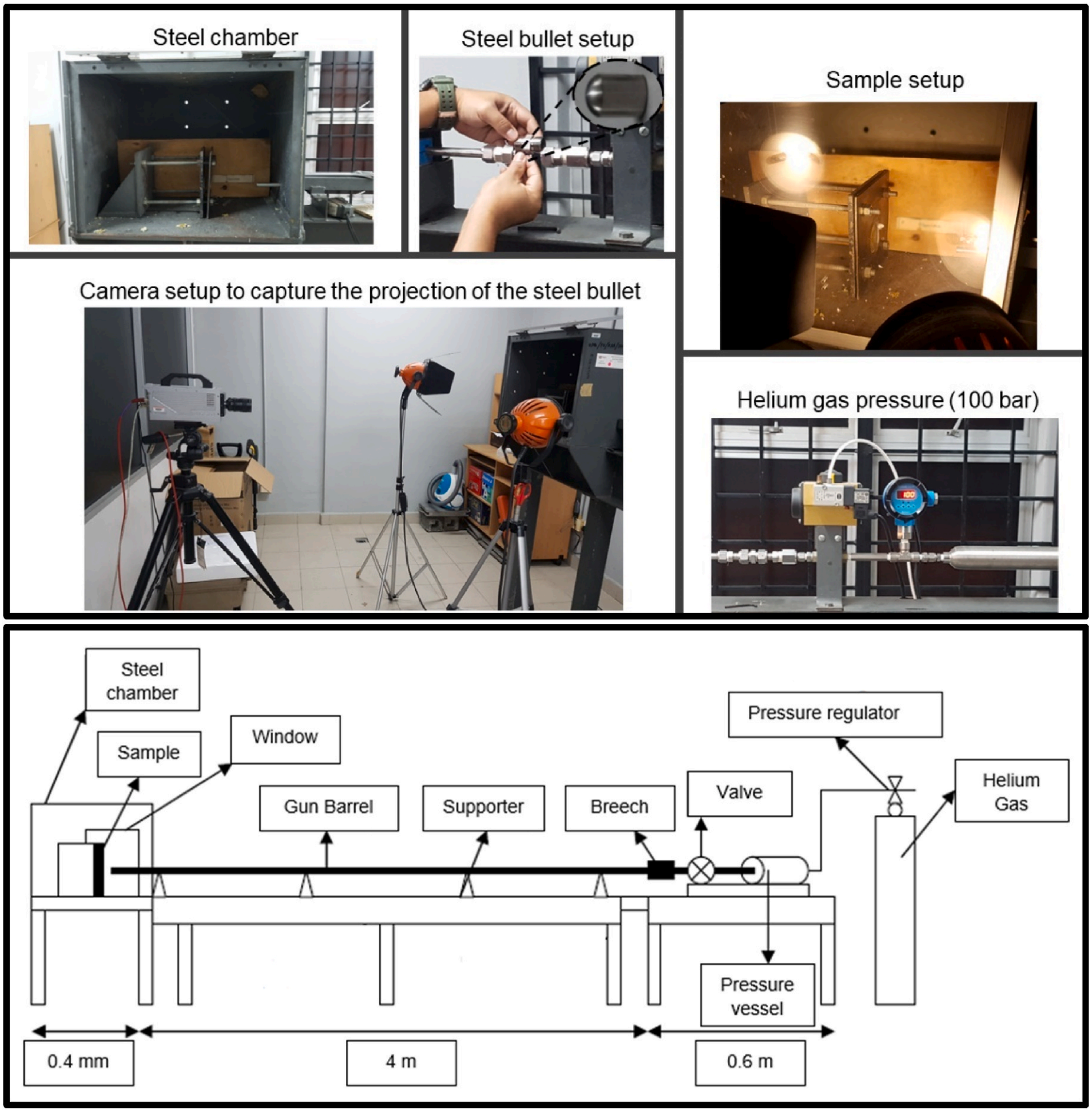

Fig. 2. Experimental setup.

modulus of the hybrid composite, making it 3 times stiffer than FF composite. Further increasing the ratio of CK in the hybrid composites increase the flexural modulus, and substituting 75% of FF with CK resulted in a hybrid composite with higher flexural modulus than CK composite. The hybrid composite, 25FF75CK has greater flexural modulus due to improved interfacial bonding between the fibers and the matrix. This improved adhesion enhances the efficiency of stress transfer, which is better in 25FF75CK composite than in CK composite. A similar trend was observed in the study conducted by Naveen et al. [39] where the flexural modulus of hybrid composite of Kevlar(K)/cocos nucifer (CN) with ratio 75:25(K:CN) has the highest flexural modulus and it is higher then pure Kevlar composite. Noorunnisa et al. [38] reveals that flexural modulus of sisal/carbon hybrid composites increases as carbon fiber ratio increases. However, it does not go above the flexural modulus of carbon composites which might be due to less effective stress transfer for this composites.

4.2. Dynamic mechanical analysis

4.2.1. Storage modulus

Fig. 4 illustrates the effect of different FF to CK ratios on the storage modulus (E') of hybrid composites. This study demonstrates that temperature has a significant impact on E' of composites. As temperature rises, E' of these materials undergoes a gradual decline until it reaches transition zone, marked by a sudden drop. At elevated temperatures, the E' maintains relatively constant, recognized as rubbery plateau phase. The E' was used to measure the elastic response of material when load is applied. In glassy region, the polymer chain of the thermoset polymer is tightly packed due to crosslinking of polymer chain, which resulted in high E'. The polymer chain gains kinetic energy as temperature increases and causes the polymer chain to start vibrating vigorously. In addition, the crosslinking bonds between the polymer chains become more flexible, which causes it to stretch and bend more. Moreover, the entanglement of polymer chain becomes less restricted which allows polymer chain to move around. A material's E' decreased as a result of these events that takes place during sample being heated, making composites softer and more elastic. The researchers found that E' of the

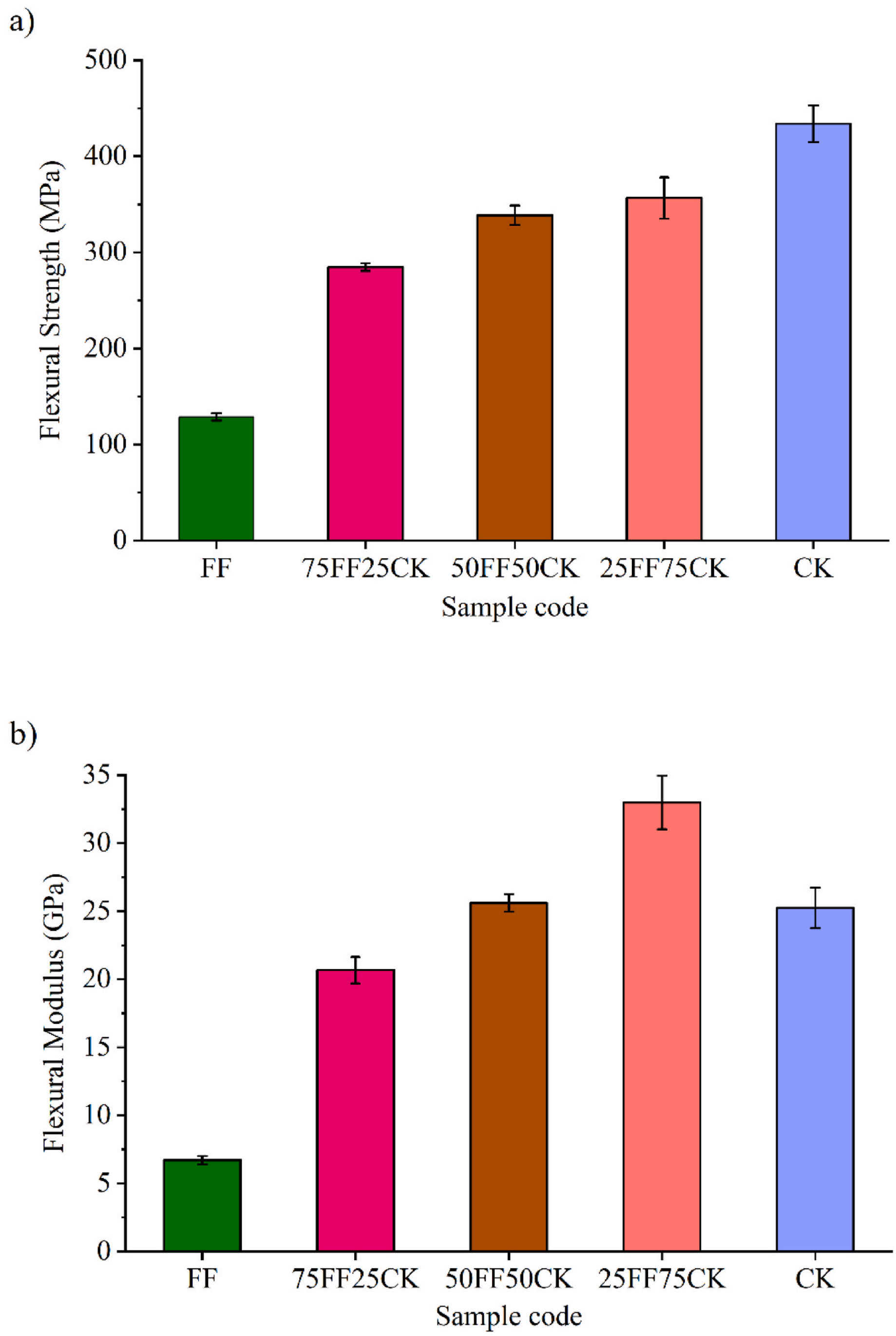

Fig. 3. a) Flexural Strength, b) Flexural Modulus.

composite decreases with increasing temperature due to increased mobility of the polymer chains [40,41].

The stiffness of the fiber has an impact on how effectively fiber acts as reinforcement by acting as a physical barrier to the movement of the polymer chains. A stiffer fiber will increase the E' of the materials [42–44]. This can be observed with the E' of FF composites and CK composites whereas, the E' of CK composite is higher compared to FF composite due to carbon/Kevlar fiber is stiffer compared to flax fiber. The results of the study revealed that hybridization of flax and carbon/Kevlar fibers improved the E' of the composites in the glassy, transition, and rubbery regions. Hybridizing flax with carbon/Kevlar fiber makes the stress transfer more effective compared to FF composite and CK composite. Hybrid composite with ratio 25:75 (FF:CK) showed the highest E'. Selvakumar and Meenakshisundaram [45] found that the combination of human hair and jute fibers improved the E' of composites due to the improved interfacial adhesion between the fibers and matrix, which resulted in better stress transfer. Veerasimman et al. [46] asserted that the improved fiber-matrix interface in hybrid composites is the reason why they have better E' than single fiber composites.

4.2.2. *Loss modulus*

Loss modulus (E") is a measure of the energy dissipated as heat during a DMA test. The maximum heat dissipation occurs at the peak of the E" curve and temperature at this point known as Tg. The effect of combination of FF and C/K on E" of composites is depicted in Fig. 5. The finding showed that, CK composite showed higher peak compared to F composite. The high stiffness of C/K fabrics compared to FF is responsible for the changes in E" of the hybrid composites. A study conducted

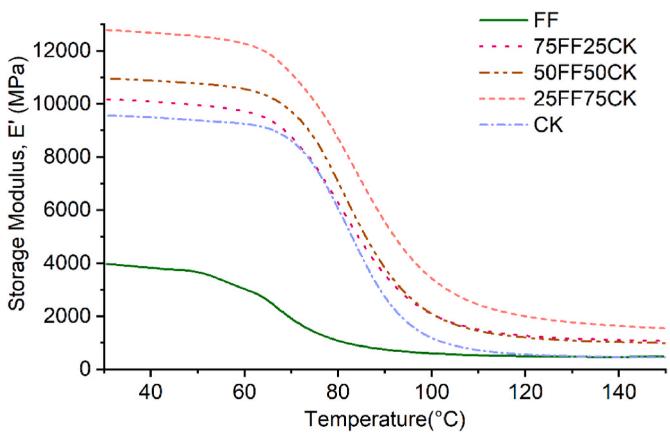

Fig. 4. Storage modulus of the composites.

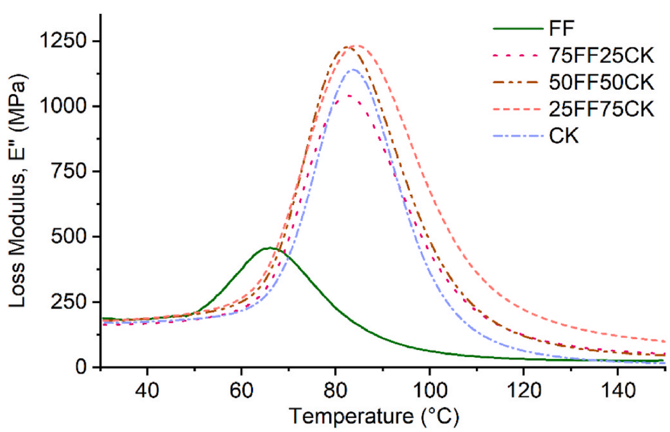

Fig. 5. Loss modulus of the composites.

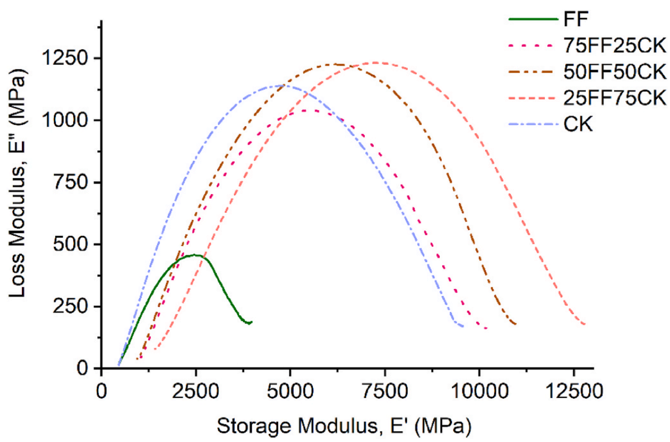

Fig. 6. Cole-cole plot of the composites.

by Mandal and Alam [47] revealed that composite with stiffer fiber will have higher E". It is also supported by study conducted by Manral et al. [48] where it was found that materials with higher stiffness dissipates more energy and resulted in higher E". The peak of the E" curve increases, and the curve broadens as the CK ratio in the F/C/K hybrid composite increases. The broadening of the curve indicates an inhibition of the relaxation process that occurs in the composites [49,50]. Moreover, increase in chain mobility and free volume is the main cause of increasing in peak and broadening of the curve of E" [51]. In addition,

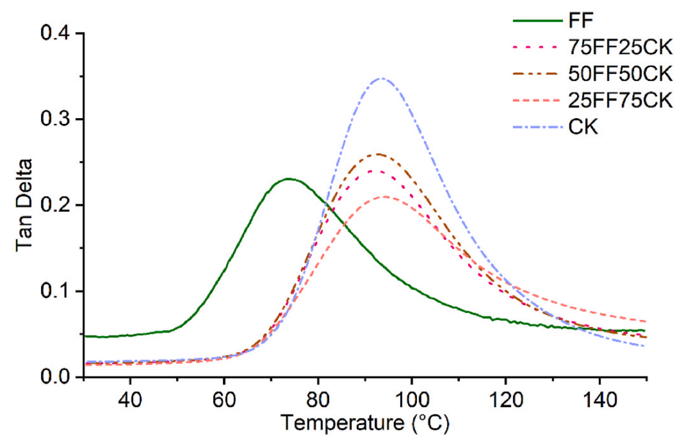

Fig. 7. Damping factor of the composites.

the broadening of the E" peak was caused by the internal fraction within the composites, which enhanced the energy dissipation [52]. The improvement in interfacial adhesion between fibers and matrix resulted an increase in frictional resistance, which in turn led to an increase in energy dissipation and a higher peak value of E" [53,54]. The highest E" peak was shown by hybrid composite 25FF75CK (1232.33 MPa) followed by 50FF50CK (1226.03 MPa) and 75FF25CK (1039.81 MPa)

4.2.3. Cole-cole plot

The cole-cole plot showed relationship between E" and E' which can be used to determine the homogeneity of fiber and matrix. The shape of the plot of E" versus E' can be used to predict the homogeneity of the composite where even and semi-circular arc shows a homogeneous, while imperfect or elliptical curve indicate the non-homogeneous. The graph of E" versus E' of the composites was depicted in Fig. 6. The elliptical shape of the cole-cole plot indicates that the combination of fibers and matrix is non-homogeneous. The wider width of the cole-cole plot for the CK composite compared to the FF composite suggests that the fiber adhesion between CK and bio-phenolic epoxy blend is better than FF and bio-phenolic/epoxy polymer blends. This work intriguingly revealed that hybridizing FF with CK significantly improved the interfacial bonding of fiber and matrix, as evidenced by increasing width of the curve in Fig. 6 as CK loading increases. The improvement of interfacial adhesion between the fibers and the matrix is likely the reason why the hybrid composites have the highest flexural modulus and storage modulus, even better than the CK composites.

4.2.4. Damping factor

The effect of combination of FF and CK on the damping factor were depicted in Fig. 7. Tan delta represents the energy dissipating due to the molecular rearrangements and internal friction of the materials [55]. The peak of Tan delta can be indication of the adhesion of the fibers and matrix. The FF composite has lower Tan delta peak than CK composite, suggesting that FF composite has better fiber/matrix adhesion. The researchers found that peak of tan delta can be used as an indicator of the interfacial bonding between the fibers and matrix whereas, lower peak of Tan delta indicates higher fiber/matrix adhesion [50,56,57]. However, finding for mechanical properties and E' of CK composite is higher compared to FF composites and this is due to the strength of C/K fabrics which is higher compared to the FF. This is because the strength of the fiber plays a vital role in polymer composite followed by the fiber/-matrix adhesion. Based on the damping factor result it was shown that hybrid composites of F/C/K have better interfacial bonding between fiber and matrix. The effect of improved interfacial adhesion can be seen when looking at the result of E' of the hybrid composite 25FF75CK, where it is higher compared to CK composites. In addition, the researchers claimed that higher peak of Tan delta can be indication of

Table 3
Glass transition of the composites.

Composites	Tg from loss modulus (°C)	Tg from tan delta (°C)
FF	66.08	73.92
75FF25CK	82.67	92.20
50FF50CK	82.36	92.64
25FF75CK	84.37	94.14
CK	83.64	93.42

Table 4
The impact velocity, residue velocity, impact energy and residual energy of the composites.

Composites	Mass	Impact velocity (m/s)	Residue velocity (m/s)	Impact energy (J)	Residual energy (J)
FF	72.15 ± 1.86	337.57 ± 5.96	264.65 ± 13.11	341.85 ± 11.98	210.11 ± 19.33
75FF25CK	69.63 ± 0.66	302.67 ± 13.43	214.06 ± 8.01	274.82 ± 23.89	137.47 ± 10.03
50FF50CK	68.10 ± 0.15	321.81 ± 4.14	238.79 ± 6.41	310.69 ± 7.92	171.06 ± 9.16
25FF75CK	70.03 ± 0.97	313.32 ± 9.22	225.06 ± 5.07	294.51 ± 17.57	151.96 ± 6.92
CK	69.97 ± 1.59	319.87 ± 8.92	228.11 ± 8.22	306.96 ± 16.90	156.11 ± 11.05

lower internal energy dissipation in the interphase of fiber and matrix [58,59]. Furthermore, peak of Tan delta can signify the composite's ability to support loads with better load bearing capacity and ultimately show lower damping value [60].

4.2.5. Glass transition (Tg)

Various methods including DMA can be used to determine Tg. In DMA, Tg can be determined from three different points of DMA curve: peak of Tan delta, peak of loss modulus, or the onset of the E' curve. In this study Tg obtained from the peak of E" and peak of Tan delta was reported. Table 3 showed Tg of composite obtained from the peak of E" and peak of Tan delta. The finding showed that CK composite has higher Tg compared to F composite and this can be observed from both E" and Tan delta curve. Higher Tg indicates that CK composite has better thermal stability in contrast to F composite. The difference of Tg between FF and CK composites is attributed to the stiffness of the fibers, with C/K fabrics being stiffer than FF. This will increase the stiffness of the composite which make it difficult for the polymer chain to bend and stretch which results in higher Tg. Hybridization of FF with CK increases Tg of the composites. The result showed that 25FF75CK has the highest Tg among the others hybrid composites. '

4.2.6. High velocity impact

The high velocity impact performance of F/C/K hybrid composites was investigated by varying FF to CK ratio. The impact velocity, residual velocity, impact energy, and residual energy of FF composite, CK composite, and hybrid composites are presented in Table 4. The impact velocity was maintained 300–340 m/s during testing. The information in Table 4 was used to calculate the E_{abs} and V_{50}. Fig. 8 illustrated the E_{abs} and V_{50} of FF composite, CK composite and hybrid composites. E_{abs} refers to the amount of energy dissipated by the composites during impact testing. It is determined by comparing the kinetic energy of the steel bullet before and after it penetrates the samples [61]. While V_{50} is the probability projectile has 50% chance of partially penetrating or perforating target [62]. CK composite exhibits higher E_{abs} and V_{50} than FF composite, with 14.51% increase in E_{abs} and 7% increase in ballistic limit. This is due to C/K fiber has higher energy absorption and dissipation capacity than FF. The combination of FF and CK composites shown enhanced in E_{abs} and ballistic limit. The improvement is greater with increasing in CK ratio. Similar finding was reported by Yahaya et al. [63] where the hybridization of kenaf fiber with Kevlar fiber has improved the E_{abs} and V_{50} of the composite.

The damage analysis was done by observing impacted sample on both side of sample and cross section. It can be observed circular perforation on all tested samples. A visible delamination of fiber was observed on FF composite only involving small area. In addition, on the rear side of the tested sample it can be observed the fiber completely break and this can be the reason why FF composite has lower E_{abs} compared to CK composite. The damage area for the CK composite was smaller compared to FF composite. This attributes superior strength of carbon/Kevlar fiber. On the rear side of the sample, it was shown that delaminated carbon/Kevlar fiber still attached to tested sample which

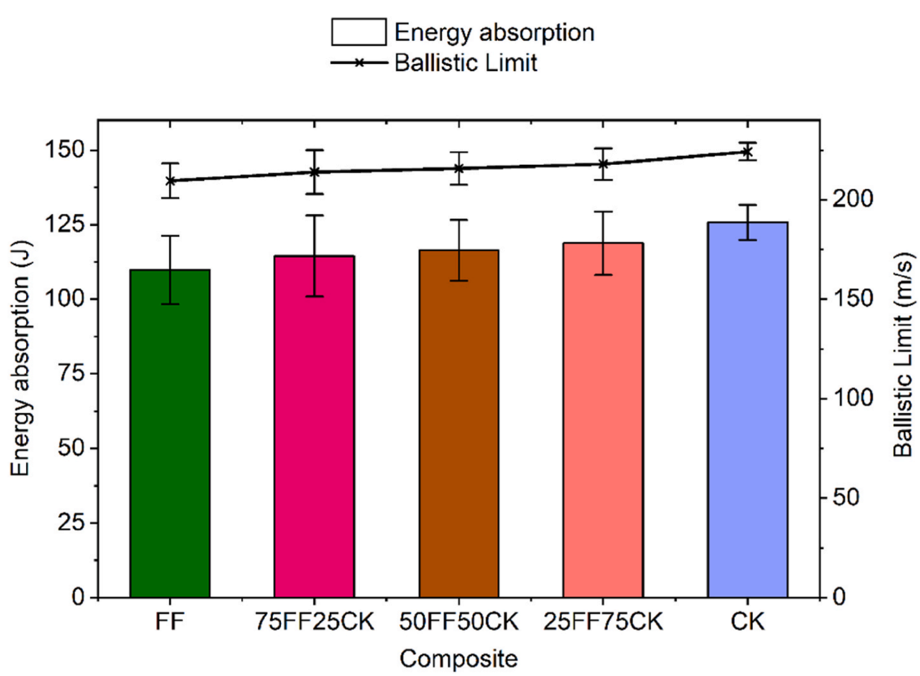

Fig. 8. Energy absorption and ballistic limits of the composites.

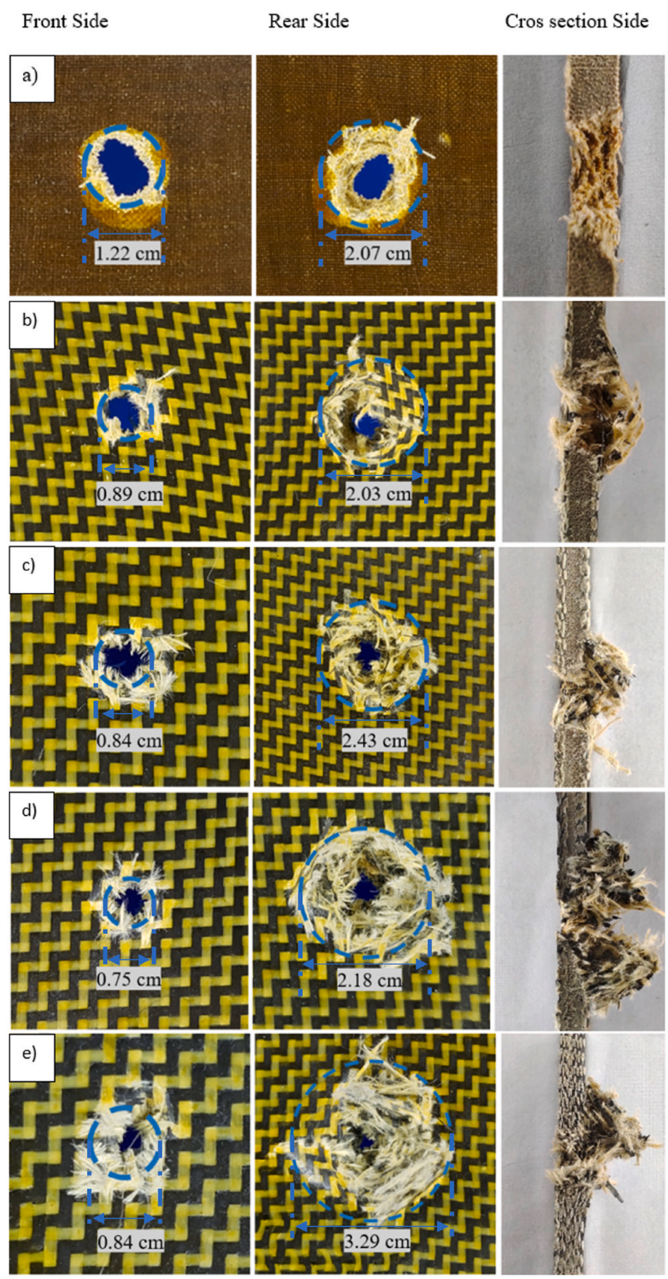

Fig. 9. The failure analysis of tested samples: a) FF, b)75FF25CK, c) 50FF50CK, d)25FF75CK, e) CK.

will help the sample to absorb more energy. Hybridization of FF with CK has reduce the diameter of the hole created from the penetration of the projectile. The higher the ratio of CK smaller the hole created from the penetration of the projectile. This is observed in Fig. 9 on the front side of the tested sample. Fig. 9 also showed cross section of sample after impact. Cross section of FF composite showed completely break the fiber and there is no visible sign of delamination of fiber which indicates adhesion of the fiber/matrix is strong and compared to the strength of the fiber. This is the one of the reasons of lowered E_{abs} compared to other composites. All the hybrid composite showed delamination of the fiber due to higher fiber strength of C/K fiber which help to absorb more energy during the impact. According to the researcher delamination and debonding of fiber will increase the E_{abs} during the test [64].

5. Conclusion

Hybrid composites consist of three different fibers with polymer blend as a matrix was successfully fabricated. A positive outcome was shown from this experimental work where in term of the properties which has been evaluated in this study showed a positive trend. A significant enhancement was shown in flexural properties where hybrid composite 25FF75CK showed highest flexural strength and modulus among the other hybrid composites. The flexural strength hybrid composite 25FF75CK has 176.64% higher compared to FF composite and 17.78% lower compared to CK composite. While flexural modulus of hybrid composite 25FF75CK is highest compared to both FF composite and CK composite which is 391.65% and 230.71% respectively. In addition, hybrid composite 25FF75CK also showed the highest in storage and loss modulus. This is due to the better fiber/matrix adhesion in hybrid composite 25FF75CK and it was confirmed by the cole-cole plot and damping factor findings. The E_{abs} and V_{50} of the hybrid composites has increased with increasing CK ratio. In addition, the hybrid composite 25FF75CK has only a slight decrease in E_{abs} and V_{50} compared to CK composite, with 5.50% and 2.79% reductions, respectively. The finding showed that F/C/K hybrid composites has great potential in high performance applications such as ballistic helmet.

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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