

A Low Velocity Impact Properties of Hybrid of Pineapple Leaf Fibre and Kenaf Fibre Reinforced Vinyl Ester Composites



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Abstract In this study, Pineapple leaf/kenaf fibre (PALF/KF) reinforced vinyl ester (VE) hybrid composites have been fabricated and tested with low velocity impact (LVI) and compression after impact (CAI) testing. The PALF/KF/VE hybrid composites have been fabricated by hand lay-up technique. For the LVI testing, there were three different level of energy were analysed, 5, 10 and 15 J. The level of energy was determined by the maximum impact force that the specimen can withstand. In the case of CAI testing, the specimen impacted by 5 J of impact energy produced the maximum compression force before it completely breaks down into two parts. The results showed that the hybrid composites impacted with 15 J of impact energy produced the highest peak force during LVI testing but lowest in CAI strength. The hybrid composites impacted with 5 J of impact energy illustrated the lowest peak force but highest in CAI strength. The study of impact properties of PALF/KF/VE hybrid composites was shown in this research work.

Keywords Pineapple leaf fibre (PALF) · Kenaf fibre · Vinyl ester (VE) · Low velocity impact (LVI) · Compression after impact (CAI)

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1 Introduction

Nature-based fibre composites have been extensively used in the various application including structural, aerospace, automotive and maritime application due to their biodegradability, environmentally friendly, cheap and lightweight (Ismail et al. 2019). Natural fibres have been the reinforcement from a long time ago (Nadlene et al. 2016). The industries as well as the government are currently moving towards the green technologies due to their advantages over synthetic materials. Nowadays, most of the research work conducted on the natural fibres were based on their specific performances including their mechanical, physical, thermal and chemical performances. There were several parts of the natural fibres that were taken during conducting the research work such as leaves, stalk, bast, stem etc. The implementation of natural fibres in the manufacturing process will eventually reduce the usage of synthetic fibres (glass, carbon, aluminium) and contributed to the preservation of natural fossil resources. Pineapple leaf fibre and kenaf fibre were the example of natural fibres that being widely used as a reinforcement in the composites.

Pineapple, *Ananas Comosus* is one of the most essential tropical fruit in the world that were abundantly available. Pineapple's leaves being extracted to obtain its fibres to be reinforced with polymer matrix to form a biodegradable composite. The production of pineapple leaf fibre (PALF) has been proved successfully as a reinforcement material in the production of composites (Kalapakdee and Amornsakchai 2014; Nopparut and Amornsakchai 2016; Yuakkul et al. 2015). Kenaf, *Hibiscus Cannabius* L., one of the annual herbaceous plant most planted in Africa and Asia. In reinforcing fibres for the composites, kenaf fibre (KF) is one of the most natural fibres used as a reinforcement due to its superior mechanical properties (Saba et al. 2015). Besides being biodegradable, KF possess high mechanical properties due to its chemical constituents (56–64% cellulose, 21–35% hemicellulose and 8–14% lignin) (Mazuki et al. 2011). Previous study investigated the impact performance of PALF/KF reinforced with phenolic hybrid composites (Asim et al. 2017, 2018), while another study conducted an impact testing on PALF reinforced VE composite (Mohamed et al. 2014).

In determining the strength of natural fibres composites, it is important to investigate the impact properties of composite materials especially when they are being widely used as aircraft structures because the tendency to encounter impact force is high. Thus, it is crucial to know how these properties work for better application. Flax was hybridized with basalt fibres and tested with drop impact test (Fragassa et al. 2018). Flax reinforced vinyl ester composites undergone drop impact test (Habibi et al. 2019). Hemp fabric reinforced bio-based epoxy composite tested with low velocity impact testing (Scarponi et al. 2016).

In this study, PALF/KF reinforced vinyl ester (VE) hybrid composites have been fabricated and tested with low velocity impact (LVI) and compression after impact (CAI) testing. Previously, There are some research works that conducted on the same materials, PALF/KF but on different matrix which is phenolic resin (Asim et al. 2017, 2018) and high density polyethylene (HDPE) (Aji et al. 2011). The current research

work used VE as a matrix. For the LVI testing, there were three different level of energy were analysed, 5, 10 and 15 J. The level of energy was determined by the maximum impact force that the specimen can withstand. In this project, 15 J is the maximum impact force that the hybrid composites can withstand. In the case of CAI testing, the specimen undergone compression testing to determine the maximum compression force that the specimen can withstand before it completely breaks down into two parts. This research work should give some information on how to implement the natural fibres in such application that worked on impact and compressive testing.

2 Materials and Methodology

2.1 Materials

PALF used in the reinforcement is in thin yarn form, with the average thickness of 1 mm. The PALF is chopped into 30 mm length. The chemical components of PALF used in this study are 18.8% hemicellulose, 82.0% cellulose and 12.7% lignin (Siakeng et al. 2018).

Woven KF has average thickness of 0.51 mm. The woven KF used contains 49% of cellulose, 24% hemicellulose and 21% lignin.

The matrix used was a premium standard Bisphenol-A type epoxy VE resin obtained from Sino Polymer Co., LTD.

2.2 Fabrication of PALF/KF/VE Hybrid Composites

In this research work, the fabrication is done by using two layers of woven KF (300 × 300 mm) for each top and bottom layer while random oriented chopped PALF was in the middle layer of the composites. The figure of composite layer is shown in Fig. 1. The hand lay-up method was used to prepare the composites. The ratio of fibre:resin was 30:70 while the respective ratio of resin:hardener was 100:3. The

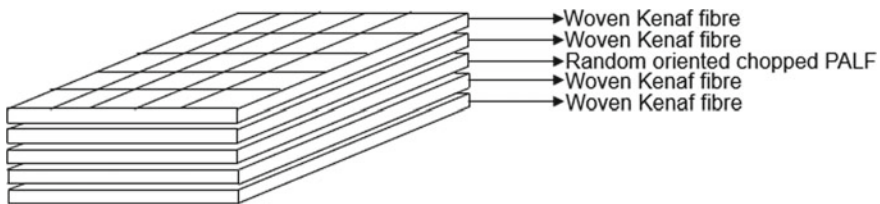


Fig. 1 PALF/KF/VE hybrid composite layer

Table 1 Height of striker

Impact energy (J)	Height of striker (m)
5	0.1
10	0.2
15	0.3

hybrid composites were kept for 24 h before they hardened completely and tested for the next testing.

2.3 *Experimental Testing*

2.3.1 Low Velocity Impact (LVI) Test

LVI testing was done by using the Imatek IM10 ITS Drop Weight Impact Tester according to ASTM Standard D7136 in aerospace engineering laboratory of UPM. The computer was connected to the instrument that were equipped with data acquisition system in order to record the captured data. A diameter of 10 mm and a mass of 5.101 kg of hemispherical nose striker was used as impactor in this research. The corresponding incident impact velocity was from 1.00 to 2.08 m/s and the incident impact energy varied from 5 to 15 J with an increment of 5 J (adjusted by the height of the impactor). A 150 × 100 mm of specimen dimension were placed on the impact support with a clamped using rubber tip toggle clamps at four points with an identical clamp force. In order to prevent the unintentional multiple impacts on the specimen, a rebound break was used. By using the gravitational energy equation

$$E = mgh$$

where m = mass, g -gravity, h = height in meter (m), and E = energy, the height of the striker was determined based on the value of impact energy as in Table 1.

Three specimens will be tested for each impact energy. This is important in order to obtain constant and average result of the impact energy. All the data being recorded while the table being tabulated. The average values were calculated for each sample.

2.3.2 Compression After Impact (CAI) Test

All the impacted specimens were then further tested with compression testing based on ASTM D7137 in a servo-hydraulic machine (Shimadzu AGX, 300 kN) at the rate of 2.00 mm/min located at the Faculty of Engineering, Universiti Teknologi Malaysia, Kuala Lumpur. Preloading of specimen was applied to ensure all the loading surfaces are in contact as well as to align the plates.

3 Results and Discussion

3.1 Low Velocity Impact (LVI) Test

3.1.1 Force–Time Response

Figure 2 showed the force–time response of PALF/KF/VE hybrid composites subjected to 5, 10 and 15 J of impact energy.

From the curve, the specimen that undergone 15 J of impact energy possessed the highest peak force (2.34 kN) at time of 0.82 ms while the specimen that undergone 5 J of impact energy presented the lowest peak force (1.46 kN) at time of 1.24 ms. The PALF/KF/VE hybrid composites impacted with 15 J of energy exhibits a peak value of maximum force that exceeds the value for the hybrid composites impacted with 5 and 10 J of energy level by at least 63% and 43%, respectively. From 5 to 10 J, the peak force increases 13.7% while from 10 to 15 J, the peak force increases 43.4%. For the hybrid composite impacted with 15 J of impact energy, the stage one lasted at a time of 0.15 ms before the impact force rises again to about 2.27 kN at a time of 0.49 ms. The event of the stage is due to the resistance of bending upper layer of hybrid composite. For the hybrid composite impacted with 10 J of impact energy, the force response after the peak force showed longer plateau than the hybrid composite impacted with 5 J of impact energy. This is due to the PALF that has larger elastic core buckling followed by destruction of its core. The hybrid composite impacted

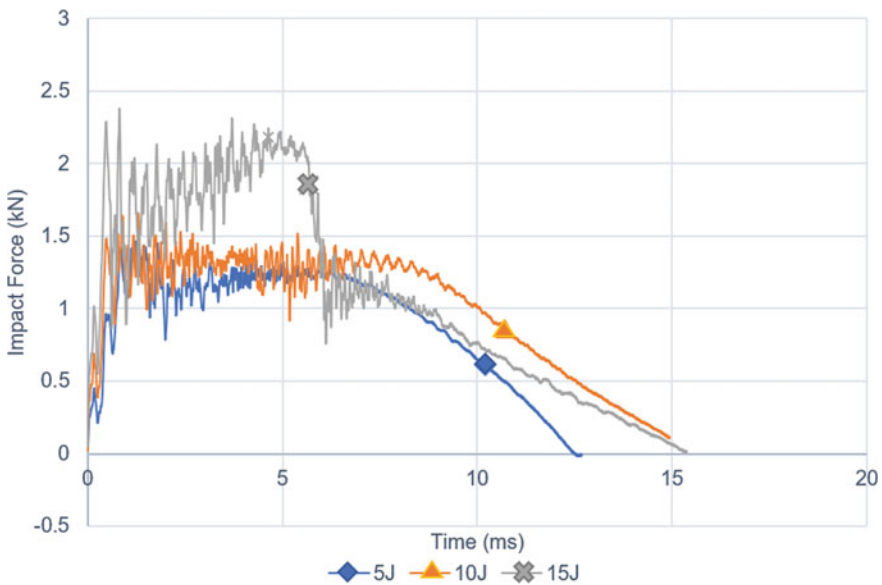


Fig. 2 PALF/KF/VE hybrid composites subjected to 5, 10 and 15 J for force–time response

with 10 and 15 J of impact energy can be compared to each other in corrug force–time response. Figure 3a–c, the impacted specimens showed corrugation angle and core buckling damage of KF, respectively. The repartee fluctuation of force response can be observed because of the external destruction of top layer of hybrid composites. The force curve increases dramatically with increase in impact time until the peak force. Before the force curve reach the peak value, the force–time trace showed a little fall between 400 to 1000 N. This is due to the thin core in thickness which is tendency to buckling. This statement is in lined with (Zangana et al. 2020) who mentioned that the deformation of composite is due to the thin core thickness. With the following increase in impact time, the kinetic energy started to mitigate followed by the gradual decrease in impact force due to the deformation of the hybrid composite and elastic buckling of core. At the time between 0.8 and 9.0 ms, the impact force produced an oscillation due to the disintegration of the KFs' quality at the upper layer of hybrid composites at the impacted area.

Figure 3a–c showed that the elevation of impact energy increases the impact mark for all the hybrid composites. However, the hybrid composite that were impacted with 15 J of impact energy has steeper slopes and cracks than the other two hybrid composites (5 and 10 J). This indicated that the hybrid composites impacted with 15 J of impact energy dispersed the impact force in a larger area compared to other two hybrid composites as it received higher impact energy. The hybrid composite impacted with 5 J of impact energy showed minimal cracks or slope compared the other two. This is due to the height of impactor which is 0.1 m that produced the smallest kinetic energy. Thus, less cracks and slopes produced at the impacted surface area.

Table 2 showed the LVI properties of PALF/KF/VE hybrid composites.

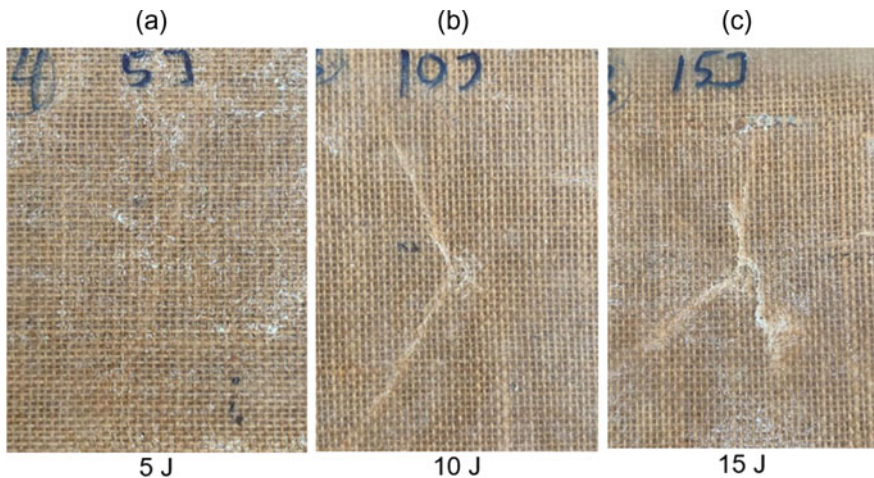


Fig. 3 Captured image of specimen at the end of impact test

Table 2 LVI properties of 5, 10 and 15 J impact energy

Impact energy (J)	Peak force (kN)	Peak deformation (mm)	Absorbed energy (J)	Energy to peak deformation (J)
5	1.46	4.97	3.69	5.3
10	1.66	8.52	8.6	10.53
15	2.38	9.28	14.19	15.65

3.1.2 Force–Displacement Response

The force–displacement graph was presented in the Fig. 4.

The graph of force–displacement showed the closed curve indicates the striker did not manage to penetrate the specimen completely but bounced back after hitting. An open curve happened when the striker completely penetrated the specimen. Thus, from the picture of specimen itself in the Fig. 3a–c, it can be concluded that no specimen experienced penetration, as the incident energy was transferred back to the specimen where the maximum displacement occurred. Maximum displacement recorded when the specimen transfers elastically the excess impact energy to the striker back which leads to bouncing phenomenon between the striker and specimen. From the testing, the specimen can hold up to 15 J before the striker completely penetrated the specimen. The peak deformation of 5, 10 and 15 J impact energy were 4.97 mm, 8.52 mm and 9.28 mm respectively. The curve of specimen that were impacted by 5 and 10 J illustrated quite similar impact force value and showed

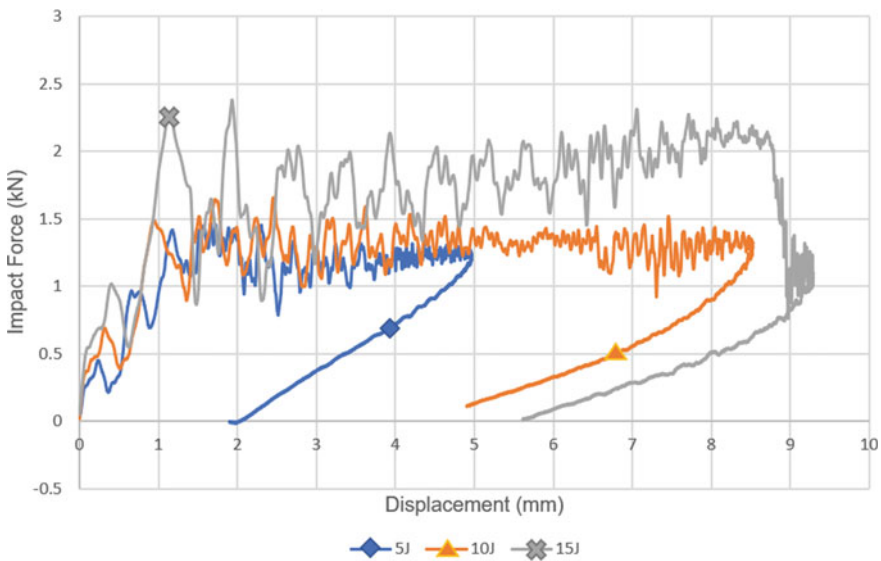


Fig. 4 PALF/KF/VE hybrid composites subjected to 5, 10 and 15 J for force–displacement response

smooth curve rather than the curve of specimen that was impacted by 15 J of impact energy. The curve of specimen impacted by 15 J of impact energy showed larger oscillation and displacement value. The peak deformation recorded associates with the production of cracks produced during impact testing. The sample impacted with 15 J of impact energy showed the highest deformation while the sample impacted with 5 J of impact energy showed the lowest deformation.

3.1.3 Energy–Time Response

The absorbed energy–time responses for all three level of impact energy was presented in Fig. 5.

As the impactor being released on the composites, the kinetic energy in the impactor was being transferred to the laminate composites as soon as the impactor in contact with the laminate composite. The energy began absorbed during the process of delamination, damage and vibration dissipation of the laminate hybrid composites (Tuo et al. 2019). From the curve, the absorbed energy for 5 J impact energy reached 3.69 J while 10 J impact energy showed 8.6 and 14.19 J of absorbed energy recorded by 15 J of impact energy. This is because the height of impactor is the highest among the other samples. The highest height of impactor created the highest kinetic energy, thus create severe interlaminar damage to the composite layers. The surface of KF was severe when the impact energy applied was 15 J. From the Fig. 5, the amount of damage is directly proportional to the amount of energy absorbed.

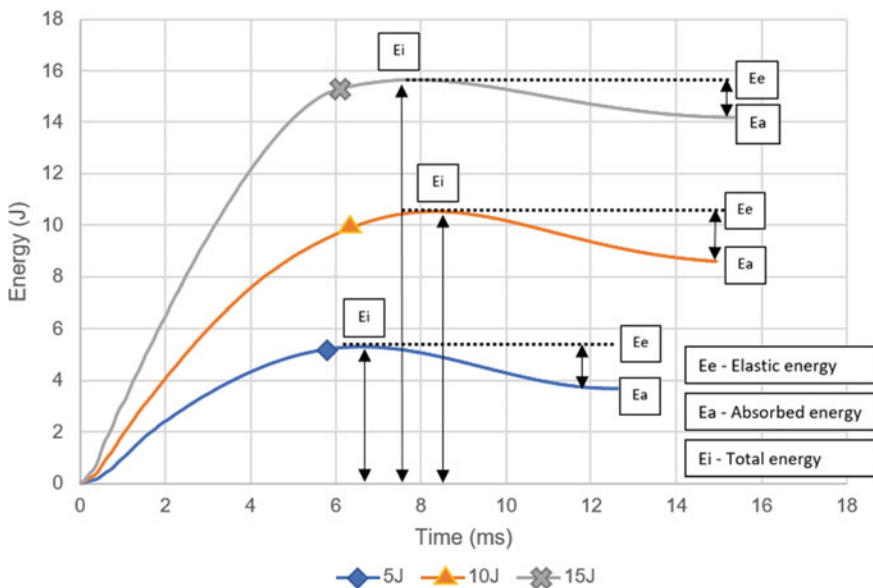


Fig. 5 PALF/KF/VE hybrid composites subjected to 5, 10 and 15 J for energy-time response

3.2 Compression After Impact (CAI) Test

The specimens were further tested with compression after impact (CAI) testing. Figure 6 present the stress versus strain curve of hybrid composites at three different impact energy (5, 10 and 15 J). When the samples are subjected to the compression testing, the compressed samples contributed to the compressive failure, specifically fibre compressive failure and laminated buckling at the back face of the samples. Therefore, due to the impact testing, the fibre and matrix breakage during CAI testing tend to focus on the concentration area. The delamination of the hybrid composites seemed perpendicular to the direction of compression testing. At 5 J of impact energy, the maximum compressive strength recorded was 35.08 kN before the specimen failed, with a displacement of 6.16 mm. At 10 J of impact energy, the maximum compressive strength obtained was 27.08 kN with a displacement of 5.01 mm while 15 J of impact energy produced 18.05 kN prior to failure, with a displacement of 4.19 mm.

Figure 7 showed the ultimate compressive strength of the hybrid composites for different level of energy.

From Fig. 7, the maximum compressive strength recorded was 70.17 MPa for the sample impacted with 5 J, 54.17 MPa for the sample impacted with 10 J and 36.09 MPa for the sample impacted with 15 J. The percentage differences between the compressive strength of sample impacted with 5 J and 10 J is 25.74% while between 5 and 15 J of sample impacted, the percentage differences are 64.14%. From the samples tested, the high impact energy acted on the specimen will produce lower compressive forces and vice versa. This is because due to the LVI testing,

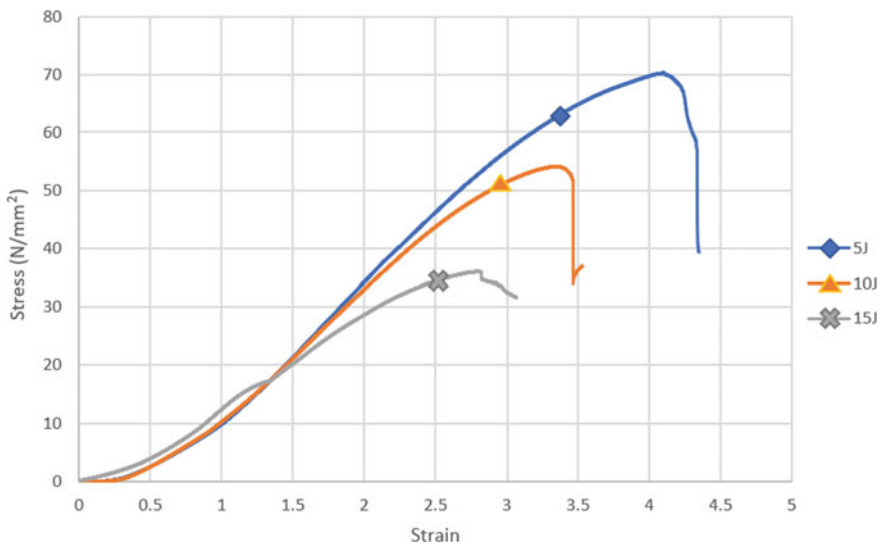


Fig. 6 Stress–strain curve of hybrid composites on CAI testing

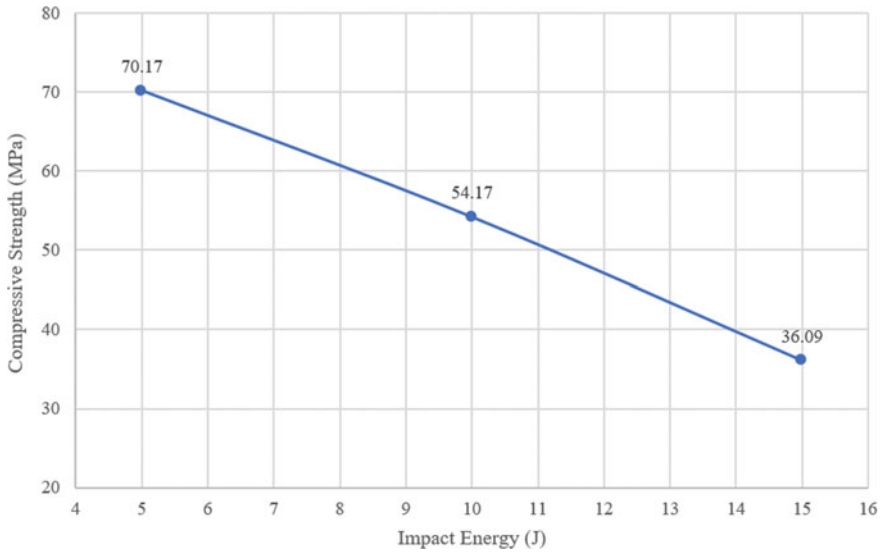


Fig. 7 Compressive strength of PALF/KF/VE hybrid composites

when the energy level increase, the damage of fibre breakage and matrix cracking increase, thus weaken the CAI strength. Another reason is that the high in energy level increase the delamination of composites layer. This result has been found to be in agreement with the previous studies (Rivallant et al. 2014; Selver et al. 2016). The damage on the specimen can be observed by naked eyes as well as the cracks on the samples. It can be understanding that the specimens had previously undergone low velocity impact testing. Thus, the CAI testing had increased the damage area and its cracks. The analysis of CAI properties is important in such application like maritime, aerospace, structural and others.

4 Conclusion

In conclusion, the impact and compressive of PALF/KF/VE hybrid composites were investigated. Based on the discussion above, the conclusion made are as below:

1. The force–time response recorded that the PALF/KF/VE hybrid composites impacted with 15 J energy produced 2.34 kN force.
2. The force–displacement response recorded that when the hybrid composite impacted with 15 J, it produced the largest deformation among the others. The severe delamination in the KF occurred on the PALF/KF/VE hybrid composite impacted with 15 J energy.

3. The energy-time response showed that when the hybrid composites impacted with 15 J of energy, it produced the highest absorbed energy which is 14.19 J due to the highest height, thus produced the highest kinetic energy.
4. For the CAI testing, when the hybrid composite impacted with 15 J, it produced the lowest CAI strength which is 36.09 MPa while the hybrid composite impacted with 5 J of energy produced the highest CAI strength which is 70.17 MPa. It can be noticed that the hybrid composite that was impacted by the highest impact energy will produce the lowest CAI strength.

The current research work that investigated the impact and compressive properties of PALF/KF/VE hybrid composites will provide necessary information needed in real-life application.

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